THE COSTS AND BENEFITS OF SOIL CONSERVATION: THE FARMERS' VIEWPOINT

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Most countries in Central America and the Caribbean depend heavily on agriculture; efforts to sustain and improve the sector's productivity are therefore crucial to the region's economic development and to the welfare of its people. Land degradation is thought to pose a severe threat to the sustainability of agricultural production. Yet despite long-standing concern about this threat and dramatic claims of environmental damage, surprisingly little empirical analysis has been done on the causes and severity of land degradation problems in the region and on how best to tackle them. Meanwhile, many of the conservation programs designed to address the problems have fallen short of expectations. Often farmers have not adopted the recommended conservation practices or have abandoned them once the project ended.

The research presented in this article attempts to bridge the empirical gap, using cost-benefit analysis to investigate the nature and severity of the soil degradation problem and to assess the cost-effectiveness of proposed solutions. Because soil degradation problems tend to be site-specific, the analysis is rooted in case studies, and because conservation programs stand or fall on the participation of farmers, the study's main focus is on the profitability of the measures and the deterrents to their adoption from the farmers' point of view.

Soil degradation can be defined as a reduction in the land's actual or potential uses (Blaikie and Brookfield 1987). Many cultivation practices tend to degrade soil over time. For example, cultivation can expose soil to water and wind erosion, repeated tillage can weaken soil structure, crop production can remove nutrients, and use of machinery can compact the soil. Central America's mountains and heavy rainfall make much of the region particularly

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vulnerable to degradation—a problem exacerbated by population pressures that have opened to farming new areas only marginally suited to agriculture. Soil degradation, in turn, affects productivity. As soil is degraded, crop yields decline or the levels of inputs (and hence costs) needed to restore productivity rise.

Despite long-standing concern about these problems, surprisingly little hard evidence exists on their magnitude. The degradation figures quoted in the literature are often extrapolated from very limited data and may exaggerate the problem because they often consider "moved soil" as "lost soil," even though much of it may have been deposited on other agricultural land. For instance, in a recent assessment of the extent of human-induced soil degradation, the International Soil References and Information Centre (ISRIC) estimated that 56 percent of the land in Central America had experienced moderate degradation, implying that productivity has been substantially reduced, and that 41 percent had experienced strong degradation, implying that agricultural use has become impossible (Oldeman, Hakkeling, and Sombroek 1990). Aggregate measures such as these, however, often have a weak empirical basis. Few studies have directly measured erosion rates and the factors that influence them, and these studies have generally been scattered and unsystematic. Even less effort has been devoted to studying other forms of land degradation, such as depletion of nutrients, damage to physical and chemical properties of soil, or reductions in its capacity to retain moisture.

Table 1 presents the available estimates of erosion rates in Central American countries. The data were obtained in a variety of ways and are therefore not always strictly comparable, but they do give some idea of the great diversity of erosion rates present within the region.

Predictions abound of catastrophic effects on agricultural productivity arising from soil degradation. Evidence on the magnitude of these effects, by contrast, is hard to find—in fact, in many cases claims of declines in productivity are made with no evidence at all (see Biot, Lambert, and Perkin 1992 for some African examples). Leonard (1987, p. 130), for example, simply asserts that a "pattern of extensive land use leading to soil loss or decline in fertility is apparent" in the Caribbean areas of Central America. Speaking of the highland areas, he points to "increasing reports of localized desertification in areas of western Honduras and Costa Rica." He also mentions that cotton yields are "reportedly declining" where severe erosion has been experienced. But nowhere does he provide any indication of the size or rate of fertility loss. More generally, the assumption that fertility must be declining rapidly is usually left implicit from statements about high rates of erosion.

But erosion rates, even where they are significant, may have very little effect on productivity under certain conditions. Erosion rates in the Tierra Blanca area in Costa Rica's Cartago Province, for example, are extremely high, but the effect on productivity is minor because soils in that region are deep (up to 1 meter in some places) and contain a high percentage of organic matter. Moreover, the subsoil is itself productive, although less so than the topsoil. The

Table 1. *Empirical Evidence on Soil Erosion in Central America and the Caribbean*

Country and area	*Source*	*Rainfall (millimeters)*	*Slope (percent)*	*Farming system*	*Average annual rate of erosion per hectare* Metric tons	Millimeters
Dominican Republic						
Taveras	Hartshorn (1981)	—	—	—	275	—
North Central	Altieri (1990)	—	36	Various	24–69	—
South West	Veloz (1988)	—	30	Various	2–1,254	—
El Salvador						
Metapán	Flores (1979)	1,895	—	Corn	137	9
	CTA (1956)	1,724	30	Corn, beans	230	15
Haiti						
Camp-Perrin	CUNARD (1991)	2,000	30	Hedges	4–45	—
Papaye	Grosjean (1987)	1,214	25	Grasshedge	8	—
Honduras						
Tatumbla, Morazán	Welchez (1991)	2,000	45	Corn, beans	42	3
Tatumbla, Morazán	Sánchez (1991)	900–1,500	15–40	—	18–30	—
Nicaragua						
Cristo Rey	PCEO (1981)	1,700	30–40	Cotton	40	—
Panama						
Cuenca del Canal	Soto (1981)	1,200	35	Rice	153	—
Cuenca del Canal	Soto (1981)	1,200	35	Corn	137	—
Cuenca del Canal	Soto (1981)	1,200	35	Rice	118	—
Coclé	Vásquez (1991)	1,937	—	Rice, corn, cassava, beans	340	17
Chiriquí	Oster (1981)	1,500–2,800	—	Pasture	35	5
Chiriquí	Oster (1981)	1,500–2,800	—	Coffee	77	11
Chiriquí	Oster (1981)	1,500–2,800	—	—	183	27

— Not available.
Note: Figures rounded.

Chiriquí region in Panama provides a similar example. Conversely, areas with shallow soils or unfavorable subsoils, such as the Turrubares area in Costa Rica, can be very sensitive to even limited rates of erosion. The same phenomenon is true of other forms of soil degradation. The effect of nutrient loss on productivity, for example, depends on the initial stock of nutrients and on their rate of regeneration.

Because of the different effects of soil degradation on productivity, a specific soil conservation technique—particularly an expensive one—may not be worth-while from either a farmer's perspective or society's. Degradation can be slowed or arrested by a large range of methods, including cultural practices such as contour plowing and minimum tillage; vegetative practices such as grass strips, strip-cropping, and vegetative barriers; and mechanical measures such as terraces and cutoff drains. Implementing any of these techniques can be costly, either directly in investment requirements or indirectly in forgone production, and some measures are better suited than others to specific conditions. The critical question facing farmers—and society as a whole—is whether the benefits of a given conservation measure or set of measures are worth the costs.

