1.3 Land and Soil Quality

Multiple measures can be used to measure land and soil quality. While measures of land capability, productivity, and erodibility are well known, there is an increasing emphasis on soil quality measures that incorporate properties more fully reflecting a soil's potential for long-term agricultural production without negative environmental impacts.

Why Do We Measure Land and Soil Quality?

Measures of soil quality are needed to: (1) monitor long-term effects of farming practices on soil properties; (2) assess the economic impact of alternative management practices designed to improve soil quality (such as cover crops and alternative tillage practices); (3) assess the effectiveness of policies designed to address factors affecting soil quality; and (4) improve economic assessments of land by including both economic and environmental values (Granatstein and Bezdicek, 1992).

Measurement of land or soil quality has often included characteristics needed to determine appropriate land use or to address a single resource problem. For example, measures are often used to determine whether a soil is suitable for a particular type of agricultural production or whether there is a need to control soil erosion to preserve or enhance farm productivity. These measures have traditionally focused on the needs of agricultural producers and other private land holders. Land, however, is a public resource, as well as a private one, and it is a fundamental component of the Nation's natural resource base. Maintaining land quality requires a better understanding of the multiple functions of soil and a better understanding of the interaction between agricultural activities and soil quality. Traditional measures of land capability and erodibility need to be augmented to reflect more fully overall land quality. While most productivity measures reflect landowners' concerns surrounding soil quality, other concerns, such as surface water pollution from runoff, soil productivity for future generations, and the health of agricultural and rural ecosystems, are of broader national interest.

An economic assessment of land and soil quality is a complex undertaking. It involves combining the many physical attributes that capture the multiple dimensions of land and soil quality into meaningful indicators and then assigning economic values to these indicators. For example, economic values include onfarm costs associated with declines in soil fertility or productivity, as well as off-farm costs associated with sediment washing into waterways, which can affect aquatic life, degrade recreational resources, and interfere with water conveyance systems (Ribaudo, 1986). When economic values are generated for these indicators, the trade-offs among alternative natural resource policies and alternative farming practices can be assessed.

Land Capability and Suitability

Existing measures of land quality are often used to monitor the use of land or the capability or suitability of land for a particular purpose, such as growing crops or trees, grazing animals, or pursuing nonagricultural uses. Two commonly used measures are land capability classes (LCC) and the prime farm land designation. These land classifications convey information about the suitability of land for a particular kind of activity. Land inventories incorporating these measures are conducted by USDA's Soil Conservation Service (SCS) through the Soil Survey Program and every 5 years through the National Resources Inventory (NRI) (USDA, 1989b).[1]

Land capability classes range from I to VIII. Class I has no significant limitations for raising crops. Classes II and III are suited for cultivated crops but have limitations such as poor drainage, limited root zones, climatic restrictions, or erosion potential. Class IV is suitable for crops but only under selected cropping practices. Classes V, VI, and VII are best suited for pasture and range while Class VIII is best suited for wildlife habitat, recreation, and other nonagricultural uses (USDA, 1989). Land capability classes I-III total 354 million acres, or 84 percent of U.S. cropland, excluding Alaska (fig. 1.3.1 and table 1.3.1).

---

[1] The NRI covers the status, conditions, and trends of the Nation's nonfederal land in order to assess land use, soil, water, and related resource conditions. This inventory began in 1934 as the National Erosion Reconnaissance Survey. Since 1934, new authorities and requirements have been provided, which expanded the scope of the original survey. Currently, the NRI is linked to SCS's RCA Appraisal, which is authorized by the Soil and Water Resources Conservation Act of 1977 (RCA) and requires the Secretary of Agriculture to report on the status, conditions, and trends of the soil, water, and related resources on the Nation's nonfederal lands.

Another measure of land suitability is USDA prime farmland designation, which is based on physical and morphological characteristics such as depth of the water table in relation to the root zone, moisture holding capacity, the degree of salinity, permeability, frequency of flooding, soil temperature, erodibility, and soil acidity. Land classified as prime farmland has the growing season, moisture supply, and soil quality needed to sustain high yields when treated and managed according to modern farming methods (USDA, 1989). Prime farmland totals 232 million acres, or 55 percent of U.S. cropland, excluding Alaska (fig. 1.3.2 and table 1.3.1).

These measures of land quality are often confused with the capability of land to produce economic returns. Land in capability classes I-III or prime farmland does not necessarily have the highest value of crop production per acre (Vesterby and Krupa, 1993). Alternatively, lands earning high economic returns may not be classified as prime farmland or in LCC I-III. For example, prime and LCC designations are based on characteristics that reflect suitability for row crop production. Florida and Arizona have little prime land or land in LCC I-III, but these areas rank among the most economically productive in the Nation.[2]

Table 1.3.1—Cropland and soil quality, selected measures, 1980's

Measure	Million acres	Percent of total cropland
Land capability class in 1987:[1]		
I (highest quality)	29	7
II	191	45
III	134	32
IV and above	69	16
Total cropland	423	100
Prime farmland in 1987[2]	232	55
Erodibility on cropland in 1987:[2]		
Nonerodible (RKLS/T < 2)	81	19
Moderately erodible (2 ≤ RKLS/T < 8)	218	52
Highly erodible (8 ≤ RKLS/T)	123	29
Total cropland	422	100
Vulnerability to pesticide leaching in 1982:[3]		
Low (GWVIP < 30)	128	31
Moderate (30 < GWVIP < 124)	143	35
High (124 < GWVIP)	143	35
Total cropland	414	100

[1] USDA, 1989b. Includes cropland in the contiguous States and Hawaii and the U.S. Caribbean islands (less than 0.75 million acres).

[2] USDA, 1989b. Includes the contiguous United States only.

