Staff Paper

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Too Poor to be Stewards?

Rural Poverty and Sustainable Natural Resource Management

Scott M. Swinton

Sustaining natural resource stocks – especially those underpinning the capacity to produce food – is key to most definitions of sustainable development. Yet troubling evidence has surfaced of instances where the rural poor were forced to sacrifice long-term sustainability for the sake of near-term survival (Mink 1993; Figueroa 1998). Are such cases special ones, or is rural poverty a driving factor in causing soil erosion, overgrazing, deforestation, and degradation of other natural resources? This paper argues that natural resource sustainability in developing countries is not the result of a direct cause-effect relationship, but rather is engendered by a web of causal factors. Untangling that web entails separating out strands for poverty from those for location-specific natural resource conditions, human institutions, technology, and population. This paper reviews the history of the poverty-environment debate, examines three sets of case studies that shed light on key relationships, and finally proposes policy interventions to promote the sustainability of the natural resources that underpin agricultural productivity.

Population and food production: Ideas and trends

The poverty-environment debate has grown from the seed planted by the English clergyman Thomas Malthus in 1798. Having studied the historic growth rates of population and food production, Reverend Malthus read an essay in St. Paul's churchyard in London in which he observed (Malthus 1798),

> "The power of population is indefinitely greater than the power in the earth to produce subsistence for man. Population, when unchecked, increases in a geometrical ratio. Subsistence increases only in an arithmetical ratio."

During many periods of human history, war and pestilence have reined in population before the food supply became a constraint. But by the 19th century, when potato late blight spread famine in the Irish population, Malthus' grim observation was gaining credence.

As population growth rates took off during the period of relative peace after World War II, Malthusian fears again reared up. Could the world possibly provide for a growing population? Two affirmative answers emerged during the 1960's. Based on her sweeping review of agricultural development worldwide, Esther Boserup found that rising population tended to trigger an intensification of agriculture, leading to higher food production from the same land. She argued that rising population increased demand for food, raising food prices and creating incentives for farmers to invest in boosting the productivity of the land by adding productive inputs, such as fertilizers and irrigation (Boserup 1965).

At the same time, the Rockefeller and Ford foundations were investing in new agricultural research centers in Mexico and the Philippines. By the end of the 1960's, Norman Borlaug and fellow agricultural researchers had bred new high-yielding varieties of wheat and rice, whose advent became known as the Green Revolution. Developed by traditional methods of crossing plant varieties with different desired characteristics, these new varieties had resistance to debilitating diseases like wheat rust and re-engineered plant architectures that shifted more biomass from stems and leaves into grain production. In regions like the Punjab, where irrigation and fertilization were available, these varieties delivered spectacular yields. The success of the early varieties triggered a generation of investment in a network of publicly funded international agricultural research centers. The goal of the new network was to bring comparable productivity gains to crop and livestock farmers working under more diverse conditions around the globe.

By the 1980's the euphoria of the boom-boom days of the Green Revolution had begun to wear off. Replicating the yield gains achieved in developing countries in wheat, rice and hybrid maize had proven more difficult in other crops and livestock. Moreover, even those more successful crops had turned out to yield significantly less when fertilizer and water inputs were lacking. Despite major investments in agronomic and socio-economic research to understand and improve farm management practices, yield gains were not keeping up. To make matters worse, by the 1990's, many developing country governments had cut back sharply on their agricultural research and extension services, in response to fiscal discipline imposed by the International Monetary Fund.

From our vantage point today, a stark contrast has emerged between food production trends world-wide and food production trends in the poorest regions. Viewed globally, Malthus' fears now look groundless: Food production outstripped population growth by 50% during the period 1960-2000. As shown in Figure 1, food available per capita has grown significantly (Wiebe 2003). Indeed, the percentage of the world population that is food-insecure has fallen markedly. Viewed regionally, however, food production in the poorest regions of the developing world has not kept up. A Malthusian trend apparent in several disadvantaged regions has been most noted in sub-Saharan Africa. There, food production per capita eroded by 15-20 percent during the last forty years of the century (Figure 2). Indeed, despite rising food productivity globally, the number of people who are at risk of hunger has remained troublingly stable (Figure 1).

How to reconcile persistent localized hunger with growing global bounty? In a world increasingly integrated by trade and communication, the crux of the problem is no longer the quantity of food produced, but rather access to it (Runge et al. 2003). Too many people are still too poor to acquire the food they need. Worse, they may feel the need to sacrifice future natural resource productivity for current consumption. The task of this chapter is to examine why poverty endures in many rural regions of the tropics, particularly how poverty is linked to natural resource degradation.

Despite technological change, why does Malthus still look partly correct?

The persistence of pockets of extreme poverty raises questions about the population-food production relationship. Why was Malthus wrong at a global level? But why has he seemed to be right in some regions of the globe? And finally, are the trends we observe inevitable?

The place to begin is the fundamental ratio of food productivity: the rate of change in food production divided by the rate of change in population. Malthus clearly overlooked the sensitivity of the numerator (rate of the change in food production) to technological change. Not only has technological change proven able to augment food production dramatically, it has also proven highly responsive to relative prices. The powerful dynamic that Ruttan and Hayami dubbed "induced innovation," describes how technological change is driven by shifts in relative prices of inputs and outputs (Hayami and Ruttan 1985). In particular, this dynamic has meant that when land becomes relatively scarce (e.g., because of rising population), technological change tends to increase its productivity disproportionately. Indeed, the Green Revolution was all about technological changes in plant genetics, irrigation and fertilization with the combined effect of sharply increasing in crop yield per unit of land.