Conceptual Issues

The problem of soil degradation and conservation can be examined from two perspectives: that of society as a whole and that of individual farmers. From the standpoint of society, all the costs and benefits of a given activity must be considered. Agricultural production that leads to siltation of reservoirs, for example, represents a real cost to society that should be considered together with the value of the output obtained and any effects on fertility. In addition, to measure the true opportunity cost of the resources used in and obtained from agricultural production, their valuation should be adjusted for any distortions resulting from policy interventions or market failures. Farmers, however, are likely to consider only the costs and benefits that actually accrue to them from the decisions they make about how to use their resources. They value these costs and benefits at the prices they actually face, with no attempt to adjust for distortions.

This article examines the returns to investment in conservation measures mainly from the farmers' point of view for two reasons. First, decisions about land use are ultimately made by the farmers themselves and not by social planners or government agencies. Farmers decide how to use their land in light of their own objectives, production possibilities, and constraints, not on the basis of any theory of the social good. Understanding the incentives (and disincentives) individual farmers face is necessary, therefore, to understand patterns of resource use and to formulate appropriate responses to problems. Second, land use problems generally depend heavily on site-specific biophysical characteristics, which can vary significantly even within small areas (Pagiola 1993). Analysis at the farm level is the most apt to incorporate site-specific effects.

A farm-level approach also places the emphasis firmly on the effects of degradation on farm productivity. In developing countries, where substantial numbers of people still depend directly on agricultural production, the effect of degradation on yields is often critical. This is not to belittle the importance, in some situations, of off-farm effects of soil degradation, such as siltation of reservoirs and waterways. But even where such off-farm effects are the primary concern, considering them first at the farm level is appropriate because that is where the conservation measures would have to be implemented.[1]

In making their land use decisions, farm households need to consider both the agroecological and the economic characteristics of the environment in which they operate. In addition, they often face numerous constraints, such as tenure and liquidity problems, the need to meet consumption requirements, and the need to compensate for missing or incomplete markets. Moreover, many farm decisions are made in the context of considerable risk and uncertainty about weather, pests, fluctuating market demand, and so on. A complete analysis of land use decisions, therefore, requires that one look at the issue in the context of overall decisionmaking of the household (Singh, Squire, and Strauss 1986; Reardon and Vosti 1992).

The farm household's problem can be formulated as one of maximizing the utility of consumption over time, subject to a budget constraint imposed by its returns from agriculture over time and any returns from nonfarm activities, and subject to any other constraints it might face. Singh, Squire, and Strauss (1986) show that if markets exist for all goods and services, the problem of maximization is separable, in the sense that production decisions are made independently of consumption decisions. Even when production decisions are not separable, however, they can be analyzed independently as long as the "prices" of goods for which markets are missing are interpreted as shadow prices that reflect the farm household's perception of the severity of the constraints they face (De Janvry, Fafchamps, and Sadoulet 1990).

The household's problem, then, can be summarized as one of maximizing the present value of the stream of expected net returns to agricultural production (Pagiola 1993). In practice, data are generally not available to estimate complex maximization models. But for empirical analysis, the model can be reformulated to fit a cost-benefit analysis framework. The household's choice can be viewed as selecting between two or more alternative cropping systems. For example, the choice might be between retaining the traditional cultivation system, in which conservation measures are limited to contour plowing, or replacing it with a new system, which conserves more soil by using terraces or reduced-tillage techniques. Each system is characterized by distinct production functions and soil conservation functions, and each generates a different optimal path. From the household's perspective, the problem is whether returns under the optimal path of the new, more conserving system are sufficiently greater than returns under the optimal path of the current, more degrading system to justify the cost of switching.

Basically, it would be in the farm household's financial interest to adopt the new system if the net present value of the incremental returns from switching were positive (NPV > 0). This formulation is equivalent to a standard cost-benefit analysis formulation and lends itself particularly well to empirical analysis, because suitable data are often available. Observing practices in use allows time paths of yields and use of inputs to be constructed; these are then used to project costs and revenues over time. The method can also be used if the only data available are on total costs and revenues in each period, and it also lends itself well to incorporating lumpy investments and other discontinuities in cropping practices (Walker 1982; Taylor and others 1986).[2]

The discussion so far has assumed that the only constraints on behavior are those imposed by the properties of the biophysical system. The NPV > 0 criterion is thus a necessary but not a sufficient criterion for adopting a new production system. Even if the NPV estimate is positive, other factors might prevent a household from adopting a new system. In principle, these other constraints could be built into the optimization framework. The effect of tenure insecurity might be included, for example, by limiting the length of the time horizon. In practice, however, the profitability of a system is generally easier to compute if one first assumes that no constraints hold and then verifies whether any specific constraints are binding. The cost-benefit calculations themselves often provide insight into whether particular constraints are likely to prove binding. The length of time it takes for an investment to be repaid, for example, can indicate whether tenure issues are likely to pose problems. If the investment is repaid quickly, insecurity of tenure is unlikely to affect adoption. Of course, if adopting a new production system is unprofitable for the farm household, the question of whether other constraints might prevent its adoption does not arise.

Methodology

Cost-benefit analysis techniques provide a coherent framework for integrating information on the biophysical and economic environments faced by farmers. Variants of these techniques have been used to examine soil conservation cases in the Dominican Republic (Veloz and others 1985), India (Magrath 1989), and Kenya (Pagiola 1992). Other simple techniques, such as calculating the value of lost nutrients (Repetto and Cruz 1991), can only roughly indicate the severity of the problem; they cannot provide guidance in selecting the best response.

The basic principles of the analysis are straightforward. First, the effects of continued erosion (or other types of soil degradation) on productivity are estimated for the time horizon of interest. These are then used to estimate returns at each point in time. Second, the calculations are repeated under the conditions that would be experienced if a specific conservation measure were adopted. The returns to the investment in this measure are then obtained by taking the difference between the streams of discounted costs and benefits in the cases with and without conservation. This method estimates the returns to the specific conservation measures being examined, not to conservation per se. A finding that certain conservation practices are not profitable does not mean that no conservation measure is profitable—often, numerous measures designed to reduce degradation rates are already being practiced, implying that farmers consider them profitable.

As was argued in the previous section, when the analysis is carried out at the farm level using prices actually faced by farmers, a positive NPV estimate for a given conservation measure can be interpreted as showing that adoption of that measure would profit the farmer. Farmers should, in principle, be willing to adopt the measure voluntarily. But, as with all cost-benefit analysis, other, unexamined options might be preferable. The analysis can be repeated for each known option, and the most profitable among them found.

