5. Farmer Responses to Land Degradation

Our analysis of erosion-induced crop yield losses in the absence of farmer response provided an example of the underlying biophysical relationship between levels of (or changes in) productivity and levels of (or changes in) land quality, given a particular practice and fixed input levels. Such analyses help determine the potential impact of differences or changes in land quality if production practices and input levels remain fixed. But practices and input levels are not, in general, fixed across producers or over time. Actual interactions between land quality and productivity are shaped by technical, physical, and biological processes, many of which are complex, highly interdependent, and dynamic. Impacts of land degradation also depend critically on farmers' choices, which change over time in response to (and in anticipation of) changing economic and environmental conditions.

Farmers' incentives and choices

A variety of activities may be considered conservation practices because they maintain or improve soil fertility or reduce soil erosion and runoff of nutrients and pesticides. These activities include residue management practices (e.g., conservation tillage), soil-conserving crop rotations, nutrient and pest management practices, and land improvements (e.g., installation of grassed waterways). These practices differ from one another and from conventional management practices in the expected magnitude and timing of their costs and returns to the farmer. Some practices, such as conservation tillage, may be profitable in the short term due to reduced labor and machinery costs (Rahm and Huffman, 1984). Others may become profitable only over the medium term (e.g., contour farming, stripcropping, and grassed waterways) or the long term (e.g., terracing) as they control erosion and maintain or enhance soil fertility and thus improve productivity and land values.[6] Because of the relative availability and quality of appropriate data, the United States offers a useful case in which to examine farmers' choices regarding conservation practices.

[6]Some practices, such as grassed waterways, may not directly prevent erosion from occurring on the cultivated portion of a field, but by slowing runoff and preventing the formation of gullies near waterways, they still help sustain productivity onsite.

Soil fertility management and erosion control in a dynamic context

To understand farmers' decisions about practices that affect land quality and productivity, it is necessary to take a longrun perspective. One such approach is to examine farmers' choices using a dynamic economic analysis. For simplicity, some previous simulation studies of degradation and productivity assumed that current practices continued into the future and generated a range of estimated erosion-induced productivity losses. Pierce et al. (1984) estimated productivity losses of 1.8-7.8 percent over 100 years, while Alt et al. (1989) estimated losses of 3.5 percent over 100 years. Improved models (e.g., Burt, 1981 and Van Kooten et al., 1990) allow for both farmer response to resource conditions and resource-quality change in response to management practices in a single-dimension (topsoil depth) framework.

Hopkins et al. (2001) extend Burt and Van Kooten et al. in several ways. First, they allow farmers to consider economic incentives under all resource states, rather than just the steady state. They also analyze a two-dimensional definition of soil degradation rather than just a single dimension—thereby incorporating both irreversible soil erosion and reversible nutrient depletion. Finally, they determine how optimal levels of two practices—fertilizer application and residue management—vary with the two dimensions of soil degradation.

The Hopkins et al. model chooses levels of fertilizer application (F) and residue management (R) to maximize the expected present value of net returns over time from corn production, recognizing that yields (Y), soil nutrient condition (N), and topsoil depth (D) are determined jointly. Yields are determined jointly in any period by the interaction of fertilizer, soil nutrient condition, and topsoil depth, based on specifications derived from earlier research (Johnson and Shepherd 1978; Schumacher et al., 1994). Soil nutrient stocks may be built up or drawn down relative to initial levels (at least for potassium and phosphorus), depending on removal in harvested crops, fertilizer application, and changes in topsoil depth. Topsoil depth in any given period depends on soil depth in the previous period and on the level of residue management (in conjunction with the inherent erosion potential of the soil based on physical soil properties, landscape position, and climate condition). Costs of residue management are assumed to increase exponentially in residue levels, to represent the additional complexity of management required, based on data from Rausch and Sohngen (1997). The farmer's problem is thus to plan the optimal path of fertilizer application levels and residue management levels (for each period t, present and future) given that

$$Y_t = f(F_t, N_t, D_t)$$
$$N_t+1 = g(N_t, F_t, Y_t, D_{t+1}, D_t)$$
$$D_t+1 = h(D_t, R_{t+1})$$

By planning an optimal management path, the farmer is, in effect, choosing the optimal path of soil degradation over time. Optimal choices of fertilizers and residue management vary with initial levels of soil depth and soil nutrients and change at different rates with changes in these variables. These optimal choices vary with soil depth and nutrients, depending on soil type and other characteristics. For some soils and soil properties, for example, yields will decline at an accelerating rate with reductions in topsoil depth. On other soils, yields will change at a constant or decelerating rate. (Alternatively, as depicted in figure 1.4, each of these three patterns may be exhibited at different levels of erosion on a single soil type.) These differences in soil quality imply differences in optimal choices.

