Chapter 3

Land Quality and Land-Use Change

Producers allocate land to the use they expect will yield the greatest benefit over time.[1] In an agricultural context, maximizing benefits entails selecting which commodity to produce (e.g., corn, hay, or timber) and how, using land as an input.[2] The expected return to land depends on the price of outputs and (nonland) inputs, available technology (which can affect the per-unit cost of production), government policies, skills and preferences of the producer, and land quality.

Studies of land allocation, particularly among major land uses, have focused on the role of land quality and policy in determining land use. Policy can affect land-use decisions in a variety of ways. Price supports can alter the relative return between commodities that are supported and those that are not (Wu and Segerson, 1995; Plantinga, 1996). The tax code may favor certain land uses by its treatment of associated investments (Lichtenberg, 1989). Crop insurance, by reducing the risk of crop production, may promote crop cultivation where it is relatively risky (Goodwin et al., 2004; Wu, 1999). Government-funded infrastructure developments, such as flood control projects, may also enhance the economic viability of crop production in particular areas (Stavins and Jaffe, 1990).

In these studies, the effect of market prices, technology, and policy are all considered in the context of the land's ability to produce various goods and services. While there is no single best indicator of land quality, soil productivity—suitability of the soil as a medium for plant growth—is key for agricultural production. Most soil productivity definitions include attributes of the soil, climate, and topography. Existing studies have used a range of indictors, including the Land Capability Classification (Plantinga, 1996; Hardie and Parks, 1997) and one or more specific soil parameters such as water-holding capacity (Lichtenberg, 1989; Wu, 1999; Wu and Brorsen, 1995). As a rule, land quality attributes are fixed or change only slowly. Nonetheless, changes in markets, government policy, or technology may favor some types of land over others.

The characteristics of producers also affect land-use decisions. Producers may assess returns to various land uses differently because of differences in management skills, expectations about future prices or technology, risk aversion, or personal objectives. For example, lifelong crop farmers may be more reluctant to shift from crop production to forestry than individuals who have some expertise in timber production. Likewise, producers whose primary occupation is not farming or forestry may allocate land to agriculture, forestry, or other uses based on preferences that are not centered on potential return.

When a change in land use involves significant upfront costs (e.g., removing trees to begin crop production) or delayed returns (e.g., converting land to

[1]In this report, we use the term "producer" to refer generically to the individual making the land-use decisions for a parcel of land. This decisionmaker may or may not be the owner of the land. Land-use decisions may be made by the landowner, a land manager or operator, or some combination of the two. The ability of an operator renting land to make land-use decisions will depend on the terms of the cash or share lease contract and the ability of the owner to monitor and enforce this agreement.

[2]Land may also be valued for a wider range of goods, including recreational and ecological services. Producers can capture some (but not all) of these values by charging fees for hunting or other recreational activities. Producers may also value services such as recreation, aesthetic beauty, or environmental protection even if they cannot be compensated monetarily for them.

timber production), risk aversion, wealth, and discounting may be important. Producers who are particularly risk averse may be reluctant to make a large, upfront investment or wait many years to receive a return, even when the return is likely to be higher than that of other land uses. Even if they are not risk averse, producers with limited assets may have difficulty financing a long-term investment. Also, the more an individual discounts future returns, the less likely he or she is to undertake a long-term investment. For example, if crop production yields an average annual return (to land) of $40 per acre, the net present value (NPV) of returns discounted at 4 percent per year over 20 years is $544. A pulpwood harvest occurring at 20 years would have to net $1,192 per acre to yield an equivalent NPV (1192*(1+.04)^20=544). If future returns are discounted at 6 percent, however, the timber harvest would have to yield a net of $1,471 per acre to rival crop production.