For this article and the larger work from which it is drawn, the availability of data dictated the choice both of the sites studied (see table 2) and of the aspects of the problem analyzed: erosion and mechanical methods of conservation.[3] Research efforts have mainly focused on problems arising from erosion, to the neglect of other forms of soil degradation, and most conservation projects in the past have tended to emphasize mechanical conservation structures. Consequently the case studies do not present a comprehensive overview of soil conservation problems and practices in the region; they do, however, illustrate the wide diversity of conditions encountered, help explain farmers' behavior, and indicate appropriate policy responses.

Our country studies, except for Haiti, were conducted by local practitioners; in most cases, teams were composed of economists, agronomists, and soil scientists from relevant government agencies. This collaborative and participatory approach to the research drew on local knowledge and expertise and also developed local analytical capacity.

Data on the nature and rate of degradation caused by current practices, on the effects of degradation on future productivity, and on the effects of conservation practices are very scarce. Various methods for estimating the required relationships were chosen, depending on the nature of the available data. Econometric techniques were sometimes used to estimate the effect on yield of certain observed conditions (such as the presence or absence of certain conservation measures). For our purposes, estimating a time trend of yields with and without a given conservation measure was usually sufficient, although disentangling the effect of soil degradation on productivity is very difficult (Capalbo and Antle 1988), and even the limited objective encountered problems such as bias in sample selection when nonconserved and conserved fields were compared. In addition, many of the case studies had to rely on farmer recall for data and were not able to control fully for other sources of variation in yield, such as weather. In other cases, simple models of the physical environment—such as the Universal Soil Loss Equation (USLE) and, in the Haiti study, the Soil Changes under Agroforestry (SCUAF) model—were employed, using a mixture of experimental and observational data. A modeling approach is more flexible because it allows parameter values to be drawn from a variety of data sources. But it requires detailed qualitative and quantitative knowledge of the biophysical environment; building and validating a complete and realistic model are complex endeavors. Even calibrating existing models is far from easy.

Table 2. *Case Study Areas*

Country and area	*Biophysical environment*	*Degradation problem*	*Conservation measures proposed*
Costa Rica			
Barva area, Heredia Province	Important coffee-producing region. Relatively deep soil, but vulnerable to erosion because of topography.	Soil loss affects nutrients available to coffee.	Diversion ditches.
Tierra Blanca-San Juan Chicoá, Cartago Province	Important vegetable-producing area. Deep volcanic soils.	Because of deep soils, decline in yield is not significant, but erosion washes away seed and fertilizer and exposes rocks.	Diversion ditches are recommended, but interfere with prevalent cultivation practices.
Turrubares, Central Pacific region	Previously used for pasture, now converted to production of coco yam for export.	Very high rates of erosion. Soils are thin and vulnerable to erosion.	Diversion ditches or terraces.
Dominican Republic			
El Naranjal subwatershed, Peravia Province	Subsistence agriculture. Steep slopes, soils of moderate natural fertility.	High rates of erosion.	Diversion ditches at 10-meter intervals, live barriers, and contour cropping.
Guatemala			
Patzité, Department of Quiché	Small-farm area. Strongly undulating topography; soils of medium depth and fertility.	Heavily affected by soil erosion.	Terraces with a protected embankment.

Haiti			
Maissade watershed, Central Plateau region	Hilly area. Generally less degraded and more productive than most other hilly regions of Haiti.	Erosion.	*Ramp pay* (indigenous technique in which crop residue is placed along the contour and held in place by stakes); hedgerows along the contour; and contour rock walls.
Honduras			
Tatumbla, Department of Francisco Morazán	Subsistence agriculture predominant. Thin topsoil, low in organic material and many nutrients.	Susceptible to water erosion, especially in the high areas.	Diversion ditches with live barriers.
Yorito, Department of Yoro	Subsistence agriculture, still largely forested. Shallow, easily erodible soils, of medium to low natural fertility.	Cleared plots vulnerable to erosion.	Diversion ditches with live barriers.
Nicaragua			
Santa Lucía valley, watershed of Malacatoya River	Subtropical foothills. Moderately deep soils. One of the most productive areas in the country.	High risk of erosion due to steep slopes, scarce vegetation cover, and intense precipitation. Deforestation on upper slopes.	Manually constructed diversion ditches with stone barriers.
Panama			
Coclé Province	Subsistence agriculture using slash-and-burn techniques, with plots cultivated one year in every five. Shallow soils, generally low in organic matter and nutrients, on steep slopes.	Rapid decline in yield on cleared plots; deforestation.	Combination of erosion prevention measures (planting on the contour, live and dead barriers, diversion ditches) and improved cultivation practices.

Source: Case studies in Lutz, Pagiola, and Reiche (1994).

Obtaining the required economic data was generally less problematic. Crop production budgets, used to estimate returns, were the main requirement and were generally widely available, although rarely at the degree of disaggregation needed. Fortunately, preliminary budgets built from available secondary data were easy to confirm, supplement, and correct during fieldwork. The most important task was to ensure that the crop production budgets accurately reflected practices and prices in the area. Inputs provided by the households themselves, such as family labor, were priced at their cost in the nearest market. Output and input prices used in the analysis were meant to represent long-run real price trends. Assessing the discount rate is crucial, given the intertemporal nature of the problem, but beset by controversy. Here, because the analysis examines the profitability of conservation from the farm household's viewpoint, the appropriate discount rate to use should be the farmers' cost of borrowing or their rate of time preference. However, little empirical evidence exists on either (Pender 1992). Therefore, and to facilitate comparability of results across study sites, a common real discount rate of 20 percent was used in each case study. In addition, the internal rate of return (IRR) was computed in each case. If the appropriate discount rate, assuming it were known, is smaller than the IRR, the proposed conservation measures would be profitable.

Effects of Degradation on Productivity

The estimated losses in productivity vary considerably across the case studies; table 3 presents findings for some of the crops analyzed. In several cases, the data point to rapid rates of decline in yield. In the Maissade watershed of Haiti, for example, yields of corn and sorghum were estimated to decline by as much as 60 percent during a decade. In the Tatumbla region in Honduras, corn yields declined almost 50 percent in ten years if no conservation measures were used. Elsewhere, estimated declines were minor. Coffee yields in the Barva region of Costa Rica, for example, were estimated to decline by slightly more than 10 percent in ten years, and there is reason to believe that the actual rate is lower. In Costa Rica's Tierra Blanca region, declines in potato yield caused by erosion were easily countered by small increases in fertilizer use; indeed, potato production has been steadily increasing despite high rates of erosion. The effects of degradation can also vary significantly across crops, even in the same area, as shown by the data from El Naranjal in the Dominican Republic.

