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THE ECONOMICS OF SOIL PRODUCTIVITY: LOCAL, NATIONAL AND GLOBAL PERSPECTIVES

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ABSTRACT

Soil degradation is a mounting problem on many smallholder lands in developing countries. Economic analysis has been an important tool in addressing this problem, beginning with assessments of the financial attractiveness of investing in soil conservation works. Data compiled from 67 studies of the financial attractiveness of conservation technologies suggest that many can provide positive net returns at the farm level (64·2 per cent). While such studies have made a valuable contribution, economists have been exploring additional applications of economics to the problem, such as the development of new perspectives under the guise of ecological economics. As a result, this paper argues it is an opportune time to assess progress in the field of economic analysis of soil degradation and to consider the policy ramifications of this research. Key issues are grouped into farm-level considerations, national policy linkages and global issues. A number of policy implications emerge. Clearly, devising effective incentives at the farm or community (collective action) level must be a priority. As part of this effort, even more attention should be paid to the influence of macroeconomic and sectoral policies on soil productivity. Since soil degradation is also a problem with global ramifications, there is a clear rationale for intervention at the international level via mechanisms such as international transfers. Copyright © 2004 John Wiley & Sons, Ltd.

KEY WORDS: sub-Saharan Africa; benefit-cost analysis; environmental degradation; natural capital; soil erosion; soil and water conservation

INTRODUCTION

Soil degradation is a mounting problem on many agricultural lands in developing regions (Scherr, 1999). Many economists consider the potential net returns from investing in soil conservation to be a key influence in the response to this degradation at the household level (Pagiola, 1999a; Barbier and Bishop, 1995; Barbier, 1990). With the compilation of new regional studies of net returns from soil conservation (Current and Scherr, 1995; Lutz *et al.*, 1994), there is now a sizeable body of literature on this topic. However, economics has been applied to other farm-level dimensions of the problem of soil degradation, such as assessing the reasons for the adoption or non-adoption of new conservation technology and determining the appropriate size of financial incentives for soil conservation (Sanders *et al.*, 1999). In addition to the farm-level perspective found in these studies, the economic linkages between soil degradation and national policies and institutions have been examined and economic analysis has been used to assess the damage that soil degradation imposes nationally and even globally (Bojö, 1996; Pimentel *et al.*, 1995). With the additional perspective on soil productivity offered by the new discipline of ecological economics, it is now an opportune time to assess progress in applying economics to the problem of soil degradation.

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This paper explores a range of applications of economics to soil and land management, using examples primarily from sub-Saharan Africa. In undertaking such a review and synthesis, new areas for research are discussed, such as the role of collective action in maintaining soil productivity and the global benefits of soil and water conservation. Soil productivity is the main focus and a broad interpretation of this concept is adopted, since soil depth and nutrient status are only two of the many factors influencing soil fertility (Shaxson *et al.*, 1989). In an economic context, soil productivity is now seen as an input that is ‘produced rather than primary’ (Clarke, 1992, pp. 44–45), or, more generally, as natural capital (Izac, 1997). Management decisions concerning this soil natural capital depend on a host of factors including, but not limited to, the net returns from investing in new soil management technologies.

In the next section, soil productivity is discussed from the perspective of the emerging discipline of ecological economics. Subsequent sections are organized according to farm-level considerations, national policy linkages and global issues. After reviewing the findings of a large number of studies concerned with the farm-level net returns from investing in soil and water conservation, the first of these sections considers the adoption of improved soil management at the farm-level. An important question is whether farmers truly detect declining productivity. If so, then, what are the key constraints inhibiting improvements by farm households and how important is collective action at the community level? The paper then shifts to the national level and reviews recent work on how government policies may create either positive or negative incentives for good soil management, using several examples to illustrate the situation. This process may be intentional or inadvertent, as when policies in an unrelated sector impinge on natural resource management decisions at the farm-level. Finally, the review extends beyond the confines of national borders to newer thinking concerning the global benefits of addressing the soil degradation problem. The paper concludes with a discussion of the local, national and global policy implications arising from economic analyses of soil productivity.

As an overview of economic issues in addressing soil productivity decline, the paper does not provide a comprehensive treatment of all aspects of the topic. For example, it does not describe how to undertake an economic or financial analysis of soil productivity improvements. For treatment of this subject, the reader may refer to the large number of general discussions of the economics of soil and water conservation (Lutz *et al.*, 1994; Sfeir-Younis and Dragun, 1993; Bishop, 1992; Anderson and Thampapillai, 1990).

ECOLOGICAL ECONOMICS, NATURAL CAPITAL AND SOIL PRODUCTIVITY

In conventional depictions of soil degradation, crop yield is a function of soil depth. Erosion by surface runoff or wind leads to loss of soil and, eventually, to a decline in crop yields (Anderson and Thampapillai, 1990). Often the curve is non-linear, reflecting the greater sensitivity of crop yield to soil loss when the remaining soil profile is shallower. This conventional view is concerned with the effects of soil erosion in isolation, without regard to nutrient status, soil organic matter, nutrient exchange and moisture holding capacity. More realistically, if soil resources are to provide a sustainable flow of services (e.g., agricultural output and other benefits) then these key components of soil productivity should be taken into account as well, rather than concentrating on soil depth alone. For example, Henao and Baanante (1999) indicate that all sub-Saharan African countries show a negative soil nutrient balance on an annual basis.

While agricultural economists are increasingly adopting a broader view of soil productivity, it is particularly associated with ecological economists, who recognize soil as a form of natural capital (Izac, 1997; Cleveland, 1994). Soil natural capital has qualities in common with other forms of capital, such as depletability. This view recognizes that the using up of soil productivity through unsustainable cropping practices not only leads to lost crop production in the short run, but constitutes depletion of soil natural capital and a potential loss of national wealth in perpetuity. Moreover, counting the share of farm incomes arising from the depletion of soil productivity as a benefit overstates the true sustainable level of income available from agricultural land, and results in overestimates of economic growth at the national level (Van der Pol, 1992; Repetto *et al.*, 1989).

If mineral fertilizers were perfect substitutes for *in situ* soil natural capital, then concerns about the depletion of soil natural capital would vanish: the services provided by the latter could be replaced with manufactured capital as represented by mineral fertilizers (Mortimore, 1989; Repetto, 1989). However, the nutrient content of soil organic matter is actually low and often insufficient to sustain yields alone. Conversely, additions of soil nutrients in the absence of adequate soil organic matter result in poor nutrient uptake and other problems. Thus, soil nutrients and organic matter behave as complements (Shapiro and Sanders, 1998): organic fertilizers or nitrogen fixing trees have a more pronounced effect on yields when used in conjunction with mineral fertilizers, and vice-versa. Moreover, there is evidence that the resulting interaction effects can be quite substantial (Scherr, 1999; Yanggen *et al.*, 1998). These relationships reinforce the view that *in situ* soil productivity has unique qualities that once degraded cannot be replaced with mineral fertilizers or soil organic matter alone. Indeed some degradation processes may be irreversible.