But technological change is by no means automatic. First, agricultural research is not automatically triggered by relative factor prices. This mechanism can work effectively where markets permit the intellectual property from research to produce marketable products. For example, Hayami and Ruttan (1985) highlight the spread of tractors in North America in response to the high cost of labor relative to land and the spread of fertilizer in Japan in response to the high cost of land relative to labor. But certain types of agricultural research do not generate marketable products. Private seed companies have done much to advance the genetics of hybrid corn, for which newly hybridized seed must be purchased for planting each year. But the same companies have shown little interest in improving open-pollinated cereal crops, like rice and wheat, because the seed can be multiplied on-farm, so that seed is only sold once. Hence, public sector investment in agricultural research was crucial to the original Green Revolution breakthroughs in rice and wheat.

Second, overcoming the scientific hurdles is only the first step toward technological change. Breakthroughs at the level of basic research typically require adaptive research that will tailor them to the conditions of farmers who might take up the new practices. Adult education and extension efforts are needed to inform farmers about the existence of new technologies. Finally, once aware of their new possibilities, farmers must be willing and able to adopt them (Nowak 1992). Technological change ultimately occurs because farmers decide to do things differently.

From macro to micro: What drives farmer behavior?

Given the pivotal role of individual farmers in determining how much food is produced, it helps to look at the world from a farmer's point of view. Farmers face many choices. Whether to farm at all or to engage in nonfarm employment? Whether to grow food or a cash crop, like cotton or tobacco? How much land, labor and other inputs to devote to each crop or animal enterprise? What practices (technologies) to follow?

The choices that farmers make are shaped by their objectives and the resources at their command. Objectives might include being able to feed, clothe and house the family, or avoiding the risk of failing to meet subsistence needs in case weather or pests should be bad. Defined narrowly, productive resources typically include the labor and knowledge of family members and employees (human resources), land, water, climate and biodiversity (natural resources), and equipment, buildings, and the means to buy or produce feed, fertilizers, pesticides and other inputs (financial and manufactured resources). Some would add to this list the networks of social relationships and cultural-legal institutions that enable obtaining access to needed resources (social capital).

Two important environmental factors affect the quality of these productive resources. Access to economic infrastructure – notably roads, communications, banks, and markets that supply inputs and buy products – strongly affects the costs of inputs and the earnings possible from selling products. The biogeophysical environment – notably climate, soil quality, access to water and topography – strongly affects the need for agricultural inputs, the potential productivity of the land, and the ease of selling products produced.

So if technological change was responsible for increasing per capita food production for the world on average, why have certain regions been left out? Several answers fit the question. The first is that while technological change may be driven by relative prices (which reflect the relative scarcity of specific production inputs), it is equally driven by scientific feasibility. Raising land productivity is most feasible where the land is fertile, well-watered, and well-drained. A few fortunate places in the world meet these criteria naturally. In many others, they require investment in mineral fertilizers, irrigation and drainage.

The regions of the world that have lagged farthest behind in food production are those where economic infrastructure and the biogeophysical environment are least favorable. The semiarid tropics and highland areas, like South America's Altiplano, Africa's Sahel and highland, and parts of Asia face formidable geophysical constraints. Steep slopes in highland areas exacerbate soil erosion; they may also aggravate seasonal drought if sudden tropical deluges to run off before soaking into the earth. Semiarid zones, by definition, have scanty rainfall, less surface water, and higher risk of drought.

The underdeveloped economic infrastructure in these same regions adds up to sparser, lower quality roads that make transportation more expensive. Poor communication networks make communication slower and more expensive as well. Less developed financial institutions mean that credit for purchasing inputs tends to be costlier. Sparse, poorly equipped markets mean that more farmers have farther to go to buy inputs and sell products. Expensive transportation, communication and credit make production inputs more costly on the farm (e.g., fertilizers, improved seed, irrigation, drainage); they also reduce the farm-level value of food produced. Farm income is reduced both by transportation costs and by the risk of weak market prices that comes from poor communications that deprive the farmer of information on where and when to market the crop.

Due in large part, to these biogeophysical and infrastructural disadvantages, not only has food productivity lagged in the semiarid tropics and highland regions of the world, but these regions also account for large numbers of impoverished people. The map in Figure 3 shows where global malnutrition is highest. Those zones largely coincide with the regions where public infrastructure is most deficient and where the natural endowment of biogeophysical resources is least generous. In these zones, farmers face more severe capacity constraints to the natural and infrastructural resources at their command.

Too poor to be stewards?

More troubling than the failure to expand food production faster than population in these poor regions is evidence of diminishing incomes that would enable maintaining or raising per-capita food consumption. Worse yet, projections 25 and 50 years into the future using the IMPACT model suggest that regions like sub-Saharan Africa are likely to see significant percent *increases* in the number of hungry people (Runge et al. 2003, p. 31).

For large numbers of the rural poor, agriculture offers the principal means to put food on the table, whether it be food that was produced on farm, or food bought with earnings from the farm. Farmers can respond to the imperative to increase food production to meet rising household needs with two alternative strategies: extensification or intensification. Extensification refers to expansion onto new lands. Usually uncultivated lands are less suited for agricultural production than those lands that farmers chose to cultivate earlier. They may be less fertile, steeper, or more prone to drought or waterlogging than other lands. Hence, crop yields on such marginal lands tend to be lower than average. Examples include felling the forest to open new lands or expanding from fertile valleys up onto less productive hillsides. While extending farming onto marginal lands may reduce average yields per unit of land and may also increase the riskiness of output, it does not undermine the productivity of lands already in production.