If no conservation measures were adopted, returns to agricultural production would gradually decline in each of the cases studied. Eventually, production would become uneconomic and cease—although exactly when would vary, depending on the rate of decline in yield, the cost of production, and the price of the output. (Because farmers are likely to adjust their production practices as yields decline, the time before production becomes unprofitable is likely

Table 3. *Estimates of the Impact of Soil Degradation on Productivity of Selected Crops in the Case Study Areas*

Country and area	Crop	Production, as percentage of initial yield, after					Projected shutdown year
		10 years	20 years	30 years	40 years	50 years	
Costa Rica							
Barva	Coffee	89	78	67	56	46	20
Turrubares	Coco yam	0	0	0	0	0	4
Dominican Republic							
El Naranjal	Pigeon peas	58	16	0	0	0	
	Peanuts	100	100	100	100	100	16[a]
	Beans	77	53	30	0	0	
Guatemala							
Patzité	Corn	0	0	0	0	0	10[b]
Haiti							
Maissade	Corn, sorghum	41	22	10	1	0	25
Honduras							
Tatumbla	Corn	53	39	39	39	39	8
Yorito	Corn	82	65	47	41	41	11

Note: Projected year for production shutdown is in the absence of conservation measures.

a. The sixteen-year shutdown period applies to the pigeon peas–beans–peanuts intercrop system. Because the three crops are cultivated together, peanut cultivation is assumed to cease when the yields of the other crops make production uneconomic.

b. Corn can be produced in years one through nine, but decline in yield is so rapid that it reaches zero in year ten.

Source: Case studies in Lutz, Pagiola, and Reiche (1994).

to be overestimated.) The very high rates of decline experienced in Turrubares mean that the production of coco yam would shut down in four years if no conservation measures were adopted. By contrast, in Tierra Blanca the production of potatoes would remain profitable more or less indefinitely even without conservation measures.

Not all the damage caused by soil degradation takes the form of losses in yield. In Tierra Blanca, for example, the effects of degradation are reflected primarily in higher costs arising from the need to apply higher rates of fertilizer, from the lower efficiency of fertilizer (because some washes away), and from the labor required to remove stones that accumulate on fields as soil erodes. In Panama's Coclé Province, agricultural production on a given plot can be sustained only for a very short time if no conservation measures are used. There, the costs of degradation are reflected primarily in the need to clear new plots of land.

These examples, together with the diversity of effects on yield, reinforce the need for site-specific information to understand degradation problems and devise effective ways of helping farmers respond to them. These case studies, however, are by no means a random sample of degradation conditions in the region; they are drawn from sites for which data were available and therefore primarily from areas where degradation problems were serious enough to warrant data collection. Consequently, they probably represent high-case scenarios on the degree and rate of degradation in the region.

The estimated effects on yields of conservation practices were likewise varied. In some instances, yields were expected to recover once conservation measures were established—partly because soil regenerates after the processes of degradation are halted, partly because fertilizers are used more efficiently, and partly because improved cultivation practices are sometimes introduced together with conservation. In the Tatumbla area of Honduras, for example, if diversion ditches are built and improved planting practices are adopted, annual corn yields are estimated to increase about 145 kilograms per hectare. Elsewhere, conservation measures might slow but not halt the decline in yield. In the Turrubares area of Costa Rica, for example, it was estimated that diversion ditches would halve the rate of decline in yield; the much more expensive terraces, on the other hand, were expected to reduce the rate of decline by 90 percent. Again, the diversity of conditions is evident.

As well as reducing soil loss and hence the rate of decline in yield, conservation measures can affect yields by encouraging the retention of moisture and stimulating improvements in the soil's physical structure (English, Tiffen, and Mortimore 1994; Shaxson and others 1989). In Haiti's Maissade area, land treated with diversion ditches and other conservation structures was found to produce an average of 51 percent more corn and 28 percent more sorghum than did plots without conservation structures in 1988 (a year of poorly timed rainfall) and an average of 22 percent more corn and 32 percent more sorghum than did plots without conservation structures in 1989 (a more normal year). In dry areas, therefore, soil conservation can often reduce the risk of crop failure by improving moisture retention.

But in turning over some of the cultivated area to use as diversion ditches, terraces, or hedges, these conservation measures can also adversely affect production. Physical structures, in particular, can reduce the available area for cultivation by more than 10 percent. Construction of cutoff drains in Tierra Blanca, for example, reduced the effective cultivation area by about 14 percent, while terrace construction in the Patzité region of Guatemala led to a 15 percent reduction. Further, terracing often entails movements of earth that bring unproductive soil to the surface. In Tierra Blanca, the few diversion ditches that had been constructed with subsidies had the additional disadvantage of interfering with the prevailing production practices, which rely heavily on mechanical equipment. Such drawbacks clearly, and often heavily, influence the ultimate profitability of these conservation measures.

Because some of the productivity estimates are based on weak or incomplete data, extensive sensitivity analyses were incorporated into each case study. The results are robust to changes in the estimated effects on yield in several cases, but are affected significantly in other cases by changes in assumed rates of decline in yield. In such instances, the premium to additional research would be high. In the Santa Lucía case study in Nicaragua, data were insufficient to estimate the effects of degradation on productivity. Simulation analysis was used, therefore, to examine returns to the proposed conservation measures (diversion ditches constructed manually with stone barriers) under a range of assumptions about the effect of degradation and conservation on yield. The simulations show that the proposed conservation measures are likely to be profitable only if they lead to substantially improved yields.

Farm-Level Returns to Soil Conservation Measures

Effects on yield are not the only factors to consider in analyzing the costs and benefits of investing in a given conservation measure. Table 4 summarizes the results of a full economic analysis of each case study where data were sufficient to allow adequate assessment.

The most profitable conservation measures were found in Maissade in Haiti, and Turrubares in Costa Rica. The conservation measure used in Maissade is an indigenous technique, known as *ramp pay*, which consists of crop stubble laid out along the contour, supported by stakes, and covered with soil. It is cheap to construct and very effective in halting erosion. Moreover, without conservation measures, yield would decline particularly rapidly in that area. Conservation measures in Turrubares consist of expensive terraces, but they protect highly profitable export crop production from extremely rapid rates of yield decline. Rates of return to the proposed conservation measures were also estimated to be high in the Tatumbla area of Honduras, where yields decline rapidly if no conservation measures are taken.