Soil natural capital need not be subject solely to disinvestment, as in the soil mining case. Farmers may develop new technologies that restore soil natural capital rather than attempting to imperfectly substitute mineral fertilizer in its place. This process helps explain the development of new agricultural technologies that increase cropping intensity in response to rising populations. New technology development centers on the substitution of more available factors of production (e.g., labor and capital) for the scarce factor, agricultural land. Thus, in a properly functioning agricultural system one expects to see new capital or labor-intensive technologies emerging that make more efficient use of a shrinking per capita land base (Barbier, 1998; Coxhead, 1996a). Only a few locations in sub-Saharan Africa demonstrate this process, such as Machakos District, Kenya (English *et al.*, 1994), or the Kano Close-settled Zone in Nigeria (Mortimore, 1993). Elsewhere on the continent this response is largely absent. As land gets scarce in these other areas, farmers simply deplete their soil natural capital, rather than increase their use of manufactured capital in the form of soil-productivity-enhancing technologies. Capital-intensity has increased *per se* but not in a sustainable manner.

Not all soil-management technologies address the ecological aspects of soils adequately. Structural approaches involving surface runoff control using stone lines, terracing, drainage channels and bunding represent one set of solutions, but these approaches have been criticized by some researchers (Shaxson *et al.*, 1989). From this perspective, treating surface runoff and subsequent erosion is not the right approach and, instead, soil productivity should be maintained by integrating appropriate agronomic practices into the farming system, such as mulching, intercropping, cover crops and no-till. One of the important effects of these practices is to increase the proportion of rainfall that is stored in the soil where it falls, resulting in the double benefit of increased moisture availability for plant growth and reduced erosive power of cross-surface water flows. These approaches represent more viable alternatives to the structural techniques noted above (Table I). As a result, it would be anticipated that these

Table I. Different views of soil and water conservation

Traditional focus	Land husbandry focus
• Loss of soil and water	• Loss of productivity
• Physical conservation works on the surface	• Improvements in soil conditions at and below the surface
• How much soil and water is lost	• How much water and soil retained
• Uni-disciplinary approach, distinct from normal agricultural practice	• Multidisciplinary approach, based on and strengthening normal agricultural practice
• Runoff control	• Water absorption/infiltration
• Add-on conservation technologies	• Techniques integrated into conservation-effective farming systems
• Farmers as labor for implementing works	• Farmers as managers of conservation-effective systems
• Doing soil and water conservation by decree	• Achieving conservation of soil and water as a byproduct of improved productivity
• Works costing money	• Exploiting free actions by soil meso- and micro-organisms
• Assumption that specialists' perceptions of degradation problems and their solutions are correct—outsiders judge what is best	• Awareness that other views of the reality may require different types of approaches—farm households decides what's best
• Small farmers are considered ignorant, irrational and reactionary	• Small farmers are knowledgeable about their local circumstances, but also constrained and understandably cautious in adopting new ideas

Source: FAO, 1993.

agronomic techniques would be more financially attractive to farmers, a point addressed in more detail in the next section.

Soil resources support more than just agricultural production, although farmers are unlikely to take non-agricultural services into account. Economic analysis of the different technical options for soil management can incorporate the wide range of services provided by soils when a total economic value (TEV) framework is adopted, allowing for both use and non-use values (Pearce and Warford, 1993). Commonly applied to ecosystems like wetlands or tropical forests, the TEV concept is equally valid in the case of soil complexes, since use values are liable to be present in the form of agricultural and ecosystem services, as well as non-use values relating to biodiversity conservation (Grohs, 1994). Non-market valuation techniques can be used to obtain rough estimates of these values. For example, the value of soil nutrients has been estimated in the short run as the replacement cost of supplying these nutrients using mineral fertilizers (Daily, 1997; Stocking, 1986). Implicitly, it is assumed that farmers would be willing to purchase the same quantity of nutrients otherwise provided freely by nature and that mineral fertilizers substitute for their loss.

FARM-LEVEL CONSIDERATIONS

Another area of research gaining importance is concerned with how households make decisions about managing their soil natural capital (Figure 1). Given its technological and socio-economic attributes, the household makes decisions about the use of its soil resources under the constraints or incentives imposed by the enabling environment (Pearce *et al.*, 1988). For example, land tenure may create or limit the opportunities available to the household. In addition, lacking access to financial capital, the household cannot invest in soil productivity improvements requiring a large out-of-pocket investment. In contrast, inputs of information and technical expertise can improve the management of soil resources without large financial outlays. Variable incentives

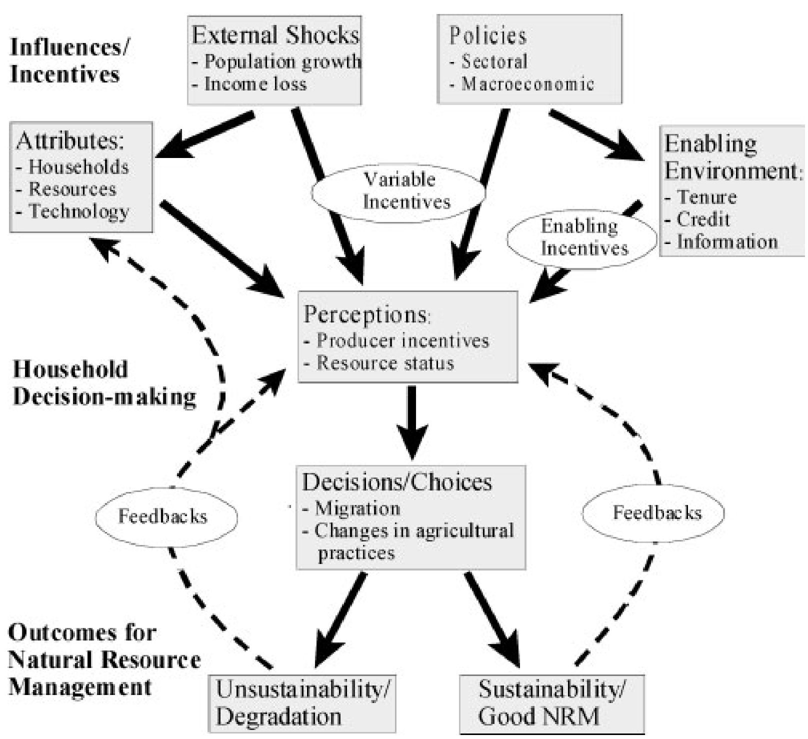

Figure 1. The role of incentives in producer decisions about soil productivity.

then determine the net returns, risks and other pecuniary elements entering into the decision-making process and, in this sense, the structure of variable incentives imposes further constraints. Feedback effects and external shocks further act on the natural and human resource attributes of the household (Pearce and Warford, 1993), leading to declining soil quality and the seasonal absence of household members who seek work in urban areas.