Over time, market transactions tend to direct land to the owners who value the land most and into the uses they perceive as most valuable. Consider the sale of land that is in grazing use but has some potential for profitable crop production. Some bidders may believe that grazing is the most valuable use of the land and submit bids accordingly. Others may focus on the land's crop production potential and submit bids that reflect returns to crop production (less the cost of converting the land to crop production). If the high bid is from an individual who believes that the land is more valuable in crop production, it is likely that land-use conversion will quickly follow the sale. Because agricultural land markets in certain areas can be "thin" (with only a small proportion of land sold in any given year), reallocation of land use may take many years and be interrupted by changes in economic conditions that alter individuals' views on relative returns.

A Model of Land Allocation and Land Quality

For the purpose of our conceptual model, we assume that land quality can be defined by a single valued index that primarily measures soil productivity. This index captures the potential of land to generate economic returns for the private owner or operator (distinct from an environmental quality index measuring benefits to society). Soil productivity refers to the suitability of the soil and climate as a plant growth medium (see box, "Soil Quality Indicators").

Location may be an important determinant of land quality in several ways. The proximity of land to centers of population and employment is critical in determining the potential value of land for development (Bockstael, 1996). Local amenities, such as open space and rural "character," may also enhance the value of land for residential development (Wu et al., 2004). In terms of commodity production, distance to markets may also be important. For example, local grain prices depend in part on shipping costs. For bulkier commodities such as hay or timber, proximity to markets is even more critical. Distance of land to population centers may also affect the profitability of providing recreational services. In some cases, the value of recreational services that can be captured by the producer may tip the balance in a land-use decision. For example, grassland may provide livestock grazing during the spring and summer, and be used for hunting in the fall and winter

Soil Quality Indicators

In allocating land among agricultural and forest uses, productivity in terms of crop, forage, or timber production is a key indicator of land quality. Productivity refers to the suitability of the soil as a plant growth medium and the favorability of the climate. While productivity itself is complex, some useful proxies include crop yields or yield potential, one or more specific soil attributes such as soil water-holding capacity (e.g., see Lichtenberg, 1989; Wu, 1999), and indices that combine multiple soil attributes into a single number such as the Productivity Index (Pierce et al., 1983) or the soil rating for plant growth (SRPG; Soil Survey Staff, 2000).

Topography can also affect productivity as the loss of soil and nutrients through surface runoff can result in higher input costs and reduced soil depth, reducing soil productivity over time. Highly erodible land, which is often steeply sloping, is less likely to be used for crop production (Miranowski and Hammes, 1984). In at least one index of soil productivity (SRPG), slope reduces the overall soil productivity score. Steeply sloping land can also be difficult to farm efficiently with large machinery typical of modern crop production.

SRPG is an index of inherent soil productivity based on soil's physical, chemical, and biological factors as well as topography and climate. While SRPG is based largely on inherent properties of the soil such as texture and water-holding capacity, the productivity of specific tracts of land can be damaged over time by soil erosion. SRPG was originally developed by soil scientists with USDA's Natural Resources Conservation Service for use in implementing the Conservation Reserve Program (CRP).

While the SRPG rating and other soil productivity measures are indicators of economic potential, they are proxies. A more direct measure is potential yield. Potential yields are estimated in a number of ways, including experimental plots, and are intended to reflect the management practices yielding the highest economic return. Estimated irrigated and nonirrigated yields from the Soil Conservation Service's (now NRCS) Soils 5 data are linked to the National Resources Inventory data set. The Soil Survey Geographic (SSURGO) data from NRCS are the most up-to-date source of yield and soil productivity information, and are being digitized for the entire country.

months. However, given the likelihood that nearby land could also provide similar amenities, the recreational services must be valued by enough people for them to be a viable land use.