The least profitable conservation measures studied were found in Barva and Tierra Blanca, Costa Rica. The Tierra Blanca case is particularly interesting, because rates of erosion are very high. But the region's deep volcanic soils mean that degradation has very little effect on productivity. In fact, production would actually be higher without the proposed conservation measures—diversion ditches—because their construction would reduce the effective cultivated area and, by interfering with current production practices, would increase the costs of production. Unsurprisingly, the farmers in the area have little interest in building the ditches.

In Maissade in Haiti, Turrubares in Costa Rica, and Patzité in Guatemala, data were available to examine the returns to different forms of conservation. In Maissade, the indigenous *ramp pay* conservation technique is clearly superior to rock walls, which are more expensive and lack the agronomic advantages of *ramp pay*. In Turrubares the choice is less clear: terraces slow erosion much more effectively than diversion ditches, but they are also more expensive

Table 4. *Estimated Returns to Investments in Conservation in the Case Study Areas*

Country and area	*Conservation measure*	*Crop*	*Net Present Value (NPV) (US$)*	*Internal Rate of Return (IRR) (percent)*	*Years to break even*
Costa Rica					
Barva	Diversion ditches	Coffee	–920	< 0	> 100
Tierra Blanca	Diversion ditches	Potatoes	–3,440	< 0	> 100
Turrubares	Diversion ditches	Coco yam	1,110	84.2	2
Turrubares	Terraces	Coco yam	4,140	60.2	3
Dominican Republic					
El Naranjal	Diversion ditches	Pigeon peas, peanuts, beans	–132	16.9	> 100
Guatemala					
Patzité	Terraces	Corn	–156	16.5	> 100
Haiti					
Maissade	*Ramp pay*	Corn, sorghum	1,180	—[a]	0
	Rock walls	Corn, sorghum	956	—[a]	1
Honduras					
Tatumbla	Diversion ditches	Corn	909	56.5	4
Yorito	Diversion ditches	Corn	83	21.9	18
Panama					
Coclé	Terraces	Rice, corn, yuca beans	34	27.2	8

Note: Net present value is computed over fifty years, using a 20 percent real discount rate.
a. Undefined, because net returns are positive from year one onward.
Source: Case studies in Lutz, Pagiola, and Reiche (1994).

to construct and entail a greater reduction in effective cultivated area. The tradeoff between effectiveness and cost is fairly easy to make in this case because the greater effectiveness of terraces more than compensates for their additional cost. But greater effectiveness does not always equate with higher profitability. In Patzité, for example, a combination of diversion ditches and live barriers appears to be substantially more profitable than terraces, even if much less effective. This situation appears to be more representative of conditions encountered in Central America: in analyses of twenty conservation techniques in Mexico, for example, McIntire (1994) also found that cultivation and cropping practices, including vegetative barriers, were superior to structural measures in terms of profitability. Only when crop production is very profitable but extremely vulnerable to degradation (as in the case of Turrubares) are expensive conservation measures likely to be justified.

Unfortunately, data were insufficient to examine differences in returns *within* the study areas. Evidence from Kenya (Pagiola 1992) suggests that returns to conservation can vary considerably even within narrowly defined agroecological zones. Farmers on different slopes, for example, experience different rates of erosion. They also face different costs of conservation; the optimal spacing of terraces and diversion ditches, for example, is a function of the slope. Whether these differences are significant in any given instance is an empirical matter.

In each case, adoption rates appeared to correlate well with the estimated profitability of conservation. The profitability of *ramp pay* is confirmed by its widespread adoption in Maissade. Conservation measures were also adopted at high rates in the Tatumbla region of Honduras and the Turrubares region of Costa Rica; not surprisingly, the rates were very low in Tierra Blanca. Adoption rates were also low in Yorito, Honduras; there, the studies estimated the conservation measures to be marginally profitable, but the estimates are based on particularly weak data and are fairly sensitive to changes in assumptions. Thus, it may be perfectly rational for farmers not to adopt the proposed conservation measures. In some cases—in Tierra Blanca, for instance—degradation simply is not a significant problem for productivity. In others, the costs of the proposed conservation measures are too high relative to their benefits. The case of Patzité in Guatemala illustrates this best: although degradation is relatively rapid and, if left untreated, will make production uneconomic within a decade, the proposed terraces are very expensive and take much of the land out of cultivation. Again, this is not to say that *all* conservation measures are unprofitable. Visits to Tierra Blanca show, for example, that although farmers have not built diversion ditches without subsidies, they do plant along contours and, on steeper slopes, construct temporary embankments on their fields. (The effects of these measures are implicit in the estimates of degradation and of impact on productivity for the "without conservation" case.)

Obstacles to Adopting Conservation Measures

Profitability of conservation practices is a necessary but not always sufficient condition for their adoption. Factors other than strict cost-benefit considerations also play a role (Van Kooten, Weisensel, and Chinthammit 1990; Murray 1994). Some of these factors are reflected in the cost-benefit analysis to the extent that they affect the prices faced by farmers. The effects of imperfect factor markets, for example, are reflected in higher prices for inputs, which affect the profitability of production activities. Most often, however, institutional issues (such as land tenure and access to credit) and the conservation ethic of farmers must be considered together with the results of the cost-benefit analysis. The analysis carried out for the case studies does not always provide conclusive evidence on these, but it does provide some insights.

It has often been argued that insecure property rights discourage farmers from undertaking long-term investments, such as investments in soil conservation, because they may not themselves be able to reap the benefits (Ervin 1986; Wachter 1992). To make tenure more secure, numerous efforts have been made to provide farmers with legal title to their land. The U.S. Agency for International Development (USAID), for example, has funded titling projects in several countries, including El Salvador and Honduras. But equating land titles with secure tenure and thus with increased investment is too simplistic. Unless numerous improvements are made to the legal system and governmental institutions, most farmers find land titles too costly to obtain or enforce, and unless access to credit is improved for farmers holding titles, the desired effect on investment may not materialize.

Tenure insecurity may not be as significant a factor in adopting conservation measures as is sometimes thought, however. Table 4 shows that in most of the case studies, profitable conservation measures had relatively short payback periods. Where long payback periods were forecast, the measures were either unprofitable or only marginally profitable and were thus unlikely to be adopted even in the absence of tenure problems. Other evidence from the case studies also reinforces this conclusion. About 80 percent of the farmers in the Tatumbla area in Honduras own land by occupation—that is, they do not have any legal titles—yet most have adopted the recommended conservation measures. In the Patzité region in Guatemala, where only 10 percent of farmers have title to their land, erosion is a significant problem, but farmers have been relatively slow to adopt conservation measures. At first sight, this might appear to be evidence for the importance of titling. But, in our view, negative profitability of the recommended conservation measures is more likely to account for low adoption rates than tenure insecurity or lack of land titles.