Hopkins et al. apply this method to data on nine soils from the north-central United States, drawn from Schumacher et al. (1994). Some of the nine soils exhibit yield losses that accelerate as soil erodes (characteristic of the upper part of the production function in figure 1.4). Other soils exhibit constant yield losses as soil erodes. A final group of soils exhibit yield responses that decelerate with erosion (characteristic of the lower part of the production function in figure 1.4).

Characteristics of the nine soils are presented in table 5.1, along with the optimal residue management levels and annual costs of soil degradation estimated for each soil. In general, differences in optimal management across soils exceed differences in optimal management over time. Optimal levels of residue management vary by only a few percentage points across soil depth within any one soil, for example, but vary by a factor of two or more across soils. A similar pattern is associated with optimal soil nutrient levels. It is also the case that decisions regarding optimal fertilizer application and residue management are more sensitive to soil nutrient levels than to topsoil depth.

Table 5.1 also shows the annual loss in the asset value of the soil by farmers who make optimal choices about management practices. An incremental inch of topsoil loss can be costly, particularly for the last inch of topsoil lost within the profile. (Note that this does not represent the last inch of topsoil on the field but rather the last inch lost in the experiments conducted by Schumacher et al. (1994).) Because these soils typically erode at rates well below an inch per year (even under minimal residue conditions), however, annual losses are less than a dollar per acre per year for most soils. Relative to cropland values,

Table 5.1—Benchmark soils in the north-central United States

				Optimal residue management			Annual cost of soil degradation			
Soil	State	Soil loss	Yield loss	First inch	Middle inch	Last inch	First inch	Middle inch	Last inch	Last inch
		Inch/year	*Percent*	*Percent*			*$/acre*			*Percent*
Accelerating yield losses:										
Beadle	SD	0.09	11	18	19	21	0.12	0.27	0.49	0.10
Grantsburg	IL	0.12	16	20	22	25	0.12	0.36	0.78	0.03
Marlette	MI	0.05	25	17	17	19	0.22	0.75	2.34	0.14
Rozetta	IL	0.35	6	31	33	35	0.68	1.27	2.15	0.09
Constant yield losses:										
Clarence	IL	0.30	32	38	38	38	3.88	3.87	3.85	0.16
Ves	MN	0.12	11	19	19	19	0.10	0.10	0.10	0.01
Decelerating yield losses:										
Dubuque	WI	0.46	7	31	31	29	0.48	0.50	0.10	0.01
Egan	SD	0.12	5	19	24	20	0.11	0.79	0.13	0.03
Sharpsburg	NE	0.01	4	27	27	27	0.01	0.01	0.01	0.00

Notes: Soil loss was estimated by Schumacher et al. (1994) using an EPIC simulation under zero residue. Yield loss is the cumulative loss associated with a change to a severely eroded condition (more than 75 percent loss of the "A" soil horizon) from a slightly eroded (less than 25 percent) or moderately eroded (25-75 percent) condition. Cropland values in 1999 were $491 per acre in South Dakota, $2,370 in Illinois, $1,300 in Wisconsin, $1,670 in Michigan, $1,080 in Nebraska, and $1,280 in Minnesota.
Sources: Schumacher et al. (1994), Hopkins et al. (2001), NASS (2001).

these dollar losses correspond to percentage losses ranging from 0.00 percent per year (for the Sharpsburg soil in Nebraska) to 0.16 percent per year (for the Clarence soil in Illinois) for the last inch of soil eroded (final column). Percentage losses for first and middle inches of soil would be correspondingly lower for the soils characterized by accelerating yield losses and higher for some of the soils characterized by decelerating yield losses. In terms of figure 1.5, these losses correspond to the difference between case (a) and the optimal level of degradation chosen by farmers.