Figure 3.1a shows the relationship between land quality and returns for three hypothetical land uses given fixed prices, technology, and policy. The concave shape of the curves (decreasing upward slope as land quality increases) is based on the assumption that the genetic capacity of plants will increasingly become the limiting factor in production as land quality rises. Land use A is best able to use land of very low quality, but also reaches its full potential at a relatively low level of land quality. Land use C, on the

Figure 3.1a

Land quality and relative return to three hypothetical land uses

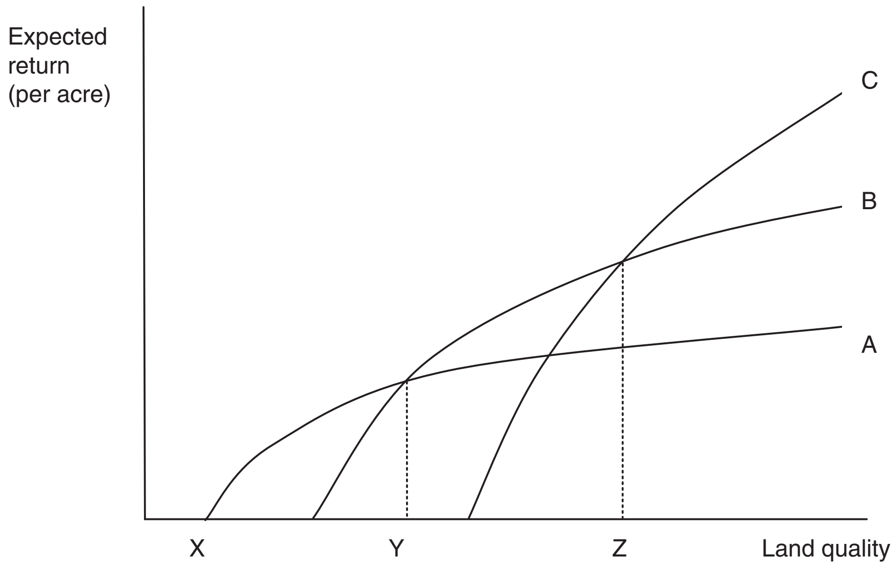
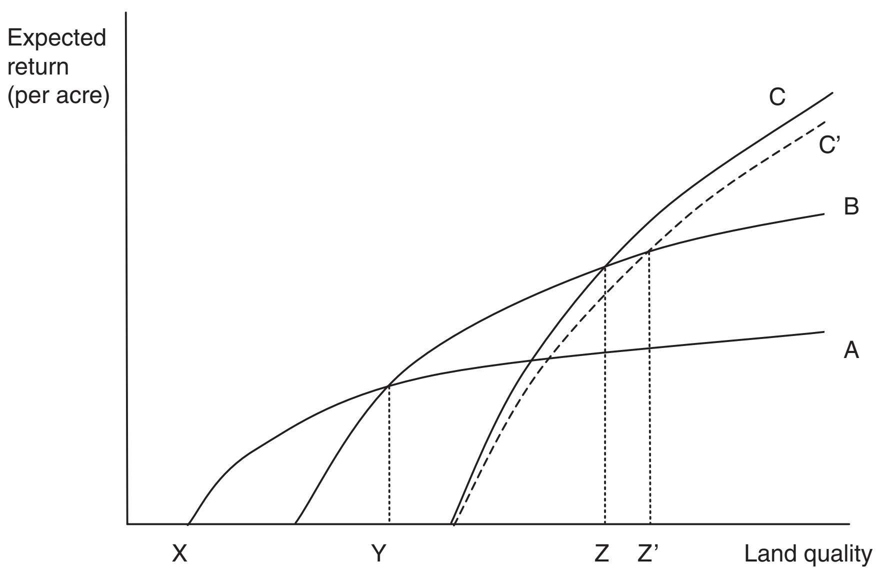


Figure 3.1b

Land quality and relative return to three hypothetical land uses: Effect of decline in output price



other hand, cannot use low-quality soils but is better able to take advantage of the greater plant growth potential on high-quality land.