At the core of the conceptual framework are farmers' perceptions. Changing incentives signal to the farmer that the use of household resources may no longer be desirable and that resource reallocations may be necessary. For example, as relative output prices change, there may be a wish to plant more of one crop and less of another, and the choices made will obviously have implications for soil management. Farmers must also be aware of soil degradation problems before they can respond. Detection of soil degradation results from the working of feedback mechanisms (depicted as dashed lines in Figure 1).

Many options are available if farmers wish to respond to perceived changes in their production environment. For example, all or a few of the household's members may migrate or accept off-farm employment, or remain behind to modify farming practices. There are many technological alternatives available to producers if they choose to change existing soil-management practices, as discussed in the previous section. Critically, the impact of these choices on soil productivity can be either positive or negative. For example, if a few household members migrate, the household may reduce the cropping intensity on existing plots. Instead, the household may abandon its old lands altogether and bring new land in frontier areas under cultivation (Southgate, 1990). The latter can have quite serious implications if unsustainable soil-management practices are transferred to these new areas.

As households respond to a perceived degradation problem, the various feedback mechanisms close the loop. If investments in soil management are made in the presence of positive feedbacks, then there will be accumulating improvements in soil productivity. Alternatively, Holmberg (1991) has described a process of 'cumulative causation' where negative feedbacks in the absence of any improvements in soil management lead to spiraling degradation, eventually culminating in the collapse of the farming or grazing system.

Farmer Perceptions of Soil Degradation

Soil erosion and related processes can be insidious: even large losses of topsoil from a single rainfall event can occur as sheet erosion without leaving tangible evidence in the short term. Clearly, little improvement can be made in soil management unless farmers can perceive the problem of degradation (see Figure 1). Increasingly, researchers have been attempting to determine whether farmers detect land degradation and related problems. Surveys of African farmers in areas known to have declining soil productivity have found a strongly positive response to such queries, ranging from 60 to 90 per cent of those surveyed, or even higher (Adegbidi *et al.*, 1999; Dejene *et al.*, 1997; Ndiaye and Sofranko, 1994). Care is required in interpreting such data as negative responses do not necessarily indicate a lack of perception of the problem, since no problem may exist on a given landholding. Nonetheless, it seems that farmers often do detect declining soil productivity.

While it seems reasonable to believe that farmers can perceive soil degradation, there are circumstances where this is more or less likely to occur. For example, differences in perception may depend upon whether the problem is erosion- or fertility-related. Some evidence suggests that farmers understand erosion problems less clearly, in cause and effect terms, than fertility decline (Ndiaye and Sofranko, 1994). Perceptions may be aided by the presence of indicator species or similar signs associated with fertility status, such as certain weeds, termite mounds or the disappearance of palatable grazing species. Such indigenous knowledge may not always accord with scientific research but often serves a useful function by flagging changes in the status of soil resources.[1]

In contrast, if the increased use of fertilizer or improved seeds serves to mask an underlying decline in soil productivity over the short term, then farmers may not perceive the problem. Anderson and Thampapillai (1990) argue that fertilizer use causes an upward shift in the functional relationship between crop yield and soil depth. As the loss of soil occurs, fertilizer application disguises the underlying decline in long-term productivity associated with this loss by maintaining productivity temporarily. Thus, there may be a failure on the part of the farmer to

[1]In Tanzania, farmers accurately detect soil fertility decline by the presence of *Sorghum hymathica* in the area, and crop near termite mounds where the soil is rich in phosphorous and well balanced in terms of acidity (Dejene *et al.*, 1997).

perceive the problem. This process may be encouraged by highly subsidized fertilizer prices and the extent of soil productivity loss may become apparent only when the subsidy is removed.

Farm-level Financial Analysis of Soil and Water Conservation Technologies

Economists consider the net returns to the farmer from soil conservation to be a primary consideration in household responses to soil degradation. A financial or net-returns analysis takes the viewpoint of a private farm household and measures the benefits and costs they would consider relevant. These benefits and costs consist of actual monetary flows, such as incremental revenues, as determined by: market prices; production costs, such as transportation or wages paid to labor; and taxes or subsidies. A number of studies have looked at the financial profitability of soil and water conservation technologies in sub-Saharan Africa; the remainder of this section is devoted to an assessment of the findings of these studies.

The results of financial assessments of 67 soil and water conservation technologies at the farm household level were compiled from nine economic studies from sub-Saharan Africa. Some studies were *ex ante* planning studies that screen prospective management improvements, while others were *ex post* evaluations of completed projects or indigenous technologies. To provide structure to the analysis, the various technologies were grouped according to the World Overview of Conservation Approaches and Technologies (WOCAT) classification system (Liniger *et al.*, 2002). Four groups of soil and water conservation technologies were used: agronomic; vegetative; structural; and management (Table II). Once grouped by type of technology, the 67 analyses were further partitioned according to whether they demonstrated positive or negative profitability, as determined by the net present value (NPV) criterion used in conventional benefit-cost analysis (i.e., $NPV > 0$, or $NPV < 0$).

Despite some differences in approach, a majority of the studies (55·2 per cent) find soil and water conservation to be at least marginally profitable (Table II). More striking is the variation in profitability across types of technologies. While the agronomic technology grouping shows high numbers of profitable techniques, the remaining technology groups contain far fewer analyses with a positive NPV. These results tend to confirm anecdotal evidence and arguments presented in the previous section, suggesting that measures that keep soil particles in place are likely to perform better than measures that simply trap soil particles after they have become detached by erosion (Shaxson *et al.*, 1989). Ultimately, depending upon site and other local conditions, a given technology may be profitable in one location but not in another. Thus, it is difficult to draw general conclusions about the overall attractiveness of adopting improved soil-management measures from these types of assessments alone.