For comparison, figures 5.1, 5.2, and 5.3 depict optimal residue management, fertilizer application, and land values for stylized examples that exhibit each of the three basic yield regimes considered (that exhibit accelerating, constant, and decelerating erosion-induced yield losses, respectively), assuming a hypothetical 20-percent yield loss associated with a change from a slightly or moderately eroded condition to a severely eroded one. The three stylized cases help depict how optimal practices and outcomes vary with soil type (and thus yield regime) and soil condition (i.e., soil depth and soil nutrient status).

Figure 5.1 depicts optimal levels of residue management as they vary with soil depth and soil nutrients for the three stylized soil types. In each case, optimal residue levels increase (at a decreasing rate) with soil nutrient levels but vary only slightly with soil depth, indicating that the benefits of residue management derive primarily from protecting soil nutrient stocks rather than slowing the rate of soil loss.

Optimal fertilizer application levels for the three cases are depicted in figure 5.2. In each case, it is optimal to apply fertilizer at relatively high rates to build up nutrient stocks when they are low and to apply no fertilizer and draw nutrient levels down when they are high. The optimal fertilizer surfaces are linear in the soil nutrient dimension because fertilizer is freely substitutable for soil nutrients.

Under optimal management practices, the three cases generate land values that vary with initial soil properties as depicted in figure 5.3. (The surfaces represent returns less the cost of practices that vary with soil depth and nutrient status, rather than land values per se.) The shapes of the surfaces reflect the shape of the underlying relationships between yields and soil properties. In each case, optimal values rise at a constant rate with respect to soil nutrient levels. By contrast, as soil depth falls, optimal values fall at increasing, constant, or decreasing rates, depending on the soil type.

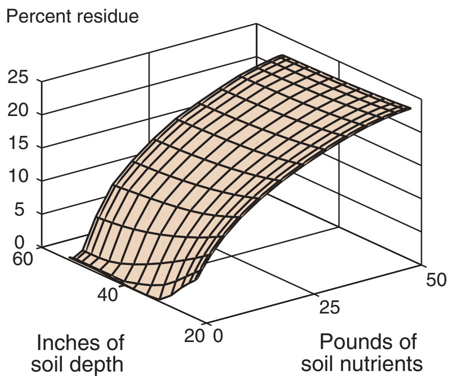
Figure 1.6 showed hypothetical net returns to alternative practices. The farmer's choice of optimal practice or the optimal level of multiple practices, such as fertilizer application and residue management, depends on the farmer's time horizon. Suboptimal choices will reduce net returns to the farmer. Using the dynamic model in this section, it is possible to estimate the gains from optimal behavior (i.e., the magnitude of optimal productivity losses relative to those estimated with suboptimal/shortsighted response, or with no response to changing resource conditions over time). Figure 5.4 depicts streams of returns (net of the costs of fertilizer and residue management) to three alternative strategies for corn production on the Rozetta soil in Illinois over 50 years.

The first strategy simply applies fertilizer to maximize current-year returns but does not update these practices over time in response to changing conditions; returns (net of fertilizer and residue management costs) start at about $340 per acre, fall sharply to about $260 per acre as soil nutrients are depleted, and then decline more gradually after a new soil-nutrient steady state is reached with returns about 30 percent below initial levels. The second strategy does update fertilizer applications so as to optimize soil nutrients over time; initial returns are slightly lower than in the first strategy, reflecting higher fertilizer application, but decline only gradually to about $280 per acre (8 percent below initial levels) after 50 years. The third strategy manages both soil nutrients and soil depth optimally; returns decline by 5 percent to $300 per acre after 50 years.