If these curves reflect a market-level assessment of the relative value of the three land uses, land with quality (Q) less than X will be idle (not devoted to any of the three uses considered in figure 3.1a); land with quality between X and Y will be devoted to use A; land with quality between Y and Z will be devoted to use B; and land with quality greater than Z will be devoted to use C. The producer is indifferent between land uses A and B at point Y, and is indifferent between uses B and C for land of quality Z.

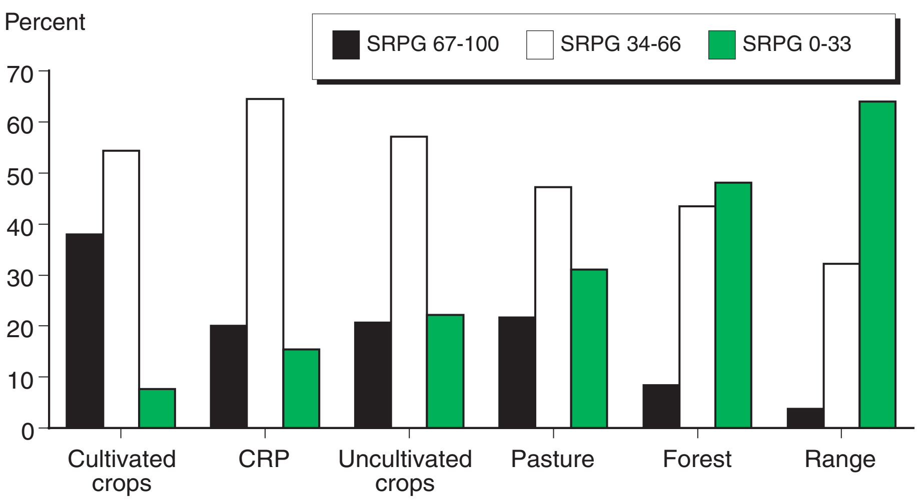
These stylized predictions are supported by the data on the distribution of land quality across land uses. Figure 3.2 shows the distribution of land quality, as defined by the soil rating for plant growth (SRPG), by land use, averaged over 1982-97. The SRPG is a measure of soil productivity that can take values of 0-100. While there is land of different qualities devoted to every use, lands in cultivated crops include a greater proportion of high-productivity land (SRPG 67-100) and a smaller proportion of low-productivity land (SRPG 0-33) than any other land-use category. These results imply that cultivated crops are best able to take advantage of high-productivity land but are relatively unprofitable on low-quality land. Uncultivated cropland and CRP include more medium-quality land (SRPG 34-66) than other land-use categories. Finally, pasture, forest, and rangelands include more low-productivity land than the cropland categories or CRP (which is former cropland). Forest and rangeland also include less high-quality land than other land-use categories.

Land enrolled in CRP is likely to be of lower quality than cultivated cropland on average as a result of program-specific objectives and economic incentives for participating. First, USDA targets highly erodible land among other environmental factors in the Environmental Benefits Index (EBI), the selection criteria used for selecting CRP parcels. We show later that highly erodible land is also less productive on average, so the program indirectly targets land with lower soil productivity.[3] Second, the cost of enrolling land is another component of the selection criteria so that, given similar environmental characteristics, producers with less to lose from participating are more likely to be accepted into CRP. Thus, lower value land is directly targeted as well. USDA also sets soil-specific caps (based on SRPG) on the maximum annual rental payments allowed under the program. All else being

[3]The relationship between soil productivity and erodibility is examined in detail in the next chapter.

Figure 3.2

Distribution of different agricultural uses, by soil productivity index (soil rating for plant growth)



Note: SRPG = soil rating for plant growth. Numbers depict the average share of land in each cell across each soil productivity category from 1982 to 1997, with shares in each cell summing to 100 percent. As seen by moving from left to right across each row, land in more intensive land uses, such as cultivated crops, generally has a higher proportion of high-productivity soils (SRPG 67-100) and a lower percentage of low-productivity soils (0-33) than land in less intensive uses, such as rangeland.