A benefit-cost analysis framework only indicates whether a given investment in soil productivity will generate a positive or negative net present value. This limitation of benefit-cost analysis, together with the dynamic nature of

Table II. Farm-level financial profitability of soil and water conservation technologies in sub-Saharan Africa (67 analyses from 10 studies), by type of technology

Technology type (WOCAT)	Sample technologies	Analyses with $NPV > 0$	Analyses with $NPV < 0$	Total technology analyses
1. Agronomic	Tied ridges, contour planting, intercropping, mulching, no till, fallowing, contour ridging, strip cropping, phosphate rock	10 (83·3%)	2 (16·7%)	12 (100·0%)
2. Vegetative	Alley cropping, farm forestry, vetiver, gum arabic, grass strips, woody fallows, afforestation, shelter belts, reseeding grazing areas	13 (56·5%)	10 (43·5%)	23 (100·0%)
3. Structural	bunds, rock dams, terraces, stone lines, trenches, fanya juu, infiltration pits	10 (41·7%)	14 (58·3%)	24 (100·0%)
4. Management	animal traction + various add-ons, Machobane system, fodder banks	4 (50·0%)	4 (50·0%)	8 (100·0%)
Total		43 (64·2%)	24 (35·8%)	67 (100·0%)

Sources: Giger *et al.*, 1999; Kuyvenhoven *et al.*, 1998; Williams, 1997; Mwanza and Place, 1995; World Bank, 1992; Ehui *et al.*, 1990; Barbier, 1992; FAO/CP, 1991; World Bank, 1990.

natural resource degradation, suggests a dynamic optimization approach may have advantages. A number of studies have used this technique to assess the optimal level of soil conservation at the farm or household level under varying sets of conditions. For example, Barbier (1998) presents a relatively simple optimization model of farm household decisions concerning soil conservation, while Barrett (1991) examines the role of agricultural price reform within a similar optimal soil conservation framework. Grepperud (1995) considers a range of policy issues influencing optimal soil conservation choices at the farm-level, including government and international assistance. For a critical review of the more mathematically complex optimization approach to model the economics of soil degradation, see Coxhead (1996b).

Constraints on the Adoption of Improved Technologies

Ultimately, farmers' investment in soil and water conservation will be determined by a number of factors, including perceived profitability but extending to other factors as well (Table III). Modeling of net returns from soil conservation can take account of many variable incentives (Figure 1), such as prices, wages, exchange rates, taxes or subsidies, and can allow for enabling incentives through discount rates and technological change. Thus, an assessment of the net returns from conservation can capture a wide range of factors that might inhibit improvements, but it stipulates that these affect behavior only through their impact on investment profitability. As a result, farmers may perceive a soil-degradation problem and be aware of potentially profitable responses, yet they may choose not to adopt an indigenous or recommended soil-management practice. This limitation reduces the usefulness of simple net returns analysis since other influences clearly may hinder soil-management improvements. These influences can be thought of as constraints on behavior at the farm household level.[2]

The characteristics of certain conservation investments, as distinct from pure production-oriented investments, may help to explain why farmer adoption is constrained. For example, the benefits of some techniques, such as agroforestry, may be perceived as more distant and riskier than investing in alternatives like animal traction and fertilizer. A host of other characteristics of individual soil-management techniques may inhibit their attractiveness

Table III. Considerations in adoption of soil and water conservation by farmers

Determinants of investment in indigenous soil and water conservation
1. Farmer's are more concerned about water and nutrient loss than depth of soil.
2. Farmers' invest less as the opportunity cost of their time and other resources rise. Other activities (e.g., off-farm income) may have a higher return than conservation investments.
3. Farmers invest more if they have more resources at their disposal (e.g., bullocks, healthy labor).
4. Farmers owning and farming their land are more likely to invest than those renting or sharecropping.
5. Farmers will invest in their more productive or irrigated plots first.
6. Where feasible, farmers invest in a stepwise manner, improving structures annually as needed, to reduce initial investment.
7. Farmers prefer to invest individually or with adjacent farmers rather than in a large, cooperative group.
Six Reasons Why Farmers Do Not Adopt Soil Conservation Innovations
1. The innovation addresses the wrong problem since farmers do not face the problem, it is not the key problem or the problem is incorrectly identified.
2. Farmer practice is equal to or better than the innovation.
3. The innovation works under some circumstances but not others, creates other problems or works against the farmers' solutions.
4. Extension fails by not correctly demonstrating the innovation or targeting the wrong farmers.
5. The innovation is too costly because labor, materials or opportunity costs are too high, costs are immediate while benefits are risky and distant or benefits have been over estimated.
6. Insecure tenure *may* limit adoption, farmers may prefer to mine resources having little commitment to the area or the innovation has negative social connotations.

Source: Kerr and Sanghi, 1992; Fujisaki, 1994.

[2]For example, Kiome and Stocking (1995) examine the specific case of the adoption of conservation measures in Kenya and find that the preferred technique, trash-lines, closely matches the predicted result based upon *ex ante* net returns modeling but also presents few non-financial constraints to adoption.

to farmers further (Table III), so that careful screening is required to adapt them to local conditions (see Ellis-Jones and Sims, 1995). Hudson (1991) argues that a good technology should be: locally tested; offer short term, on-site benefits in large increments (e.g., 50 to 100 per cent); require affordable inputs, especially labor; not use up productive land; not include any increased risk; and be consistent with existing social factors, such as the separate roles of men and women in agriculture.

Empirical researchers have tested a number of these hypotheses about farm-level investment in improved land management using techniques commonly applied in studies of agricultural technology adoption (Feder *et al.*, 1985). Many variables found to significantly influence the adoption of conservation technology reflect expectations (Table IV), such as distance to paved roads, price variation, off-farm income, leasing of land and non-agricultural wage. But there are discrepancies and counterintuitive results too, such as the negative influence of output prices on conservation technology adoption or the ambiguous influence of parcel or farm size. Some variables have a positive influence on conservation technology adoption but the reverse effect on fertilizer usage (e.g., slope, years' farming), although these can be explained to some extent.[3] Large numbers of statistically significant variables signal the importance of constraints on behavior (see Table IV), as suggested above. Ironically, without explicitly considering the perceived net returns from conservation or fertilizer use, the studies may be omitting an important consideration.