Another often-cited obstacle to adoption is the lack of capital markets. If credit markets fail, adoption of conservation will be limited by the farmers' ability to finance the required investments (Pender 1992). The research for this project did not bring to light any direct evidence on the functioning of capital markets in the areas studied. The estimated rates of return for investments in conservation measures shown in table 4 give some indication of the maximum rates of interest that could be supported before the investments become unprofitable. Several of the estimated rates of return are encouragingly high.[4]

Conclusions and Policy Implications

Whether conservation measures are profitable for the farmers is an empirical and site-specific issue. Returns to conservation depend on the specific agroecological conditions faced, on the technologies used, and on the prices of inputs used and outputs produced. Hard data on the actual extent of soil degradation and its effects on productivity remain extremely scarce despite several decades of soil conservation efforts (Lal 1988; Walling 1988). More systematic research is needed on soil degradation and its consequences—and there is considerable scope for collaboration on such research, since all countries within Central America include a large number of different agroecological regions, and many agroecological regions are found in more than one country. Regional organizations such as CATIE (Centro Agronómico de Investigación y Enseñanza) have an obvious coordinating role to play. The payoff is likely to be high, because the approach to soil conservation would be more targeted, with efforts concentrated where they are needed most.

The results of the case studies show that conservation is profitable in some instances but not in others. In view of the small number of cases studied and the weak data available, broad lessons must be drawn with care. It does seem safe to say, however, that except when high-value crops are planted on very fragile soils (such as the coco yam in Turrubares), expensive mechanical structures are unlikely to be profitable for the farmers. Conservation measures are particularly likely to be profitable either when they are cheap and simple or when they allow farmers to adopt improved practices.

Generally, the farmers' decision to invest in conservation is based on normal considerations of benefit and cost: they tend to adopt conservation measures when it is in their interest to do so, unless some constraint is present. Cases in which returns to conservation were estimated to be low or negative correlated well with low adoption rates.

A full examination of the role of government policy in conservation requires a broader analysis than that undertaken here; in particular, off-site effects of degradation would have to be explicitly included, and allowance made for distortions in observed price signals resulting from government policies or market failures. Nevertheless, several important points emerge from this analysis.

Subsidies

Advocates of soil conservation often argue that subsidies are indispensable to induce farmers to adopt conservation measures. But such statements often assume that conservation is inherently desirable whether or not there is concrete evidence that the benefits outweigh the costs. The results presented here show that this may be far from the case; frequently, the benefits of specific conservation techniques (such as mechanical structures) do not justify their costs. Unless there are important off-farm effects or the price signals received by farmers are significantly distorted, subsidies to induce adoption would therefore not increase economic efficiency.

When off-farm effects are present, the rationale for intervention is potent, because the farmers' estimation of returns to conservation will pay inadequate attention to its social benefits. In the Santa Lucía Milpas Altas watershed in Guatemala, for example, a USAID project uses subsidies (so-called *pago social*) to induce farmers to build terraces and thus reduce flooding in the historic town of Antigua. In the same watershed, farmers who do not receive subsidies generally use less costly conservation methods such as vegetative barriers and live fences. Although these measures are profitable to the farmers, they may not be enough to control floods.

The effect of price distortions is more difficult to establish; the many factors that affect the profitability of a given conservation measure and their complicated interactions make it hard to predict whether a distortion encourages or discourages conservation. It has sometimes been suggested that typical policy distortions in developing countries tend to encourage degradation (Panayotou 1993), but the empirical basis to substantiate this point is weak. The best way to deal with policy distortions or market failures is to attempt to eradicate the distortions themselves; subsidies should be used only in the rare instances when such direct action is virtually impossible.

Whatever the justification, the use of subsidies encounters several difficulties. First, the divergence between social and private returns to conservation must be established, so that intervention can be directed where it will be most effective. Subsidies are often used where no off-farm effects are present—wasting scarce budgetary resources in areas where they are not justified by any social benefits. In Costa Rica, for example, the soil conservation service (SENACSA) subsidizes half the cost of establishing conservation measures on the fields of small farmers, irrespective of location. Subsidies are also provided in areas such as Turrubares, where individual farmers already have sufficient incentive to conserve purely on productivity grounds. Conversely, subsidies are not always provided when off-farm effects are present. More commonly, subsidies are provided to construct, but not maintain, the conservation measures, so farmers sometimes allow them to decay. In Nicaragua, for example, terraces were built on fields in the Lake Xolotlán watershed above Managua in an effort to reduce flooding in the city and sedimentation in its reservoirs. These terraces were built at no cost to farmers, but because they interfered with cultivation practices and resulted in no net benefits to the farmers, most were soon destroyed. Similar experiences have occurred in the Tierra Blanca area of Costa Rica.

The second problem in using subsidies, then, is the difficulty of designing appropriate incentive structures for the farmers so that social objectives are met. The case of the Lake Xolotlán watershed illustrates a situation in which subsidies are insufficient to overcome the divergence between private and social returns to conservation. The El Naranjal watershed in the Dominican Republic provides another example. There, the USAID-funded Management of Natural Resources Project (MARENA) provided subsidized credit to participating farmers. Consequently, adoption rates were initially very high, even though the evidence suggests that the measures were unprofitable from the farmers' perspective. In 1985 more than 90 percent of the area's farms practiced soil conservation. Five years later only half of these farms continued to do so. Subsidies can persuade farmers to modify their behavior only as long as they continue to be paid. In contrast, MARENA's successor, which tied conservation to access to irrigation, seems to have stimulated considerable use of conservation techniques even though no subsidies were offered—in fact, the cost of participation was quite high. Although sufficient data were not available to analyze the new practices fully, they appear to be highly profitable.

Another risk in designing subsidization schemes is that of creating perverse incentives for farmers. In Costa Rica, for example, a reforestation credit system unintentionally encouraged farmers to deforest their land so that they might qualify for the credit. The expectation that subsidies will be forthcoming to fund conservation efforts may also encourage farmers to delay conservation, even when such measures are privately profitable, in the hope that the government will bear part of their cost. Even when subsidies are justified, then, they must be designed with great care.

Land Tenure, Research, and Extension

Governments should also ensure that constraints such as insecure tenure do not prevent farmers from adopting conservation measures. But such efforts also require substantiating research if they are to be effective. Too often the existence of tenure problems and the effectiveness of titling as a solution are simply taken as given.