Source: ERS analysis of 1997 NRI and Soil Survey Geographic data set.

equal, for any particular soil type, producers with economic benefits from crop cultivation near (or above) the cap will have smaller incentives to participate in CRP than producers on lower quality land. Because we do not observe all sources of variation in soil productivity, the relative productivity of lands enrolling in CRP may be even lower than our analysis suggests.

Change in market prices, technology, and policy can be depicted as shifts in one or more of the curves in figure 3.1a. If, for example, the price of output(s) produced by land use C decreases, the curve for land use C would shift downward (see C' in figure 3.1b).[4] If returns to other land uses are unchanged, land with quality between Z and Z' would shift from use C to use B. Similar shifts (in the opposite direction) may be observed with technical changes that lower per-unit production costs.

Economic Characteristics of Transitioning Lands

The conceptual model suggests that low-quality cultivated croplands (relative to other cultivated cropland) would be most likely to shift to uncultivated cropland, CRP, and other agricultural and forest uses as market conditions, government policies, or technology change. Similarly, theory suggests that the relatively high-quality land in uncultivated crops and pasture would be on the margin with cultivated cropland while relatively low-quality uncultivated cropland would be on the margin with forest and rangeland. Following the same logic, the relatively high-quality lands in forest and range would be those most likely to transition to crop production.

This pattern is borne out by an examination of land quality for various categories of land-use change over 1982-97. This is the longest period for which the NRI data are available and reveals the largest amount of cropland changes. Land that was cultivated in 1982 and stayed in cultivated crop production (fig. 3.3, row 1, column 1) includes a higher proportion of high-productivity land and a lower proportion of low-productivity land than land that moved to another use by 1997 (fig. 3.3, row 1, columns 2-4). Likewise, land moving to cultivated crop production from another use (row 2 and 3, column 1) includes a higher proportion of high-productivity land and a lower proportion of low-productivity land than noncultivated lands that remained in or moved to another noncultivated use (rows 2-3 and columns 2-4). In general, land that stayed in or moved to cultivated cropland is more likely to be high-productivity land than land in (or moving between) noncultivated land uses.[5]

While the SRPG rating is one indicator of economic potential, it is a proxy. A more direct measure is the potential yield—the amount of a given crop that can be produced per unit of land under the management practices providing the highest economic return (see box, "Soil Quality Indicators"). Figure 3.4 shows potential yields, relative to crop reporting district (CRD) averages, for four major crops (corn, soybeans, wheat, and alfalfa hay) in the cells of the land-use change matrix associated with our four key land uses.[6] The bar in each cell represents the average relative yield for each crop.

By focusing on yields relative to the average for a relatively small geographic area, we compare yields while holding constant other factors that are common

[4]Curve shifts need not be parallel. If lower quality land has less output (e.g., a lower corn yield), then a change in the output price would have a larger per-acre effect on higher quality land. Technology change may not affect all types of land equally, either. Lichtenberg (1989) showed that soils with greater water-holding capacity in the Nebraska sand hills were more likely to be shifted from small grains and hay to row crops with the development of center-pivot irrigation.