Intensification of agricultural production is the general process documented by Boserup that can raise food production per capita. Subsequent authors have chronicled the virtuous cycle by which initial acceleration of soil erosion in Machakos, Kenya, was reversed over a period of three generations, as rising food and coffee prices led farmers to invest in land terracing and other soil conservation measures, enabling environmental recovery and increasing food production per hectare (Tiffen et al. 1994).

Unfortunately, the "more people, less erosion" story from Machakos is matched by others where productivity has continued to decline. If access to increased income or other sources of investment capital are unavailable, farmers may have no alternative but to try to work harder to scrounge more food from the same land. In their study of agricultural intensification in highland Rwanda, Clay, Reardon and Kangasniemi distinguish between two labor-led and capital-led intensification (Clay et al. 1998). Labor-led intensification occurs when farmers work the land harder to extract more food. In Rwanda, farmers would cease to fallow fields, cropping them continuously, but without fertilization. The process does intensify output per hectare of land in the short term, but at the cost of undermining the land's longterm productive potential by mining the nutrient supply in the soil. Similar patterns of shortening fallow periods linked to declining crop yields have been observed in other parts of the semiarid and highland tropics (Swinton and Quiroz 2003).

The distinction between labor-led and capital-led intensification offers one explanation for how the decline and increase of agricultural land productivity can co-exist in the world. Based on a broad review of literature on agricultural land productivity in hilly regions, Templeton and Scherr offer a unified theory for how these effects are linked by population, as shown in Figure 4 (Templeton and Scherr 1999). They contend that at first, population increases are linked to declining productivity. For example, bush fallow cultivation systems tend to shift to long-cycle crop rotations and then to shorter rotations, but all relying on fallow to restore soil fertility. As the annual output gains from such labor-led intensification diminish, rising populations in largely autarkic regions trigger increases in the cost of food and the land that can produce it. These changes, in turn, trigger capital investment in the land, which gradually increases land productivity from a low point. The U-shape of this population-land productivity relationship can thus encompass both the labor-led (Malthus effect) and capital-led (Boserup effect) intensification explanations with a common population driver (Templeton and Scherr 1999).

In a world with trade and migration, opportunities exist for people and goods to move about. In particular, many poorly endowed areas with rising populations can receive goods produced elsewhere, often at lower costs of production than local costs. There also exist opportunities for to migrate elsewhere for work. Migration opportunities offer an alternative to intensification as a means to meet the subsistence needs of rising populations. But how migration affects land productivity depends on the specific situation: Migration reduces the labor available for farming, which can cause low-productivity systems to stagnate at the bottom of the population-productivity U-curve. On the other hand, if migrant remittances are reinvested in the land, then capital-led intensification may cause land productivity to rise. The upshot of migration patterns is that certain regions can find themselves trapped at the bottom of the U-curve when migrants move out but households choose not to invest in agricultural productivity (García-Barrios and García-Barrios 1990; Zimmerer 1993; Wiegers et al. 1999).

Where the means for investment are not available, impoverished farmers face a stark choice between meeting current subsistence needs and preserving the future productive potential of the natural resource base (Mink 1993). In the words of Adolfo Figueroa (Figueroa 1998),

> "Given the options of producing less today ... in exchange for producing more in the future, or less in the future and more in the present, the small farmer will choose the second option."

Such a Faustian bargain between survival and land stewardship directly contravenes the goal of sustainable development, defined by the Brundtland Commission as (World Commission on Environment and Development 1987), "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

If the poor are undermining their own future survival, not to mention the natural resource base shared by the rest of humanity, what does this mean for development policy? Should we revive Sir Arthur Lewis' dictum of the 1950's that the key to economic development is to transfer surplus labor from unproductive agricultural employment to the productive industrial sector (Lewis 1955; Fei and Ranis 1964)? Should agricultural development efforts be targeted only at less poor regions or poor areas endowed with abundant biogeophysical resources? Such policy remedies would represent an abrupt change in direction. Is there conclusive evidence of circumstances where there is a causal link between poverty and natural resource degradation?

The evidence

A number of recent studies have examined the evidence about the links between poverty and natural resource degradation (Wunder 2001; Barrett et al. 2002; Swinton et al. 2003). The great academic challenges to these studies are to control for the natural resource setting and the level of politico-economic infrastructure. Put differently, does poverty affect natural resource outcomes differently in the rainforest than, say, in the savanna? Does the same level of poverty cause different environmental outcomes in a setting with good roads and communications, as opposed to a more remote location? The plethora of different agricultural natural resources complicates comparisons even more. The quantity and quality of soils, natural forages for livestock, surface and ground water, and forests are just the most evident of the natural resource characteristics that interact most closely with farming. In order to parse the poverty-environment puzzle more carefully, we examine illustrative cases for three agriculturally-related natural resource degradation processes: soil erosion, overgrazing of natural rangeland, and soil nutrient depletion.