These strategies provide an empirical example of the choices described with reference to land tenure and the length of planning horizons in figure 1.6. For a farmer with a planning horizon of only a few years, it would clearly be optimal to deplete soil nutrient levels and disregard residue management, as in the first strategy. Over a longer planning horizon, on the other hand, the ranking of the first and third strategies is reversed. Over the 50-year period, the discounted present value of net returns increases by about 15 percent as a result of switching from myopic practices to those that are optimal over the long term, most of which is accounted for by soil nutrient management.[7]

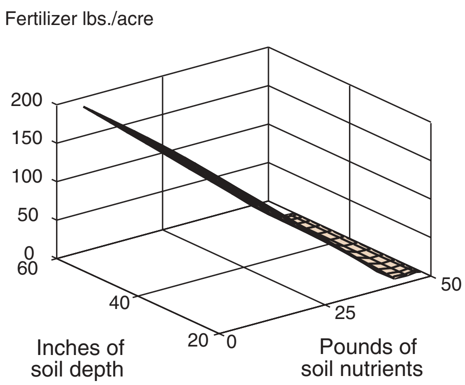
[7]Simulations over time periods exceeding a single generation are typically motivated by assumptions that farmers care about the welfare of their heirs, or that farmers care about land values over a shorter period of time but that those land values reflect the present discounted value of net returns farther into the future.

Figure 5.1—Optimal residue management levels



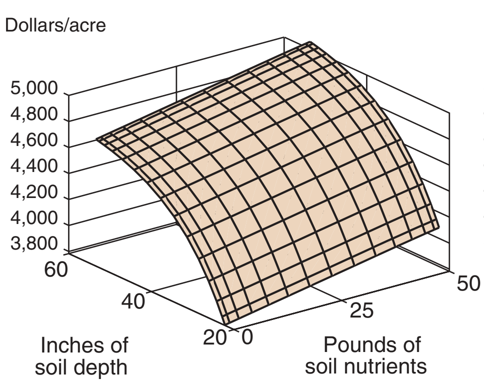
Source: Hopkins et al. (2001).

Figure 5.2—Optimal fertilizer application levels



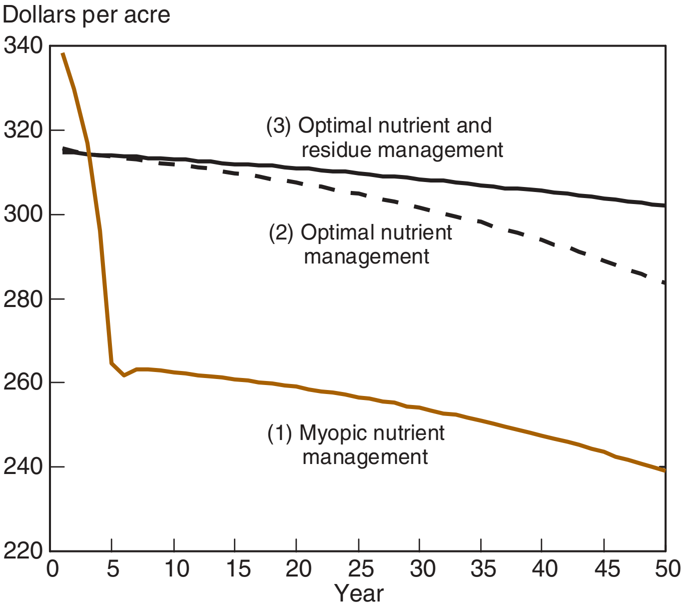
Source: Hopkins et al. (2001).

Figure 5.3—Relative land values under optimal management



Source: Hopkins et al. (2001).

Figure 5.4—Returns to alternative strategies



Source: ERS analysis.

Given the importance of long-term considerations in making management decisions in the present, it is critical to incorporate such considerations in understanding the conservation choices actually made by farmers. It is reasonable to expect that such considerations might manifest themselves in different decisions made by farm operators with different time horizons (e.g., farmers who operate land under differing forms of tenure).

Land tenure and the adoption of conservation practices in the United States

Conventional wisdom has long held that owners of a resource will take better care of that resource than users without a long-term interest in the resource. Economists have formalized this hypothesis in models in which a decisionmaker with a short time horizon was shown to have less incentive to invest in practices that provide benefits over the long term.

Previous research on this question has provided inconclusive or contradictory results, however, because it has not adequately addressed two important dimensions of the relationship between tenure and conservation. First, tenure's impact may depend on the timing and magnitude of the costs and returns generated by the conservation practice under study. For example, conservation tillage may increase short-term profits due to cost savings (e.g., on labor and fuel), but it may take several years to generate positive net returns to "medium-term practices," such as contour farming, stripcropping, or grassed waterways. Tenure's role in adoption is likely to vary with these differences.