Empirical assessments of the importance of tenure security can be considered separately, because of the complexity of this issue (Table V). In simple terms, it might be expected that privatizing land, as a means of clarifying user rights, would lead to better incentives for the adoption of improved land management (Demsetz, 1967). For example, Lopez (1997) estimates a positive return to land titling in Ghana of about 12 per cent per year, and credits this to reduced liquidity constraints, i.e., better access to credit. However, there is no conclusive evidence that privatization of land or titling has increased investments in land or motivated sustainable practices (Place and Hazell, 1993). Producers may accept titling because it guarantees land rights, but this does not necessarily bring about changes in their natural resource-use strategy. In contrast, there are numerous studies (see Table V) indicating that traditional institutions governing access to land resources are flexible in responding to internal and external pressures (Baland and Platteau, 1996). Thus, it seems clear that private titling does not bestow any universal advantage over traditional institutions, in terms of investment incentives. As a result, general claims that titling will lead to increased investment in land improvements are now viewed with caution.

The Collective Action Dimension

So far, the discussion has focused on farm-level benefits and costs and the constraints that individual households may face in deciding on the adoption of improved soil management. Many soil-management technologies do not require cooperation between households for their installation and maintenance (e.g., agronomic practices). But despite their placement on individual farmlands, other technologies benefit from cooperation (e.g., contour bunds, terraces), or they may involve a combination of on- and off-farm structures (e.g., drainage and watershed works such as check dam and gully treatments). To bring about individual gains in these cases, a network of transboundary installations or an inadequate household labor pool necessitate a collective response of some sort. Thus, soil-management programs may need to assess the prospects for the necessary cooperation, as well as to encourage it explicitly. In the former case, analyzing the likelihood of successful adoption under these conditions can draw on extensive research related to the management of common property resources (see Bardhan, 1993; Seabright, 1993; Tang, 1992; Ostrom, 1990; and Olson, 1965).

At the community level, researchers have analyzed why some communities participate in collective watershed and soil management activities while others do not (White and Runge, 1994; Wade, 1988). Factors influencing cooperation include the size of the village, ethnic homogeneity, whether households have previously adopted soil and water conservation, location within the catchment and previous experience with informal labor exchange contracts. Other researchers have tested for the conditions under which individual households will participate in

[3]Farmers may be reluctant to apply fertilizers on steep slopes where they will be carried off by surface runoff but may be more likely to invest in conservation technologies under such circumstances.

Table IV. Empirical studies of the adoption of soil-management practices

Study	Soil management practice	Variables with significant positive influence on adoption	Variables with significant negative influence on adoption
Tanzania (Nkonya *et al.*, 1997)	Nitrogen fertilizer	Area planted with improved maize seed	Farm size
Nigeria (Okoye, 1998)	Traditional soil erosion control practices (tree trunks, cover crops, diversion pits, mulching, mounds and ridging)	Input prices, interest rate, age	Off-farm employment, innovativeness index, income, education
	Recommended soil erosion control practices (zero and minimum tillage, contour strip cropping, no burning and tree planting)	Input prices, age, income	Off-farm employment, output prices, innovativeness index, education
Rwanda (Clay *et al.*, 1998)	Conservation investments (grass strips, ditches, hedgerows, terraces)	Sector-level conservation investments	Lower location on slope, size of parcel, distance from residence, leased land, landholdings owned
	Organic inputs (composting, manure, green manure, mulch)	Parcel size, years' farming, value of livestock, knowledge of conservation/production technologies, sector-level use of organic inputs	Non-agricultural wage, banana price, distance to paved road, share of holdings under fallow and pasture, slope, lower location on slope, distance from residence, leased land, price variation, landholdings owned, age of household head
	Chemical inputs (fertilizer, pesticides, lime)	Share of holdings in woodlots, parcel size, distance from residence, sector-level use of chemical inputs	Share of holdings under pasture, slope, lower location on slope, years' farming, leased land
	Land use erositivity (erosiveness of crop mix—higher value, more erosive)	Share of holdings under fallow/woodlot/pasture, plot fragmentation, parcel size, cash crop income	Lower location on slope, distance from residence, rainfall, landholdings owned, sector-level land use patterns and chemical inputs
Ethiopia (Shiferaw and Holden, 1998)	Conservation practices (retention of level bunds and graded fanya juu, bunds)	Perception of problem, positive adoption attitude, technology awareness, land/person ratio, slope, parcel size, perceived technology productivity	Age, family size, altitude of plot
Senegal (Caveness and Kurtz, 1993)	Agroforestry (live fences, windbreaks and home gardens)	Number of plots owned, adult males, male children, peanut yield	Number of horses, female children

Notes: Significance is measured at the 5 per cent level or higher, except Caveness and Kurtz, which is at the 15 per cent level or higher.

Table V. The effect of agricultural land tenure on investment in soil and land management improvements in sub-Saharan Africa

Tenure type	Study	Location	Impact on investment decisions
Private title	Lopez (1997)	Ghana	+
	Besley (1995)	Ghana	+/ ×
	Place and Hazell (1993)	Rwanda/Ghana/Kenya	×
	Roth *et al.* (1994a)	Uganda	+/ ×
	Roth *et al.* (1994b)	Somalia	×
Customary rights	Harrison (1987)	Zimbabwe	+
	Place and Hazell (1993)	Rwanda/Ghana/Kenya	+/ ×
	Blarel (1994)	Rwanda	+
	Matlon (1994)	Burkina Faso	×

Note: (+) positive effect on investment in improvements; (−) negative effect on investment; (×) neutral or no effect on investment.

collective action schemes addressing land-management problems (Gaspart *et al.*, 1998; Ahuja, 1998). They find that the probability of participation improves: as the direct private stake in community benefits rises; as knowledge about the problem, intensity of land use or potential to reap productivity benefits increases; and if the household belongs to community groups that demonstrate an inclination towards collective activities. Given the well-developed theory of collective action it is surprising that so few studies have applied this theory to soil productivity issues and this is an obvious area for further research by social scientists.

LINKING NATIONAL POLICIES AND SOIL PRODUCTIVITY

Soil productivity is liable to be influenced by national economic policies, such as fiscal and monetary measures or trade and tariff policies (see Figure 1). These policies may be enacted either in isolation or as part of far-reaching Structural Adjustment Programs (Lensink, 1996). Economy-wide policymaking in some regions, especially sub-Saharan Africa, has been highly interventionist and, traditionally, has favored manufacturing and import substitution at the expense of the agricultural sector (Cleaver, 1985). In addition to trade and exchange rate biases, subsidized prices for certain food staples (e.g., wheat) encourage their consumption in urban areas over more traditional, unsubsidized staples (e.g., sorghum, millet). Of interest here is the influence that these policies have on the incentives for farm households to manage their soil resources.

How Do National Policies Affect Soil Productivity?