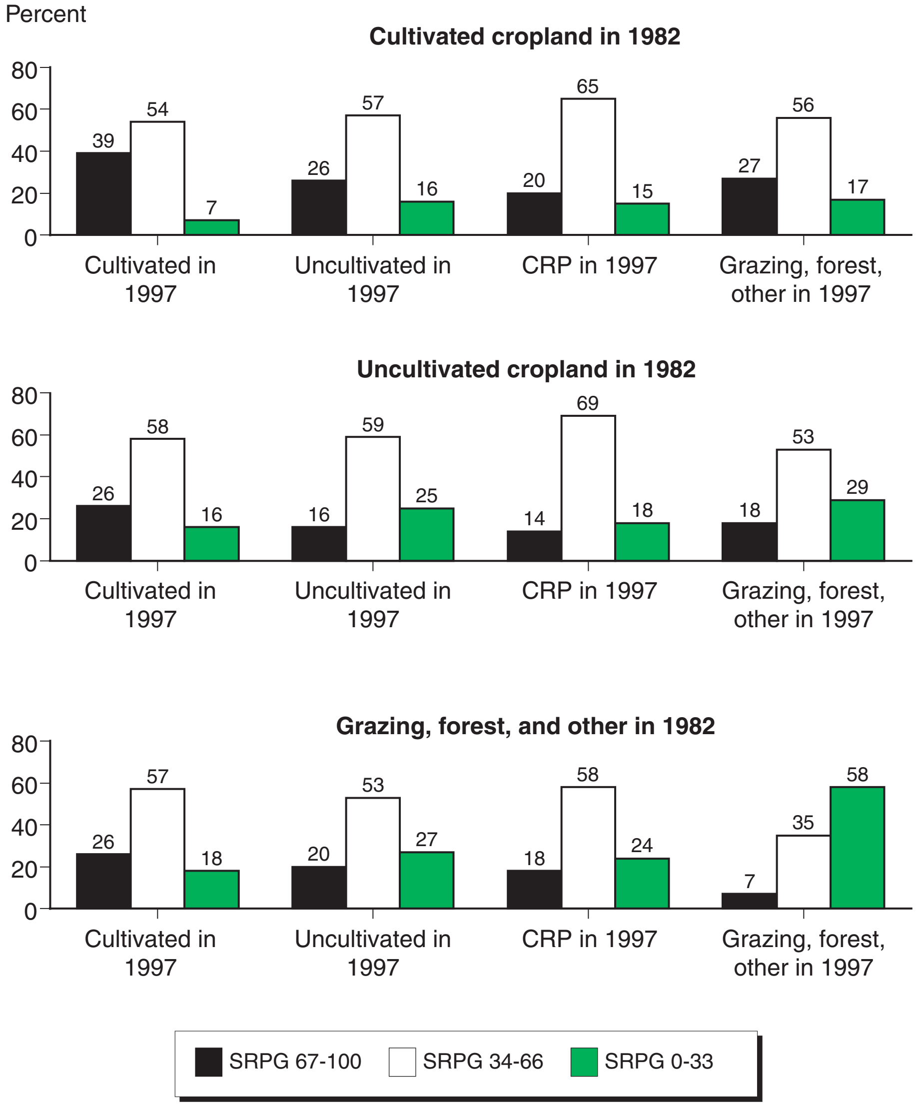
[5]Lands observed in cultivation in both 1982 and 1997 include some lands that shifted out of cultivation and then shifted back over the course of this period. Excluding these lands from our category of lands remaining in crop cultivation would likely strengthen our findings regarding the relative soil productivity at the extensive margin of cultivated cropland.

[6]Most States have between six and nine CRDs, multicounty units used by USDA in gathering data. Each National Resources Inventory point is assigned relative yields, which are the ratio of the point-specific yield to the average yields, for all four land uses in the CRD. Estimated yields are from the Soil Conservation Service's (now NRCS) Soils 5 data. While yields from the Soil Survey Geographic (SSURGO) data have been most recently updated, we used Soils 5 data for this analysis as our focus is on relative (rather than absolute) yield levels, and Soils 5 data had a wider geographic coverage at the time of our study.

Soils 5 yields are also not available for all soils; the less likely land is to be used for crop production, the less likely it is to be assigned a yield in the Soils 5 data series. Because potential crop yields on this land are likely to be relatively low, the exclusion of these lands is likely to bias estimates for average relative yield upward for land in less intensive uses. Thus, differences in relative potential yields may be even more pronounced than indicated in figure 3.4.