Second, different lease arrangements may also influence renters' conservation decisions. For example, share-renters may have an additional incentive, relative to cash-renters, to adopt conservation practices that increase use of inputs for which they bear only a share of the cost. Furthermore, landlords tend to participate more actively in the management of farms rented under share leases (Rogers, 1991). This arrangement could induce share-renters to behave more like owner-operators than cash-renters. Failure to consider such distinctions would obscure tenure's true effect on the adoption of conservation practices.

Recent research by Soule et al. (2000) and Soule and Tegene (forthcoming) explores these two dimensions both conceptually and empirically, using data on corn and soybean production from USDA's Agricultural Resource Management Survey (ARMS). ARMS data provide a valuable opportunity (with farm, land, farmer, and practice data in a single large sample) to conduct an econometric analysis of tenure and other factors affecting the adoption of conservation practices.

Soule et al. begin with a model in which farmers choose a production practice to maximize the present value of current net returns plus terminal land value (at the end of the first period), where terminal land value is itself a function of expected future net returns. Different production/conservation practices, such as conventional tillage versus conservation tillage, generate different streams of costs and returns over time. Farmers who own their land are confident of realizing future returns to investments in conservation today (either through higher yields in future periods or through higher asset value if they sell their land). Renters are less likely to realize future benefits unless they operate the land under a long-term lease.

To capture this difference in expectations, Soule et al. weight terminal land value by a tenure-security parameter γ, which takes on the value 1 for owner-operators and

Table 5.2—Distinguishing tenure classes

Tenure class	Renter's output share (α)	Renter's input share (β)	Tenure security (γ)
Owner-operator	1	1	1
Cash-renter	1	1	<1
Share-renter	<1	<1	<1

Source: Soule et al. (2000).

less than 1 for renters. Soule et al. further distinguish renters according to the terms of their lease (i.e., whether they pay a cash rent and keep the entire crop or share the crop, and possibly input costs as well, in lieu of a rental payment). To capture this distinction, output is weighted by a share parameter α while inputs are weighted by a share parameter β (both of which are less than 1 for share-renters, and equal to 1 otherwise) (table 5.2).

The farmer's problem is thus to choose production practices that maximize present and future net returns as expressed by