Governments already do some research on soil conservation and provide, through extension services, some assistance to farmers who undertake conservation work. However, research in experiment stations has tended to favor technical efficiency (including structural measures such as terraces) over profitability for farmers. Further, government extension work is often ineffective. In many cases, nongovernmental organizations, such as Vecinos Mundiales in Central America (Lopez and Pío Camey 1994) have proved to be more effective than extension services at presenting a range of conservation options to farmers and delivering related technical assistance. Because of the wide variety of conditions that farmers face, government extension services should also provide, explain, and demonstrate to farmers the corresponding variety of options available rather than, as has often happened in the past, pushing broadly for adoption of specific techniques. And governments may find it both innovative and effective to decentralize decisionmaking and channel budgetary resources for soil conservation to the local level to allow communities to participate in the decisionmaking and to contract assistance from those from whom the greatest contributions can be expected.

Research is not likely to produce a "breakthrough technology" that will solve all conservation problems. Improvements are likely to be more marginal. But, alone or in combination with others, improved techniques can significantly affect productivity. Modifications in the *ramp pay* technique used in Haiti are an example. Here, the traditional practice of gathering crop stubble along the contour was improved by more exact placement and by covering the structure with upslope soil, thus discouraging rat infestations and encouraging infiltration of the surface flow. These changes made the practice much more effective in halting degradation and more acceptable to farmers. Similar improvements in techniques arising from research have been successful in West Africa (Reij 1992).

The conflict between conservation and production noted in many of the case studies often affects the returns to conservation very significantly. Attempts to develop practices that reduce or eliminate this conflict—"overlap technologies," in the terminology of Reardon and Vosti (1992)—should be especially encouraged. And to make the research truly useful, it should be carried out primarily on the farm and in close consultation with farmers.

Notes

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1. Off-farm effects and another important land degradation problem—the inappropriate use of common-property lands—are outside the scope of this research. (Off-farm effects were discussed by Magrath and Arens 1989; for common-property issues, see Bromley 1992.)

2. Combined investments from households in a village or watershed area are sometimes required to manage land degradation problems effectively. For an analysis of such problems in the same area as the Haiti case study, see White and Runge (1992).

3. In addition to the sites listed in table 2, research was carried out at other sites in several of the countries listed and at several sites in El Salvador. Data on these sites—in particular, on the effects of degradation on yields—were insufficient to allow a full analysis of the returns to conservation measures.

4. Even when rates of return to investment in conservation are high, conservation might not be undertaken if even higher rates of return can be obtained from off-farm opportunities. Southgate (1992), for example, argues that high returns to urban employment in Ecuador encourage farmers to depreciate their land assets and then move to urban areas. Similarly, Schneider and others (1993) argue that perceptions of limitless land resources in the Amazon prompt farmers to "mine" their soils and then move on.

References

The word "processed" describes informally reproduced works that may not be commonly available through library systems.

Altieri, M. 1990. "Stabilizing Hillside Farming Systems in the Sierra of the Dominican Republic." In *Research Needs and Applications to Reduce Erosion and Sedimentation in Tropical Steep Lands*. Proceedings of the Fiji Symposium. IAHS-AISH Publications 192. June.

Biot, Yvan, Robert Lambert, and Scott Perkin. 1992. "What's the Problem? An Essay on Land Degradation, Science and Development in Sub-Saharan Africa." Discussion Paper 222. School of Development Studies, University of East Anglia, Norwich. Processed.

Blaikie, Piers, and Harold Brookfield. 1987. "Defining and Debating the Problem." In Piers Blaikie and Harold Brookfield, eds., *Land Degradation and Society*. London: Methuen & Co.

Bromley, Daniel W., ed. 1992. *Making the Commons Work: Theory, Practice, and Policy*. San Francisco: ICS Press.

Capalbo, John M., and Susan M. Antle. 1988. *Agricultural Productivity: Measurement and Explanation*. Washington: Resources for the Future.

CTA (Centro de Tecnología Agrícola). 1956. Informe Interno. San Salvador, El Salvador.

CUNARD. 1991. "Soil Erosion Estimation From the Cropping Systems Trial at the Brutus Site, 1990." Associates in Rural Development/Project Sove Te, Burlington, Vermont. Processed.

De Janvry, Alain, Marcel Fafchamps, and Elisabeth Sadoulet. 1990. "Peasant Household Behavior with Missing Markets: Some Paradoxes Explained." University of California, Department of Agricultural and Resource Economics, Berkeley. Processed.

English, John, Mary Tiffen, and Michael Mortimore. 1994. *Land Resource Management in the Machakos District, Kenya 1930–1990*. World Bank Environment Paper 5. Washington, D.C.

Ervin, David E. 1986. "Constraints to Practicing Soil Conservation: Land Tenure Relationships." In Stephen B. Lovejoy and Ted L. Napier, eds., *Conserving Soil: Insights from Socioeconomic Research*. Ankeny, Iowa: Soil Conservation Society of America.

Flores Zelaya, O. 1976–81. "Informes anuales de parcelas para investigación del control de la erosión y escorrentía superficial en el Distrito Forestal de Metapán (seis informes)." Servicio de Ordenación de Cuencas Hidrográficas y Conservación de Suelos, San Salvador, El Salvador. Processed.

Grosjean, M. 1987. "Rapport d'Ouverture: La Recherche de Conservation de Sol à Papaye. Hinche/Plateau Central. Project Agrosilvicol." Port-au-Prince, Haiti: Helvetas. Processed.

Harsthorn, G., G. Antonini, R. Dubois, D. Harcharik, S. Heckadon, H. Newton, C. Quezada, J. Shores, and G. Staples. 1981. "Perfil ambiental de la República Dominicana: Un estudio de campo." USAID Contract AID/SOD/PDC-C-0247. JRB Associates, Va.

Lal, Rattan C. 1988. "Preface." In Rattan C. Lal, ed., *Soil Erosion Research Methods*. Ankeny, Iowa: Soil and Water Conservation Society.

Leonard, H. Jeffrey. 1987. *Natural Resources and Development in Central America: A Regional Environmental Profile*. International Institute for Environment and Development. New Brunswick, N.J.: Transaction Books.

López, Vargas Gabino, and Augustin Pío Camey. 1994. "Practical Experiences and Lessons Learned by Vecinos Mundiales from Soil Conservation Work in Rural Communities of Honduras." In Ernst Lutz, Stefano Pagiola, and Carlos Reiche, eds., *Economic and Institutional Analyses of Soil Conservation Projects in Central America and the Caribbean*. World Bank Environment Paper 8. Washington, D.C.