Changes in producer incentives emanating from national-level policies can affect agricultural production and soil management in quite subtle ways (see Table VI for a summary). For example, sharp expansions or contractions in sectors that compete with agriculture for labor may lead to changing labor market conditions in the agricultural sector. Similarly, the linkage between trade and soil management is obvious in the production and marketing of tradables, such as exported crops and livestock products. Changes in labor market conditions and the production and management of tradables can have far-reaching effects on land use and, hence, on soil management. The pervasive effects of economy-wide policies that target broad macroeconomic variables like inflation, employment or the balance of payments can lead to impacts on soil management that are even more indirect than those of sectoral policies. To analyze the impact of such complex processes on natural resource management at the farm-level, researchers employ computable general equilibrium (CGE) models. These models link the various sectors of the economy and incorporate adjustment processes and feedback mechanisms (Wiig *et al.*, 2001; Persson, 1994; Unemo, 1994).

The influence of economy-wide policies on soil management may become more complicated in the presence of market and policy failures. Such distortions often characterize natural resource use, and include the under-pricing of natural resources in the presence of externalities or poorly defined property rights over these resources, such as

Table VI. Selected macro-economic policies in sub-Saharan Africa and their suggested impact on soil productivity

Selected policy	Potential impact
Expansive fiscal and monetary policies	Consequences for inflation, interest rates and exchange rates. Resulting macro-economic imbalances reduce economic stability and discourage farm-level investment in improved soil management.
High inflation	Stimulates investment in land as a hedge against declining value of other assets, with negative consequences for soil productivity. More serious if there are legal requirements for land clearance.
High interest rates	May be symptomatic of broader macro-economic instability, leading producers to maximize current output at the expense of future output.
Overvalued exchange rate	Provides incentive similar to artificially low producer prices or input subsidies but the effect is concentrated on tradables. High-input commercial agriculture is favoured over low-impact subsistence cropping systems. Encourages cheap food imports at the expense of domestic food production.
High debt service ratio	Encourages export production to generate needed foreign exchange, harming soil productivity if these activities involve erosive annual crops or production expands onto marginal lands.
Protectionism	Creates incentives for the inefficient and damaging cultivation of irrigated crops (e.g., wheat, rice) that can lead to waterlogging and salinization of soils.

Source: FAO/IFAD, 1999.

when traditional institutions break down. If these market and policy failures did not exist, then general macroeconomic reforms might improve economic efficiency, leading to better natural resource management as well. However, when distortions are present macroeconomic policy reforms may no longer have their intended effect and may even become undesirable from a natural resource management perspective. Mäler and Munasinghe (1996, p. 155) refer to this dilemma as a 'macroeconomic environmental policy failure'.

Inappropriate policies need not be targeted directly at the poor to induce soil degradation. In many countries, a large farmer bias exists, resulting in an incentive structure that favors wealthier farmers. The policy failure creates incentives for the rich and powerful to further marginalize the poor and restrict their access to resources, leading to greater pressure on those resources that are still accessible (Holmberg, 1991). Heath and Binswanger (1996) cite the case of Columbia, where public investment, credit policies and trade promotion favor large livestock producers and feed-grain producers at the expense of smallholders. Land and tax policies result in low-intensity grazing occupying the fertile bottom lands best-suited to arable farming, while smallholders are pushed onto hillsides where farming practices are inappropriate and soils quickly degrade. As a result, there is the appearance that poverty is causing degradation, when it is instead the application of inappropriate policies that has caused the problem.

The preceding discussion can be situated within a much broader policy controversy concerning the efficacy of using macroeconomic versus targeted environmental policies to address degradation problems. Some authors prefer correcting market and policy failures, since macroeconomic policies are blunter instruments and are not targeted at environmental variables, while others believe that complementary improvements in both arenas are most desirable (see Mäler and Munasinghe, 1996; Panayotou and Hupe, 1996; Hansen, 1996; Johnstone, 1996). Similarly, advocates of 'green tax' reform see a need to replace distortionary taxes on income and value-added with taxes on the depletion of natural resources and pollution, effectively reducing taxation of activities to be encouraged and shifting the burden to activities to be discouraged (Daly, 1996). Such reforms are argued to produce a double dividend or win–win situation, improving soil management as well as generating economic efficiency benefits of a more general nature.

Analyzing National Policies and their Impacts on Soil Productivity: Two Case Studies

To provide further insight into the influence of national policies on soil productivity, the remainder of this section looks at two case studies. In the first case study, Lopez (1996) presents an empirical model in which soil fertility is an input into a regional agricultural production function in the Western Region of Ghana. He uses this model to test the effects of various policy reforms on welfare and soil fertility. These reforms correct for implicit taxation of agriculture, protection of manufacturing, fiscal expansionism and poorly defined property rights, the latter a form of institutional failure leading to sub-optimal fallow periods. Macroeconomic policies that encourage expanded agricultural output interact with this institutional failure, driving down the sustainable productivity of land, and offsetting any direct output effect arising from macroeconomic policy reforms. Overall, the study shows that macroeconomic policies can exert a strong influence on farm-level decisions relating to soil productivity and that these may be either beneficial or harmful, in part depending upon the institutional framework in place.

In the second case study, Coxhead and Jayasuriya (1995) examine the effects of several policy options on annual field crop production in tropical upland areas. They assert that these production systems are more erosive than perennial tree crop systems and examine the relative effectiveness of targeted environmental policies versus more general macroeconomic alternatives. They construct a CGE model of a representative developing country economy (the Philippines) that includes four sectors. Then the authors simulate the response to four policies in terms of various indicators of economic performance and natural resource management. They find that all policies achieve the desired result of reducing upland cropped area, but not to the same extent, nor are the indirect effects of each policy identical. In general, targeted environmental policies are shown to have disadvantages compared to macroeconomic policies. The authors conclude that the indirect effects of well-meaning environmental policies could diminish or even reverse the intended impacts of these policies and that desired soil-conservation objectives could be achieved indirectly using more general macroeconomic policies.

A GLOBAL PERSPECTIVE

Barbara Underwood (President, International Union of Nutritional Sciences) has stated that as many as 30 million babies are born undernourished in the developing world each year, and that by school age one quarter are underweight and one third are stunted; about 15 per cent of adults in the same region are considered underweight (Underwood, 1999, p. 3). As a result, sustaining and even enhancing the productivity of agriculture in developing regions is seen by many as a global priority. Yet there are divergent views of the linkage between agricultural productivity and the global economy. One question under debate involves the influence of global markets on the management of soil resources. For example, Jagannathan (1989) suggests that monetization and expanding market access may help the income insecure diversify income sources, thereby leading to less pressure on the natural resource base. But Perrings (1996) cautions that by creating an 'open economy', international market access makes producers more vulnerable to a whole new set of market-related shocks (e.g., international price fluctuations) that can destabilize the farming system and result in land degradation. Similarly, expanding market access may favor the elite and speed up the process of social differentiation in ways that further marginalize the poor and encourage mining of soil resources. Further discussions have occurred over the role of trade liberalization and related topics (see Bredahl *et al.*, 1996; Anderson and Blackhurst, 1992).