Soil conservation with terraces

Of the many natural resource management technologies that developing country farmers have considered, terracing to conserve soil and runoff water offers the advantage of paired cases under similar geophysical and socio-economic environments. Recent case studies from Peru and Ethiopia offer nuanced complexity. In both countries, farmers have been observed both to build and to destroy stone terraces. In Peru, terraces have existed for over 600 years, since before the time of the Incan empire. Many of these terraces are maintained to this day, yet others have been allowed to decay, despite the fact that terrace maintenance requires far less work than new construction. Remarkably, elsewhere in Peru, farmers are constructing new terraces. How to explain this conundrum that in similar topographic conditions in the same country, farmers would choose such different approaches to soil conservation? Efraín Gonzales de Olarte and Carolina Trivelli argue that the present value of returns to investments in terracing differ markedly from one part of Peru to another (Gonzales de Olarte and Trivelli 1999). In more remote parts of the country, like the south-central Andes, where low value crops like potato and forages are raised, the payoff to investments in terrace construction – or even terrace maintenance – are unattractive. But in the Pacific valleys, where cash crops can be raised for export or sale in coastal cities like Lima, farmers are actively building new terraces because they see an appealing payoff and can obtain the resources to do it (Wiegers et al. 1999). What effect of poverty? The poorest farmers are the ones in the remote areas who are allowing terraces to decay. Many of them were opting instead to invest in migration to the cities, rather than invest in agricultural land productivity.

A continent away, Ethiopia offers a similar contrast. Terraces that were built by local workers under food-for-work projects have been destroyed by some landowners, allegedly because the value of their soil and water conservation services could not justify the foregone productivity of the land they occupied (Shiferaw and Holden 1999). Yet at the same time, other terraces were being built voluntarily in similar parts of the country. It seems that on the steepest slopes, farmers felt the benefits of terraces were too modest, while on the most gently sloped land, soil bunds offered comparable benefits at lower cost of construction and lower opportunity cost of land unproductively occupied. But perhaps the biggest reason for destroying terraces had to do with land tenure security. Where farmers felt confident of passing fields on to their children, they were much more prone to build terraces than when they expected to control the fields for five years or less (Gebremedhin and Swinton 2003).

The effect of poverty is not apparent here, although households with more members are more likely to build terraces.

Native forage protection from overgrazing

Conservation of native range forage species offers another case in contrasts. In Chile's arid Region IV, impoverished farmers grazed goats on native scrub in a common pool grazing area, watching the digestible native vegetation slowly disappear. Due to growth of off-farm jobs in the grape industry during the 1990's and a government policy subsidizing small-scale irrigation, many families earned enough income to invest in irrigation to raise alfalfa for livestock feed. As a result, the livestock population of these communities increased, along with resurgence in the native forage species (Bahamondes 2003). In the presence of attractive livestock prices, the income available for investment and the costs moderated by government subsidy contributed critically to this success story. Although the protagonists began the decade of the 1990's as poor people and ended it the same, the Chilean economy had created considerable wealth at many levels in the meantime. Some of that wealth allowed investments that relieved the population pressure on the rangeland resource base.

By contrast, both the total biomass and the biodiversity of native forage species in the Peruvian Altiplano have declined precipitously in the upland villages that relied upon communal grazing. Increasingly, the only species available are ones that are indigestible to the sheep, alpacas and llamas grazed there. Yet the livestock owners most at fault turn out not to be the poorest in the area (who own few animals), but the relatively well-off, who own many (Swinton and Quiroz 2003). Yet indirectly, this story still traces back to a poverty root. Over three-quarters of the people in the Altiplano lack what the Peruvian government defines as basic human needs. Even the relatively less poor there are still poorer than the peasant farmers of Chile's Region IV, whose off-farm earnings allowed investment in irrigated forages. While livestock farmers in both areas have communal grazing lands at hand, the herders in Peru's Altiplano are far more distant from major urban markets than their Chilean counterparts.

Maintenance of soil nutrient levels

One additional case study of maintaining soil quality adds a nuanced perspective on the role of property rights. In a set of eight villages in the Peruvian Altiplano, farmers reported declining crop yields and soil fertility, compared with their recollection of 20 years previous. Very few used mineral fertilizers or manure amendments to restore fertility, due to a shortage of cash and the need to use dried manure for cooking fuel. Regression analysis highlighted the primary importance of fallow cycles in their crop rotation. A second stage analysis pointed to the importance of a cultural institution known as "*aynoca*" for influencing farmers to include fallow in crop rotations. *Aynoca* is the Aymara word for a community-level cropping pattern, whereby fields in a certain part of the village are all sown to the same crop. While the *aynoca* system originated to make it easier for villagers to take turns protecting maturing crops from predators and thieves, the system has had the side effect of enforcing a community-level crop rotation (even though the individual fields are privately owned). Farmers in communities that had abandoned the *aynoca* system conceded that it had helped them to maintain soil fertility, although they reported having given up the *aynoca* system in order to have more land to plant to boost short-term production to meet household needs (Swinton and Quiroz 2003).

Why do the poor sometimes succeed as stewards?

The evidence can be interpreted at two levels. Certainly the clearest environmental success story presented here comes from Chile, where capital-led intensification was made possible by off-farm earnings. Likewise, terrace construction in Peru responded to capital-led intensification simulated by agricultural income-earning opportunities. When income is available to poor farmers, whether by cross-subsidy from other sources or by increased income from farm sales, capital-led intensification is possible and may have dramatic results.

But successful natural resource stewardship also occurred among poor farmers without capital-led intensification. Poor Ethiopian farmers achieved largely labor-led intensification for stone terrace construction. Likewise, there was evidence that the poorest do not necessarily cause the greatest natural resource degradation, as shown by the overgrazing in the Peruvian Altiplano by livestock owners who are relatively less poor than their neighbors. And the link from the *aynoca* institution to reduced soil fertility loss highlighted a common property management institution able to support sustainable stewardship, at least at a basic level.