Figure 3.3

Land-use change and land quality (Soil rating for plant growth)



Notes: Numbers depict the share of land in each cell across each soil productivity category, with shares in each cell summing to 100 percent. As seen by moving from left to right across each row, land that transitioned to (or remained) in a more intensive land use, such as cultivated cropland, generally has a higher proportion of high-productivity soils (SRPG 67-100) and a lower percentage of low-productivity soils (0-33) than land transitioning (or remaining) in a less intensive use, such as grazing, forest, and other land. As seen by moving from top to bottom along each column, land in more intensive land uses generally has a higher proportion of high-productivity soils (SRPG 67-100) and a lower percentage of low-productivity soils (0-33) than land in less intensive uses.

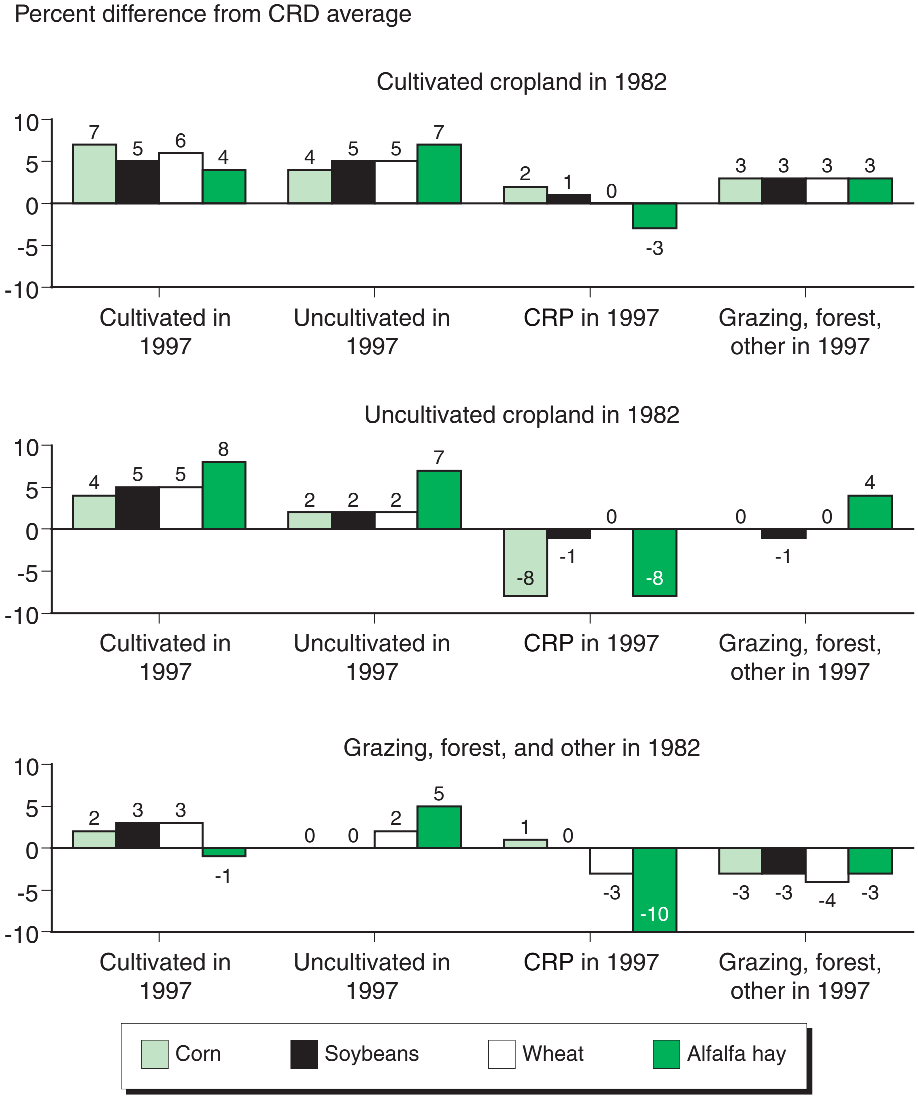
Source: ERS analysis of 1997 NRI and Soil Survey Geographic (SSURGO) data.

to this region. Given that prices for agricultural output and inputs are not likely to vary much within a CRD, estimated differences in yields are strong indicators of differences in the profitability of different subsets of land.