Lutz, Ernst, Stefano Pagiola, and Carlos Reiche, eds. 1994. *Economic and Institutional Analyses of Soil Conservation Projects in Central America and the Caribbean*. World Bank Environment Paper 8. Washington, D.C.

Magrath, William B., 1989. "Economic Analysis of Soil Conservation Technologies." Environment Department Divisional Working Paper 1989–4. World Bank, Policy Research Division, Washington, D.C. Processed

Magrath, William B., and Peter Arens. 1989. "The Costs of Soil Erosion on Java: A Natural Resource Accounting Approach." Environment Department Working Paper 18. World Bank, Washington, D.C. Processed.

McIntire, John. 1994. "A Review of the Soil Conservation Sector in Mexico." In Ernst Lutz, Stefano Pagiola, and Carlos Reiche, eds., *Economic and Institutional Analyses of Soil Conservation Projects in Central America and the Caribbean*. World Bank Environment Paper 8. Washington, D.C.

Murray, Gerald. 1994. "Technoeconomic, Organizational, and Ideational Factors as Determinants of Soil Conservation in the Dominican Republic." In Ernst Lutz, Stefano Pagiola, and Carlos Reiche, eds., *Economic and Institutional Analyses of Soil Conservation Projects in Central America and the Caribbean.* World Bank Environment Paper 8. Washington, D.C.

Oldeman, L. R., R. T. A. Hakkeling, and W. G. Sombroek. 1990. *World Map of the Status of Human-Induced Soil Degradation: An Explanatory Note.* 2d ed. rev. Wageningen: International Soil Reference and Information Centre.

Oster, R. 1981. "Conservación de suelos en tierras altas de Chiriquí." Informe Técnico, David, Panama. Processed.

Pagiola, Stefano. 1992. "Quantifying the Returns to Soil Conservation in Kenya." Paper presented at the Annual Meetings of the Soil and Water Conservation Society, Baltimore, Maryland, August 10–12, 1992. Processed.

———. 1993. "Soil Conservation and the Sustainability of Agricultural Production." Ph.D. Diss., Food Research Institute, Stanford University. Processed.

Panayotou, Theodore. 1993. *Green Markets: The Economics of Sustainable Development.* ICEG Sector Studies 7. San Francisco: ICS Press.

PCEO. ("Proyecto de Control de erosión de Occidente.") 1981. Internal report. Irena, León, Nicaragua. Processed.

Pender, John L. 1992. "Credit Rationing and Farmers' Irrigation Investments in Rural South India: Theory and Evidence." Ph.D. Diss., Food Research Institute, Stanford University. Processed.

Reardon, Thomas, and Stephen A. Vosti. 1992. "Issues in the Analysis of the Effects of Policy on Conservation and Productivity at the Household Level in Developing Countries." *Quarterly Journal of International Agriculture* 31(4, October-December):380–96.

Reij, Chris. 1992. "Building on Traditions: The Improvement of Indigenous SWC Techniques in the West African Sahel." Paper presented at the International Symposium on Soil and Water Conservation, Soil and Water Conservation Society, Honolulu, Hawaii. Processed.

Repetto, Robert, and Wilfrido Cruz. 1991. *Accounts Overdue: Natural Resource Depreciation in Costa Rica.* Washington, D.C.: World Resources Institute.

Sánchez, Héctor. 1991. Personal communication from Héctor Sánchez, DIMA-SPS. Tegucigalpa, Honduras.

Schneider, Robert, Gunars Platais, David Rosenblatt, and Maryla Webb. 1993. "Sustainability, Yield Loss and *Imediatismo*: Choice of Technique at the Frontier." LATEN Dissemination Note 1. World Bank, Latin America Technical Department. Washington, D.C. Processed.

Shaxson, T. F., N. W. Hudson, D. W. Sanders, E. Roose, and W. C. Moldenhauer. 1989. "Land Husbandry: A Framework for Soil and Water Conservation." Soil and Water Conservation Society, Ankeny, Iowa. Processed.

Singh, Inderjit, Lyn Squire, and John A. Strauss, eds. 1986. *Agricultural Household Models: Extensions, Applications, and Policy.* Baltimore: Johns Hopkins University Press.

Soto, J. G. 1981. "Evaluación experimental de la erosión hídrica en el suelo de la subcuenca de Río Indio, bajo el sistema tradicional de manejo." Thesis, Facultad de Agronomía, Universidad de Panamá.

Southgate, Douglas. 1992. "The Rationality of Land Degradation in Latin America: Some Lessons from the Ecuadorian Andes." Paper presented at the International Symposium on Soil and Water Conservation, Soil and Water Conservation Society, Honolulu, Hawaii.

Taylor, Daniel B., Douglas L. Young, David J. Walker, and Edgar L. Michalson. 1986. "Farm Level Economics of Soil Conservation in the Palouse Area of the Northwest: Comment." *American Journal of Agricultural Economics* 68(2, May):364–65.

Van Kooten, G. C., Ward P. Weisensel, and Duangdao Chinthammit. 1990. "Valuing Trade-Offs between Net Returns and Stewardship Practices: The Case of Soil Conservation in Saskatchewan." *American Journal of Agricultural Economics* 72(1, February):104–13.

Vásquez, Tomás, and Julio Santamaría. 1994. "Economic and Institutional Analysis of Soil Conservation at the Farm Level in Coclé, Panama" in Ernst Lutz, Stefano Pagiola, and Carlos Reiche, eds., *Economic and Institutional Analyses of Soil Conservation Projects in Central America and the Caribbean.* World Bank Environment Paper 8, Washington, D.C.

Veloz, Alberto, Douglas Southgate, Fred Hitzhusen, and Robert Macgregor. 1985. "The Economics of Erosion Control in a Subtropical Watershed: A Dominican Case." *Land Economics* 61(1, May):145–55.

Wachter, Daniel. 1992. "Land Titling for Land Conservation in Developing Countries." Environment Department Divisional Working Paper No. 1992–28. World Bank, Washington, D.C. Processed.

Walker, David J. 1982. "A Damage Function to Evaluate Erosion Control Economics." *American Journal of Agricultural Economics* 64(4, November):145–55.

Walling, D. E. 1988. "Measuring Sediment Yield from River Basins." In Rattan C. Lal, ed., *Soil Erosion Methods.* Ankeny, Iowa: Soil and Water Conservation Society.

Welchez, L. 1991. Personal communication from Welchez of LUPE/SRN project, Francisco Morazán, Honduras.

White, Thomas A., and C. Ford Runge. 1992. "Common Property and Collective Action: Cooperative Watershed Management in Haiti." Working Paper P92–3. Center for International Food and Agricultural Policy, University of Minnesota, St. Paul. Processed.