These examples signal possibilities for sustaining natural resource management at modest cost. Land tenure security in Ethiopia was instrumental in making it worthwhile to exert the effort needed to build terraces when benefits from soil conservation would only accrue slowly over time. The success of the *aynoca* system at checking soil fertility loss by maintaining crop rotations with fallow illustrates how an appropriate community-level institution can help to sustain natural resource productivity.

Policy guidelines

So if the poor are not *necessarily* bad stewards of natural resources, what factors can public policy manipulate to improve their stewardship – and ultimately to promote sustainable development? The answers will clearly vary from place to place, based on the politico-economic infrastructure and the natural resource setting. But the recurring themes consistently relate to understanding farmers' incentives and the constrained resources that limit their feasible alternatives. Policy guidelines are listed below, beginning with ones related to farmer incentives and going from least costly to more so. Many are familiar recommendations for strengthening small-farm incomes, because better incomes are key to meeting the incentive and capacity needs for increased investment in sustainable natural resource management.

Incentives #1: Clear, durable property rights

Clear, durable property rights are a *sine qua non* for longterm investments in conserving natural resources (Feder et al. 1988; Baland and Platteau 1996). Uncertainty about whether future benefits will accrue to the person who made the investment can sharply undermine the expected value of returns even in a riskless world, as noted in the Ethiopian stone terrace investment case above. For a risk averse, impoverished farmer, uncertainty about poverty rights undermines even further the expected utility of future benefits in exchange for a known up-front cost. Although, in principle, clear property rights would not seem difficult to establish, in practice the great challenge is to ensure their diffusion and consistent enforcement. Indeed, abundant evidence shows that formal land titling is not equivalent to land tenure security, particularly in countries where changes of regime have made enforcement of land titling unpredictable (Gebremedhin and Swinton 2003).[2]

Incentives #2: Local institutions that support natural resource stewardship

Farmers' objectives are not limited to the consumption of goods by household members; they also include intangibles like respect earned from others. Local institutions for community-based natural resource management can be effective by using peer pressure for the common good. The Peruvian *aynoca* system by which collective decision making over adjacent private parcels of land illustrates a mechanism by which peer pressure helps to enforce a community-level crop rotation that could maintain soil fertility at modest levels.

Incentives #3: Efficient infrastructure

An efficient system of transportation, communication, and markets for agricultural inputs and products can dramatically improve the expected net benefits from investments in natural resources that support agricultural productivity. To the extent that agricultural growth alleviates poverty, which in turn alleviates natural resource degradation (e.g., soil erosion and soil nutrient depletion), this can advance the sustainability of some resources. Ready access to a transportation network can sharply

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[2] A thoughtful literature exists on various common property management structures apt for sustaining certain types of natural resources, especially biological resources, such as native forage species and forest-dwelling species Baland, J.-M. and J.-P. Platteau (1996). Halting Degradation of Natural Resources: Is There a Role for Communities? Rome, Food and Agriculture Organization of the United Nations.
Otsuka, K. and F. Place (2001). Land Tenure and Natural Resource Management. Baltimore, Johns Hopkins University Press..

reduce farm-gate input costs of inputs and increase expected prices at the farm-gate for food products. The same kind of effect comes from a reasonably dense network of markets, though market density and road transportation quality are substitutes. Access to roads and markets were key stimuli prompting construction of new terraces for soil conservation in Peru (Gonzales de Olarte and Trivelli 1999). Effective rural communications, not only broadcast media but also telephone systems, can markedly improve the timing of market transactions.[3] All three of these infrastructural elements contribute to the net returns of agricultural production, thereby augmenting the value of conserving the natural resources that make agricultural production possible.[4] Indeed, the continued viability of capital-led intensification methods like mineral fertilizer and improve seeds requires access to markets that offer these inputs (Howard et al. 1999).

One important caveat to the call for improved infrastructure is that while better infrastructure tends to make farming more profitable (hence more likelihood of available capital to invest in resource sustainability), better infrastructure also facilitates the spread of agriculture. Where agriculture competes directly with valued natural land uses, such as forests or prairies, better infrastructure may undermine the sustainability of those non-agricultural natural resources (Reardon and Vosti 1995; Angelsen and Kaimowitz 2001; Lee and Barrett 2001; Vosti et al. 2003).

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[3] In fact, with the rapid expansion of private contracting in the developing world, better communications and transportation can make possible access to high-margin global markets that are totally inaccessible to impoverished farmers otherwise.

[4] Improved infrastructure will certainly benefit the household. The net effect on natural resources is indeterminate. As noted in the case studies above, investments in natural resource conservation depend in part on the profitability of agricultural products that may be produced from them (e.g., case of stone terrace construction in Peru). But better infrastructure also improves access by household members to off-farm jobs, raising the opportunity cost of family labor. This is why research in Tigray, Ethiopia, found that farm households in less remote villages were less prone to construct stone terraces.

Capacity #1: Access to education

Human resources are the most abundant assets in poor households. The level of education is often associated with adoption of natural resource management practices for several reasons. First, better educated farmers tend to manage their resources more efficiently, obtaining better net returns (Kelly et al. 2002). Better net returns imply higher shadow prices for the natural resources that made production possible, and higher shadow prices favor conservation of those resources. Second, household members who are literate and numerate appreciate more fully the economic benefits and costs of natural resource management. For example, research into cotton growers' pesticide management in Zimbabwe showed that farmers who could read and understand pesticide labels were less likely to suffer pesticide poisoning (Maumbe and Swinton 2003).