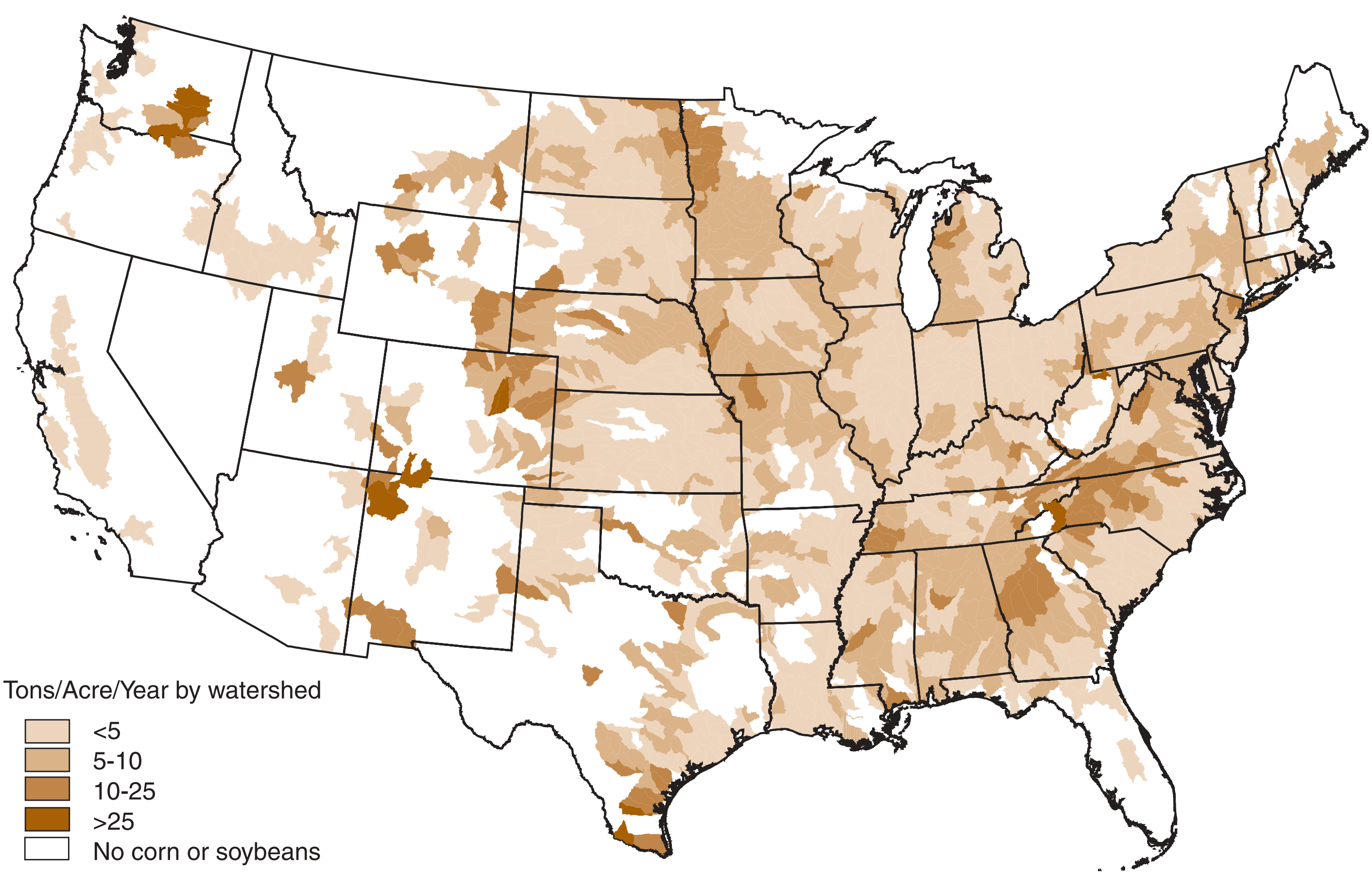
$$(\alpha \times \text{output value}) - (\beta \times \text{input costs}) + (\gamma \times \text{terminal land value})$$

If a practice, such as conservation tillage, reduces labor and/or fuel costs sufficiently to be profitable in the short run (as well as in the long run), little difference in incentive to adopt would be expected between owner-operators and renters. Within the category of renters, however, share-renters may find it especially profitable if the practice saves on inputs (such as labor and fuel) that are commonly supplied by share-renters (for whom $\beta < 1$).

Renters may have less incentive to adopt a practice such as contour farming or terracing, however, if it requires upfront costs that are not recovered until some time in the future because the value of the renter's objective function would be reduced by the parameter γ. In the case of share-renters, this reduced incentive might be offset by the increased participation of landowners in share-rented farm operations.

Data used to test these hypotheses were obtained primarily from ARMS, with information on 941 U.S. corn producers in 1996 and 1,417 U.S. soybean producers in 1997 (fig. 5.5). Variables included farm characteristics (e.g., farm size, field tenure, erodibility, location, climate, urban proximity, and program participation), farmer characteristics (e.g., age and education), and choice of practices (e.g., conservation tillage, contour farming, and grassed waterways).

Figure 5.5—Erosion on U.S. cropland in corn and soybeans



Source: ERS, based on data from the 1997 National Resources Inventory.

Table 5.3—Probability of adopting a conservation practice, relative to owner-operators

Tenure class	Conservation tillage		Medium-term practices	
	Corn	Soybeans	Corn	Soybeans
All renters	same	same	less likely	same
Cash-renters	less likely	same	less likely	same
Share-renters	same	less likely	less likely	same

Source: Soule et al. (2000); Soule and Tegene (forthcoming).

These data were analyzed econometrically to examine the effects of tenure on decisions by corn and soybean producers to adopt conservation tillage and "medium-term practices" (namely, contour farming, strip cropping, or grassed waterways) that offer benefits only in the future. (Data limitations prevented analysis of longer-term practices, including investment in conservation structures, such as terraces.)