An additional controversy concerns whether soil degradation itself is of global significance. While Pimentel *et al.* (1995) estimate global damages from soil degradation at US$400 billion per year, based on the costs of replacing nutrients and water lost via erosion, plus an allowance for off-site costs, Crosson (1995) critiques these estimates, suggesting they are too high. Similar dissenting views argue that such estimates may be alarmist. For example, the severity of soil losses from land degradation in Ethiopia is now questioned (Bojö and Cassells, 1995). Instead, soil degradation is argued by some researchers to be a regional problem and not a threat to global food production (Rosegrant and Ringler, 1997).

Notwithstanding these critiques, there is a global concern with soil degradation and, commensurately, a potential case for intervention at the international level. This argument holds as long as there are regional or global costs imposed by soil degradation or, what is the same, there are global benefits from improving soil productivity. To better appreciate how this might be so, consider the various ecosystem services associated with global soil resources (Table VII). These range from supporting plant growth and the hydrological cycle to more complex phenomena like the regulation of elemental cycles involving atmospheric gases. Where the loss of these services has a global or regional spillover effect, the impacts at the extra-national level constitute global externalities that

Table VII. Ecosystem functions of soil resources and the global consequences of soil degradation

Ecosystem functions of soil	Potential global or regional consequences of soil degradation
Supports cropping and grazing via nutrient delivery and physical anchoring of plants (e.g., food quantity)	Loss of crop and livestock production, leading to famine, eco-refugee problems; remedies require international intervention
Source of micro-nutrients for human consumption (e.g., food quality)	Dietary deficiencies and diseases, although linkage not well-investigated; remedies are crop breeding or supplements but soil management may be cost-effective
Buffering and moderation of hydrological cycle (e.g., drainage, temporary storage), and watershed protection	Trans-boundary flooding, water quality and siltation problems, and poor infiltration leading to reduced crop yields (see above); some revisions in thinking to account for natural processes
Decomposition and recycling (e.g., waste disposal)	Waste accumulation (e.g., leaf litter) and loss of significant soil microbe and earthworm biodiversity (e.g., sources of penicillin, streptomycin)
Regulation of atmospheric gases and elemental cycles (e.g., carbon sequestration)	Greenhouse gas releases and related global warming as organic matter is released; ultimate effect depends on where carbon ends up (e.g., reservoir sedimentation may avoid releases)

Sources: Adapted from Scherr, 1999; Pagiola, 1999b; and Daily, 1997.

are distinct from the national-level externalities (e.g., sedimentation) that routinely are included in conventional economic analyses of soil conservation projects (Bojö, 1996). If global externalities characterize soil management, then there will be insufficient investment in soil productivity improvements at the national level, since neither farm households nor national planners will take these global effects into account.

Economic analysis can provide useful insights in estimating the magnitude of the oversight. For example, the adoption of recommended management practices (e.g., conservation tillage, cover crops, agroforestry) can sequester substantial amounts of atmospheric carbon (C) in agricultural soils, leading to a reduction in the harm imposed by the accumulation of greenhouse gases (Lal, 2003). Economists are increasingly interested in this ecological service provided by agricultural soil (Kimble *et al.*, 2002); there is an obvious opportunity for the application of non-market valuation techniques to value this service. Such estimates would require a measure of the value of damages avoided by sequestering C and the quantity of C permanently removed from the atmosphere. Some qualifications arise in assessing the economic benefits of C sequestration in soils. Although the extent of C sequestration in soil and the implications for climate change are reasonably well established (Lal, 1997), the benefits of sequestration may be elusive if C is simply shifted from one location to another, with no net absorption from the atmosphere (Uri *et al.*, 1999).

While economic modeling of the potential for C sequestration in agricultural soils has been conducted in the US (Antle *et al.*, 2001; Pautsch *et al.*, 2001), there have been few, if any, such analyses in developing countries.[4] Moreover, recent findings suggest that the application of manure to agricultural soils leads to increased emissions of greenhouse gases (N_2O), and that this effect may be more pronounced in tropical areas (Bouwman, 1998). This effect would then partially offset the benefits from sequestering carbon in tropical soils. Clearly, further research is required in this area.

DISCUSSION AND POLICY IMPLICATIONS

This review of the economics of soil productivity leads to a number of policy implications. Past experience demonstrates that developing appropriate policies to conserve soil productivity benefits from extensive economic

[4]The World Bank has conducted a review of the benefits of C sequestration as part of a broader assessment of the global benefits of land degradation control on agricultural lands (Pagiola, 1999b), but this does not include formal modeling of the problem.

research and this review has shown that this research extends beyond traditional benefit-cost analysis. This section raises some of the key policy issues at the local, national and global levels.

Policy Implications at the Local Level

Much of the policy debate at the farm and community level is concerned with developing and implementing appropriate incentives for improved soil management (see Sanders *et al.*, 1999). But to design appropriate incentives requires an understanding of the desired soil-productivity goals. As an example, Table I indicated that the newer thinking associated with the land husbandry movement takes a more integrative and participatory approach to soil management in comparison to the structures-oriented approach associated with more conventional approaches to soil and water conservation. Not surprisingly, the incentives that encourage investing in farm structures are different from those that increase crop cover and organic matter, and the supporting policies that generate these incentives will be different as well. The former approach requires credit assistance to finance the necessary on-farm structures, while the latter is liable to benefit most from extension improvements and farmer-to-farmer training programs. Realistically, some mix of these two approaches may be preferred, since investment in certain equipment or structures may be complementary to agronomic improvements.

When a soil degradation problem requires a community-wide response, favorable incentives must exist at this level (Izac, 1997). Wade (1988) argues that incentives for cooperating can be consistent with self-interest, but only when the collective benefit is large enough to outweigh the transaction costs involved in obtaining this benefit. In such cases, the individual's share of the collective benefit, less his or her costs, must exceed the potential benefits of not cooperating, to bring about cooperation. But certain preconditions may be necessary too, such as the extent of a community or society's social capital (Pretty and Ward, 2001). Isham (1999) considers the role of social capital in contributing to the success of community-based development projects, arguing that parallel investments in social capital can help create the proper enabling environment. Project development and policy making must take into account such considerations to ensure interventions are effective.