By contributing to skills for off-farm work, primary and secondary education can help with natural resource management indirectly as well. Migration to find work is common in much of the developing world. Remittances from such activities can have the same salutary effects on sustainable natural resource management as the off-farm earnings of the Chilean goat owners described earlier (Bahamondes 2003).

Agricultural extension education, when effective, can rapidly affect farm management. Thirty years of research have highlighted the importance of participatory approaches to extension and applied agricultural research. One promising approach, called "farmer fields schools," links farmer-to-farmer learning with on-farm research (van de Fliert 1993).

Capacity #2: Access to knowledge about natural resource conservation

Over the past 15 years, many countries have eliminated or sharply reduced their capacity for research and outreach in agriculture and natural resources. None of the case studies evaluated here involves a significant research element, because most of the countries cited have sharply curtailed their research (and extension) activities. Yet adapting agricultural and natural resource management research results to local farmers' needs is a *sine qua non* for adoption, making participatory research approaches especially apt (Kelly et al. 2002). Research and education need not be carried out by the state, and non-governmental organizations in many parts of the globe are finding ways to meet these needs. But clearly, awareness of the services offered to humans by natural resources and the alternative management practices needed to maintain those service flows are necessary conditions for adoption of such practices.

Capacity #3: Access to external sources of income or credit

Capital-led intensification may not represent the only means to intensify sustainably, but it has certainly proved effective again and again. The Chile case illustrates how economic growth in other areas can create off-farm earnings by members of farm households whose income cross-subsidizes natural resource conservation. Research among the cotton farmers of the Office du Niger in Mali has shown that cotton farmers are more likely than nearby farmers to apply fertilizer and productivity-enhancing inputs to their cereal grain fields. The cotton crop serves both to guarantee credit for inputs and to grant access to input markets that exist to support cotton production (Kelly et al. 2002). The research in Ethiopia that estimated farmers' willingness to pay for the benefit flows from soil conservation also found that the poorest farmers were willing to pay the least (Holden and Shiferaw 2002). While this is not surprising, it re-emphasizes the importance of financial capital for natural resource conservation investments; even terrace construction, which is largely labor-led, requires the means to nourish the labor force, if not to meet its opportunity cost.

Capacity #4: Emigration to relieve population pressure

Frequently unmentioned is the option of relieving population pressure on natural resources through migration. Large regions of the Appalachian Mountains in the Eastern United States were once hardscrabble farms, causing severe soil erosion while failing to generate adequate income to meet basic needs. Migration to urban jobs (sometimes paired with government buy-out of farms) has returned that region largely into forest. A similar option exists for developing countries, but the policy challenge is how to generate sufficient economic growth in other areas to absorb the population of marginal farms. The risk is that migration just serves to create irreversible natural resource degradation, as when poor farmers from populous regions suffering declining productivity move to the rainforest frontier and begin to convert the forest cover into fertilizer for short-lived gains before having to move on.