Results indicate that land tenure is an important factor in farmers' decisions to adopt conservation practices, in ways that may not be revealed in conventional analyses (table 5.3). Specifically, conventional models that do not distinguish between types of renters fail to recognize the different incentives faced by cash-renters and share-renters (at least in corn production). Among corn producers, cash-renters are less likely than owner-operators to use conservation tillage, although share-renters behave much like owner-operators in adopting conservation tillage. Both share-renters and cash-renters are less likely than owner-operators to adopt at least one of the medium-term practices. Among soybean producers, the results do not follow the prediction so closely, but cash- and share-renters do seem to have different incentives for adopting conservation tillage, if not the medium-term practices.

Among other factors that help explain adoption of conservation practices, only designation of highly erodible land is consistently significant across crops and practices. This finding may reflect a combination of factors, namely, that such land is identified as needing conservation measures more urgently and that conservation measures on such land are a requirement if farmers wish to receive certain government program payments. Larger farms were significantly more likely to adopt conservation tillage (on both crops) but not medium-term practices. Younger farmers were significantly more likely to adopt both types of conservation practices in corn production but not in soybean production.

Econometric analysis shows that tenure is an important factor in the adoption of some conservation practices—at least those for which benefits to the farmer outweigh costs only over the longer term—underscoring the importance of a long-term perspective in assessing likely paths of farmer response to realized or anticipated changes in land quality. Given the extent of leasing in the United States (40 percent of all farmland, and 50 percent in the Corn Belt), and the fact that a majority of landlords are neither engaged in nor retired from farming (suggesting that most are not actively involved in farm decisionmaking), it is important to keep tenure in mind when considering policies to encourage adoption of conservation practices. Gaps in the analysis also reinforce the need for better data on tenure (e.g., lease conditions and duration) to improve our understanding of farmers' choices, especially regarding investment in long-term conservation practices (such as terracing).

Adoption of conservation practices in other countries

The foregoing analysis focused on conservation choices in a setting in which property rights are well defined, incomes are relatively high and secure, markets for commodities and inputs (including credit) function well, and information on alternative management practices and their economic and environmental consequences is relatively widely available.

By contrast, less-developed countries are generally characterized by property rights that are less well-defined (at least in formal terms), incomes that are lower and more variable, imperfect markets, and incomplete information on alternative management practices. These factors can shorten time horizons, raise discount rates, and otherwise limit investment in practices to reduce or reverse land degradation. Shiferaw and Holden (1999) argue that such factors drive low levels of conservation-related activities—and subsequent dismantling of poorly conceived conservation structures built under food-for-work programs—in Ethiopia's highlands.

Some observers (e.g., Pagiola) note, however, that informal property rights may well offer considerable tenure security in some cases, and that poverty could conceivably increase a household's incentive to conserve its land over the long term—particularly if that is its only productive asset apart from its labor power. Building on previous research on soil conservation in Kenya (Tiffen et al., 1994), Pagiola (1996) found that terraces were widespread in Machakos District even in the absence of public incentives or extension efforts. Site-specific land characteristics are critical—adoption of terraces was found to be profitable only on slopes of about 15 percent or more. Output prices and proximity to markets in Nairobi are also influential factors that may limit generalization from the Machakos experience. Despite concerns about severe land degradation in El Salvador, Pagiola (1998) found that ignorance, tenure insecurity, and lack of credit are not significant constraints on the adoption of conservation practices, while data were insufficient to draw firm conclusions about the influence of poverty. Pagiola found that a third of surveyed fields (and over half of steep fields) had some form of conservation in place, mostly minimum tillage and crop residue cover, but that terracing was unlikely to be cost effective in most cases.

Templeton and Scherr (1999) reviewed more than 70 empirical studies from around the world and find that incentives to invest in the maintenance and improvement of land, and thus land productivity, tend to increase as the value of land rises relative to the cost of labor. In Burkina Faso, Kazianga and Masters (forthcoming) found that stronger property rights (even in the absence of formal tenure) were positively associated with investment in soil and water conservation.

The particulars of land, property rights, markets, wealth, and information will vary from farm to farm and from one period to the next, and optimal choices about agricultural production and conservation will vary accordingly. In general, however, conservation choices in less-developed countries are driven by the same principles as those that drive conservation choices in the United States and other more developed countries: farmers' perceptions of what is best for them and their families over the short and long term.