Using relative potential yields gives roughly the same pattern of land use and land quality as SRPG, though it provides some additional insights. In general, land in cultivated crops has higher yield potential than land in other uses (fig. 3.4, compare column 1 to columns 2-4). Average yields for land

Figure 3.4

Land-use change and land quality base on expected crop yields



Note: To account for variations in climate and other nonland quality factors that could cause yields to vary spatially, each NRI point is assigned relative yields that are the ratio of the point-specific yield to the average yields, for all four land uses, in the crop reporting district (CRD). For each cell, the average relative yields are reported.

Source: ERS analysis of 1997 NRI and Soils 5 data.

that was in cultivated cropland in both 1982 and 1997 are generally higher than for land that moved from cultivated cropland to another use. The exception is alfalfa, where potential yields are higher on uncultivated cropland (row 1, column 2). Also, potential yields of corn, soybeans, and wheat on land that moved to uncultivated crops (row 1, column 2) are almost as high as for land that remained in cultivated cropland. Moreover, land that shifted from cultivated crops to CRP (row 1, column 3) had lower yields than all other land moving from cultivated crops (row 1, column 4).

Clear economic differences exist across lands at the extensive margin of crop production. Most strikingly, land enrolled in CRP appears to be the lowest quality land in a crop reporting district across each of the cropland categories considered. Cultivated cropland enrolled in CRP is just slightly above average for corn, soybeans, and wheat and below average for hay. It appears to be less productive than land converting to other agricultural and forest uses. Uncultivated cropland enrolled in CRP follows the same pattern.

Many of the yield differences observed are small. Estimated yields on land in cultivated crops in both 1982 and 1997 are 4-7 percent above CRD averages (fig. 3.4, row 1, column 1), while land that was in grazing, forest, or other uses in both years had yields 3-4 percent below CRD averages (row 3, column 4). The overall pattern is striking given the coarseness of the underlying data. The Soils 5 data do not reflect all of the factors affecting yields on each land parcel. The data are specific to a soil map unit and capture only general variation in potential yields based on soil type. Considering additional parcel-level characteristics would tend to increase the variation in estimated yields within a small geographic area, and thus magnify the departure in yields from the CRD average.

Conclusion

The theoretical model of land allocation provides a framework for analyzing data on the economic characteristics of lands at different extensive margins. Two land quality indicators—SRPG and potential crop yields—suggest clear patterns in the relative profitability of lands at different extensive margins, with higher (lower) quality lands more likely to be devoted to more (less) intensive land uses. The extensive margin of cultivated cropland is largely cultivated cropland that is of lower quality than other cultivated cropland and land in less intensive uses is higher quality than other land in those uses. These results indicate that land quality is, indeed, a critical factor in the allocation of land among agricultural and forestry uses. Lands enrolled in the CRP appear to be of particularly low quality relative to other land in the same geographic area.

The indicators examined do not fully explain land use. For example, some land with high productivity (SRPG 67-100) is in other agricultural and forest uses, while some land in cultivated crops has low productivity (SRPG 0-33). Of course, soil productivity indicators do not capture every dimension of land quality that is important to agricultural land-use decisions. An unfavorable location far from infrastructure and transportation facilities, for example, may make land otherwise quite suitable for crop production unprofitable for this purpose.

In this chapter, land quality was defined narrowly to focus on land characteristics that are of direct economic value in agricultural production. However, the environmental impact of land-use change at the extensive margin of cultivated cropland will depend largely on factors like erodibility and nutrient runoff potential. Some analysts have assumed that land which is economically marginal for crop production is also more environmentally sensitive than other cropland. In the next chapter, we test this assumption by examining the relationship between economically marginal croplands and different indicators of environmental sensitivity.