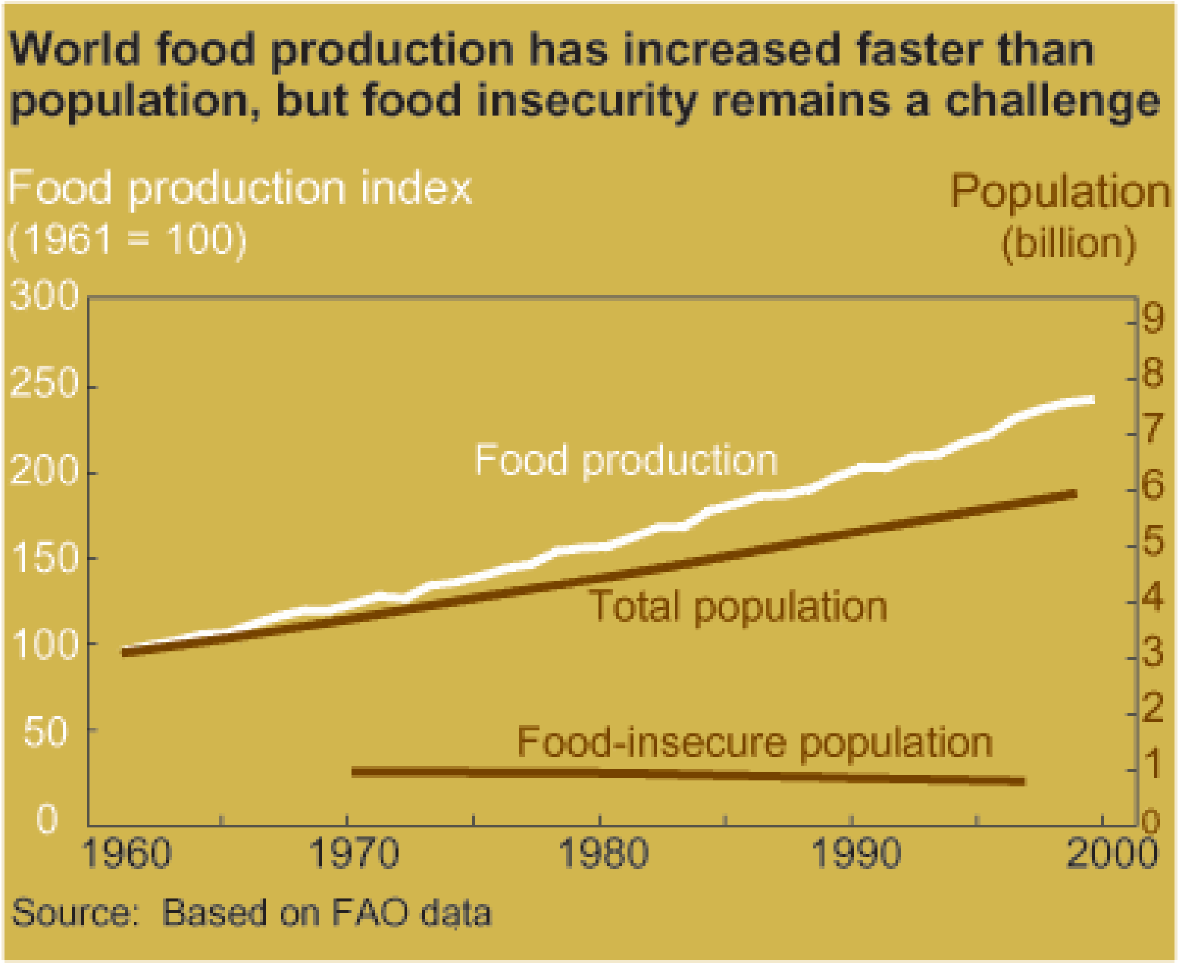
Conclusion

Poor farmers in the developing world are not necessarily bad stewards, but nor are they typically very good ones. Like the rich, the poor respond to incentives. But the poor face inherent capacity constraints; even when they may earn enough to survive, they may not earn enough to invest in land productivity (Reardon and Vosti 1995). Although Thomas Malthus underestimated the potential of technological change to keep food production ahead of population growth, productivity-increasing technological change typically requires capital-led intensification. The most promising way to slow or reverse agricultural natural resource deterioration is to contribute to rural incomes. Several policy approaches with this general effect are proposed, ranging from incentive schemes to narrow the marketing margin (making farming inputs cheaper and products more valuable) to attempts to strengthen the capacity to earn income on or off the farm.

The natural resource perspective that shapes much of this chapter focuses on resources supporting agricultural productivity, notably soil and rangeland. Overexploitation of these resources can often be relieved when suitable incentives exist and increased incomes alleviate constraints on the capacity to invest in future resource sustainability. For natural resources that are best sustained by limiting human access – as in the case of native primary forests and prairies – either carefully designed property rights must create incentives for sustainable management or else there must exist income earning opportunities from sources unrelated to the resource to be protected (e.g., urban employment (Escobal and Aldana 2003)).

The common element among all the policy alternatives presented here is the importance of tailoring policy to the specific socio-economic, infrastructural and biogeophysical setting in which agricultural natural resources are managed. Ways exist to ameliorate sustainable natural resource management practices from nearly costless to highly demanding of the public treasury. But successful policies require a tailored understanding of the human and natural environments as well as clear targeting of the natural resource objective to be met.

Figure 1: World food production outstrips population growth during 1960-200.



Source: (Wiebe 2003)

Figure 2: Food production per capita in sub-Saharan Africa has declined during 1960-2000.