Policy Implications at the National Level

A key area of policy analysis relating to soil fertility at the national level is mineral fertilizer subsidies. Until the advent of Structural Adjustment Programs (SAPs), large fertilizer subsidies were the norm throughout such regions as sub-Saharan Africa (Repetto, 1989). These subsidies have now virtually disappeared, but there is an emerging call to rethink their removal that is controversial (Reardon *et al.*, 1997; Matlon and Adesina, 1997). Aside from the obvious budgetary concerns of a major subsidy program, the difficulty lies in the relationship between mineral fertilizers and other inputs, such as soil organic matter, which are emphasized in newer thinking.

Since many farmers perceive these two inputs as substitutes, designing an effective subsidy is challenging. If fertilizer becomes relatively cheaper, farmers may choose to apply greater amounts at the expense of other inputs like organic matter. Neglecting soil organic matter risks reducing the sustainability of the cropping system as the outcome of the subsidy, rather than enhancing it. By reducing its price to the farmer, a subsidy on fertilizer also changes the relative price of fertilizer *vis-a-vis* alternative technologies for maintaining soil productivity, and thereby reduces the incentive to use these alternative means. In effect, the subsidy causes the short-run cost of soil degradation to fall by lowering the costs of replacing lost nutrients with fertilizers (Bojö, 1996; Barbier and Burgess, 1992). Designing policies to increase the quality and quantity of soil organic matter is even more challenging, given the limited potential supply of soil organic matter within many farming systems. Certainly there are synergistic effects, since increased fertilizer use generates higher crop yields and more crop residues, and these can help to increase soil organic matter. An ideal subsidy would link fertilizer assistance with action on soil organic matter and avoid the worst pitfalls of previous fertilizer subsidies.

The debate over mineral fertilizer subsidies can be situated within a broader context pertaining to the development of national policies for soil management. In theory, subsidies are preferred to general price supports because of the better-targeted response (Tolley *et al.*, 1982). Price supports encourage a range of production responses, including investment in new soil-management technologies but they also may encourage extensification into sensitive, marginal lands or frontier areas (Cleaver, 1985). In contrast, Alfsen *et al.* (1997) use a model of fertilizer subsidies in Ghana to show that subsidies may reduce extensification by increasing the productivity of existing cultivated lands. They argue that subsidized fertilizer substitutes for land (at least in the short run), leading to less expansion in the cultivated area and decreasing deforestation and other potential degradation. Both price supports and subsidies may be more effective and over longer periods than Food-for-Work schemes that support the constructing of soil conservation works, but at the cost of fostering dependency.

Policy Implications at the Global Level

It was argued earlier that individual nations will not take into account global benefits stemming from improved soil management unless they can capture a share of these benefits. As one option, international transfers can provide countries with the additional incentives to devote more resources to soil productivity. Establishing the benefits of soil management at the national and global levels is a first step in addressing this problem. Economic analysis can then determine the appropriate size of international transfers to compensate for the global benefits of soil productivity improvements.

While the above argument is relatively straightforward, it has only recently been advanced in international policy circles in connection with soil degradation (Pagiola, 1999b; Scherr, 1999). One mechanism for undertaking the necessary transfers is the Global Environment Facility (GEF), which provides for the financing of incremental costs incurred by countries addressing a soil degradation problem of global significance. Under the GEF, land management projects that sequester carbon within agricultural soils must do so for less than a rough estimate of the damages avoided to be acceptable for assistance (Pagiola, 1999b). More sophisticated analyses are looking at the means to convey international transfers to the farm-level. These analyses are concerned with the merits of direct payments to farmers per tonne of carbon sequestered versus payments on a per hectare basis (Pautsch *et al.*, 2001), and the potential efficiency benefits of market-based carbon credits over mandated technology adoption (Antle *et al.*, 2001).

If the link between soil productivity and global damage is uncertain and potential damage thresholds exist, then a relatively minor deterioration in soil productivity could result in catastrophic events, such as famines and eco-refugee displacement (Muradian, 2001; Myers and Kent, 1994). Such a risk provides an incentive for the international community to apply the Precautionary Principle, acting sooner rather than later to prevent such an occurrence (O'Riordan and Cameron, 1994). The resulting costs can be viewed as an insurance premium paid by the international community to avoid such social and economic disruption. Economic analyses can estimate the opportunity costs of adopting the Precautionary Principle but are limited when establishing a permissible level of the degrading activity in light of the uncertainties involved.

CONCLUSIONS

This paper has reviewed applications of economics to soil productivity problems at the local, national and global levels. A key question that arises out of this review is the following: if economic analyses demonstrate that soil productivity decline is worth addressing (and most do, although this was not the focus of this review), then how best to use economics to further this goal? It is clear from the analysis of net returns that 'agronomic' technologies present more favorable returns at the household level, evidence that accords with widely held beliefs among practitioners. Yet many of these technologies have not been adopted en masse, despite highly positive net present values. Thus, it can be concluded that profitability is perhaps a necessary condition for technology adoption but not one that is sufficient. A variety of constraints inhibit this response. Clearly, devising effective incentives at the farm and community level that take account of this reality must be a priority, the latter recognizing that not all improvements can be implemented at the farm household level in isolation. Indeed, there is increasing recognition of this needed shift in focus.

Even more attention must be paid to the influence of sectoral and macroeconomic policies at the farm level. There is little use in expending large sums on direct farm-level incentives to conserve soils if policies at higher levels inadvertently discriminate against these improvements and can be adjusted at less cost. Modeling of the economy-wide effects of such policies has developed rapidly in recent years and this is a favorable sign.

Addressing incentives at the national level and beyond is a further concern. For example, more effort is required to estimate the global benefits from improved soil management in developing countries using conventional economic modeling techniques. These calculations can help in establishing the appropriate size of international transfers, so that countries are encouraged to make soil degradation a higher national priority.

Clearly, there is much that economists can contribute to the improved management of global soil resources beyond the confines of conventional benefit-cost analyses undertaken during project appraisals. For example, the economist's tool kit now includes various approaches for screening new technologies, to assess the prospects for community implementation of soil and water conservation works and for the modeling of national policy linkages with soil productivity at the farm level.

Obvious areas for further research include:

- the role of inorganic fertilizers in masking soil productivity decline and the potential existence of thresholds leading to a risk of collapse in the face of adverse events;
- the link between above-ground carbon sequestration benefits (e.g., tree crops) and soil management; and
- intergenerational issues, such as the rationale for state intervention to safeguard resources needed for the livelihood of future generations.

In the meantime, this paper has attempted to provide an outline of initial efforts and future possibilities.

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