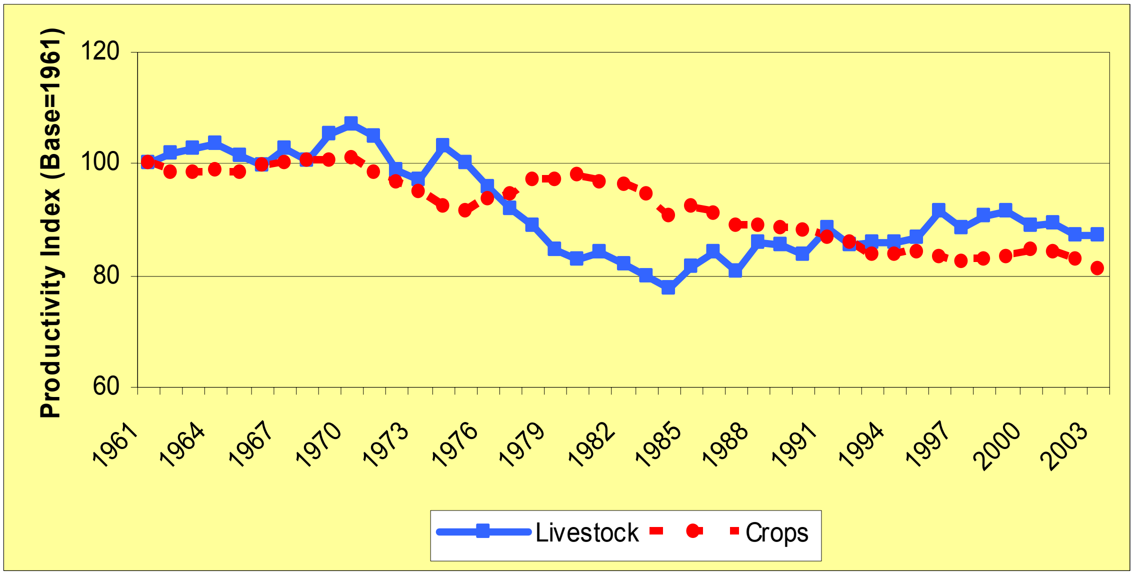
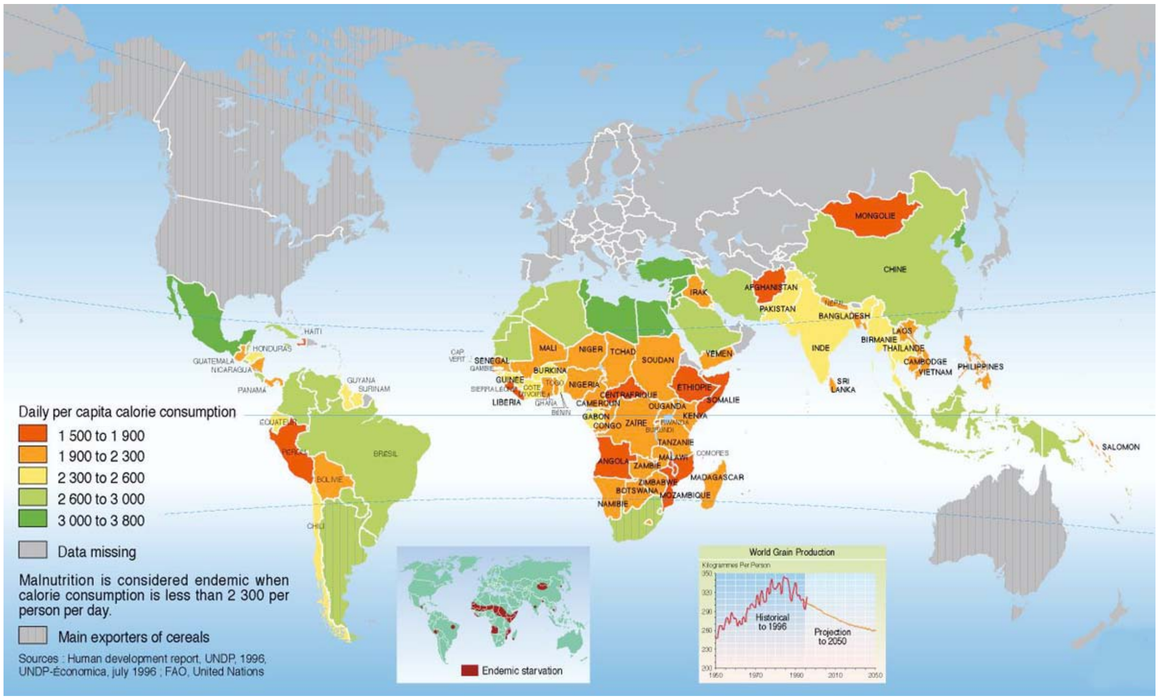
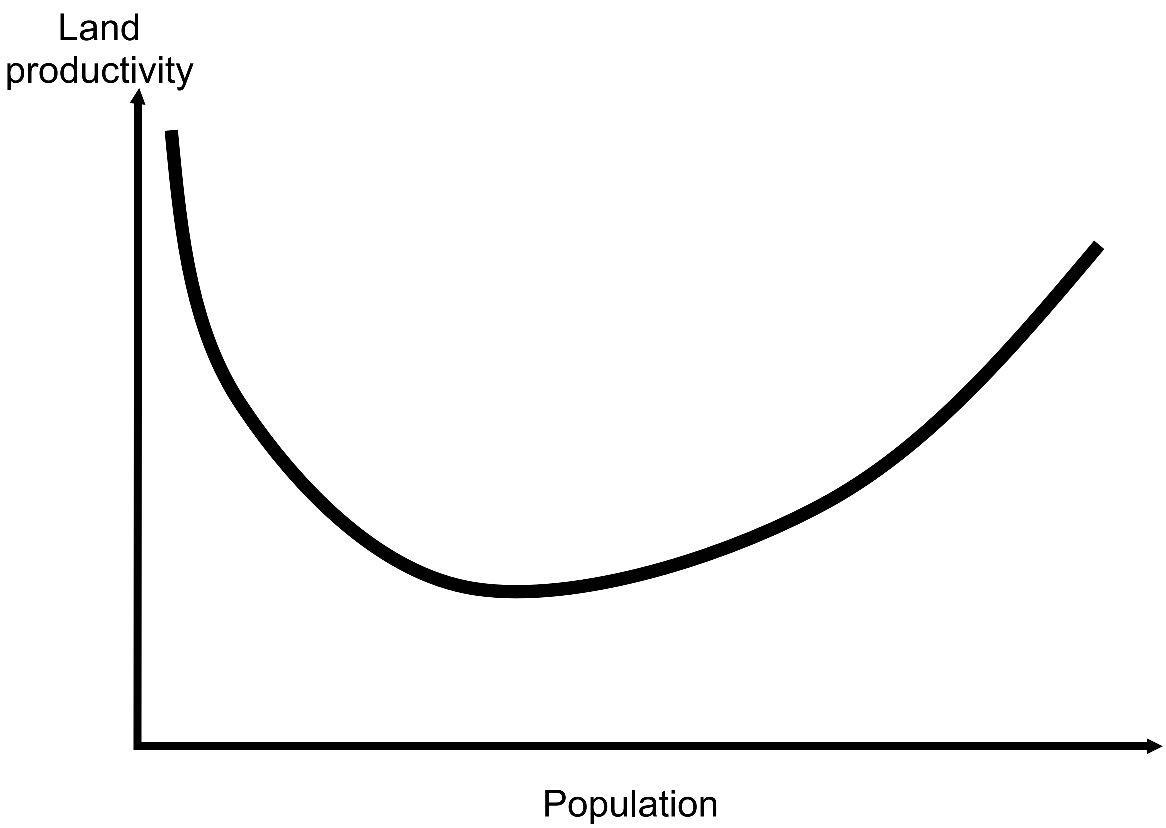


Figure 3: Daily per-capita calorie consumption, 1995.



Source: (Marin and Marin 1998).

Figure 4: Hypothetical relationship between population and land productivity (Templeton and Scherr 1999).



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