[3] Kellogg, Maizel, and Goss, 1992. GWVIP = Ground Water Vulnerability index for Pesticides. "Sample points that could not be associated with the Cartographic data base" were excluded, reducing the cropland base to 414 million acres.

Productivity

Soil productivity, which measures output per unit of input, is often the primary reason for monitoring soil erosion (or other degradation processes) and is itself a measure of soil quality. Productivity is often measured as crop yield per acre. Alternatively, productivity can be measured by the expected net returns per acre from production (dollar returns to production net of cash production costs). Highest values are in coastal areas where climate, soil, location, and irrigated conditions favor production of perishable crops (fruits and vegetables), or where integrated livestock operations draw from an extended cropping area (fig. 1.3.3). The next rank of productive lands are in the Corn Belt, Lake States, the Northeast, and Southern Coastal Plain. The least productive lands, by this net returns measure, occur in bands across the Northern Plains and Central Plains. Productivity can reflect soil degradation if yields decline as soils become degraded or if input use increases to compensate for declines in soil quality resulting in higher production costs. However, productivity often masks environmental or health components of soil quality; lands of poor physical quality (as measured by erosion, texture, organic matter) can sometimes produce very high yields (Vesterby and Krupa, 1993).

Erodibility

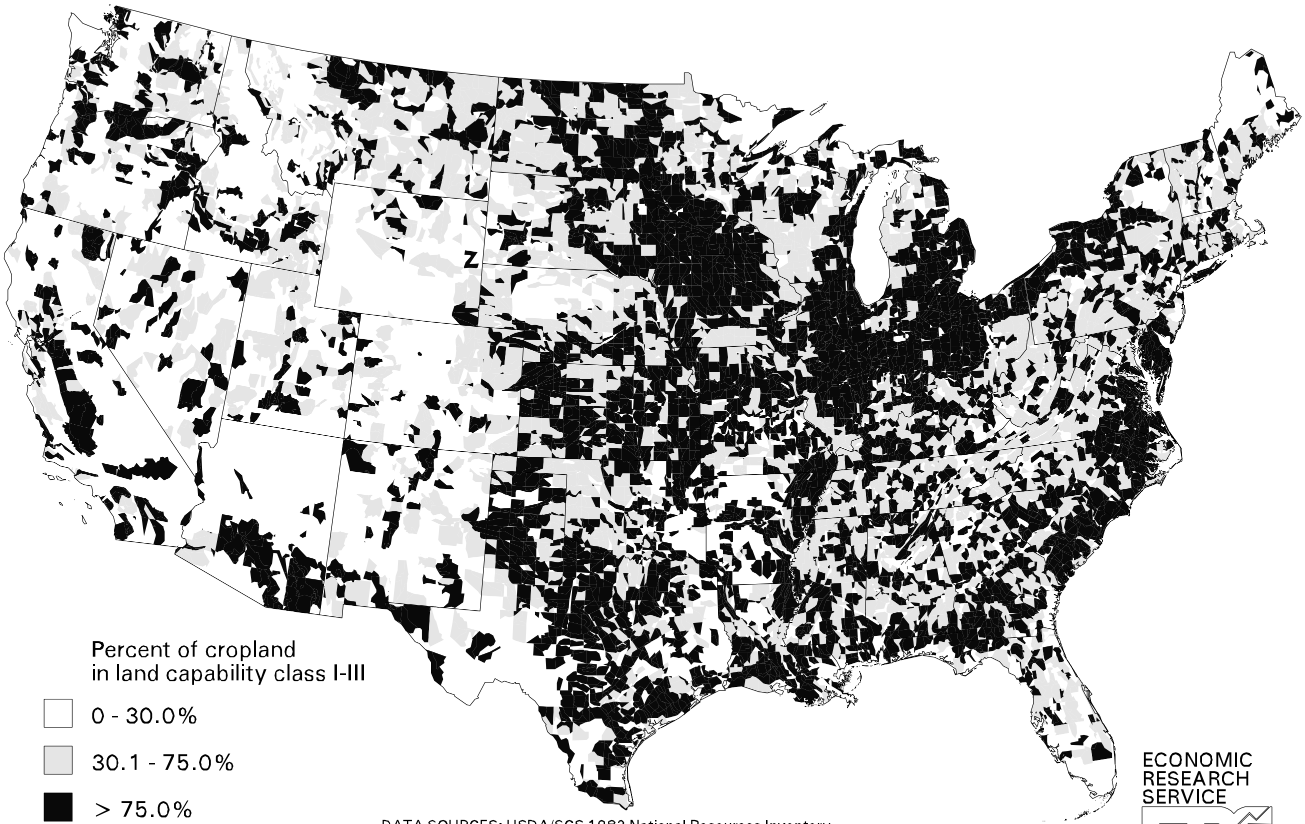
A commonly used measure of soil quality is highly erodible land (HEL), which is of particular importance for USDA conservation policy (see chapter 6). Because tons of wind and water erosion do not usefully measure the erosion potential on particular soils, USDA uses the erodibility index (EI) to determine conservation program eligibility. Soil erosion is a result both of relatively unchanging physical factors, such as rainfall, slope, and soil texture, and of changing factors associated with human management, such as crop rotations, tillage methods, and irrigation (Bills and Heimlich, 1983; McCormack and Heimlich, 1985). Highly erodible soils have the potential for erosion because of relatively unchanging physical attributes such as slope and soil texture. Erosion rates can be reduced if hay, grass, trees, or close-grown crops are grown, if

---

[2] Areas, such as those in Arizona and Florida, that have the special combination of soil, location, growing season, and moisture to produce high-value food and fiber crops may be categorized as "Unique Lands" or "Lands of Statewide Importance."

Figure 1.3.1

Distribution of cropland in land capability class I,II, and III on rural, nonfederal land

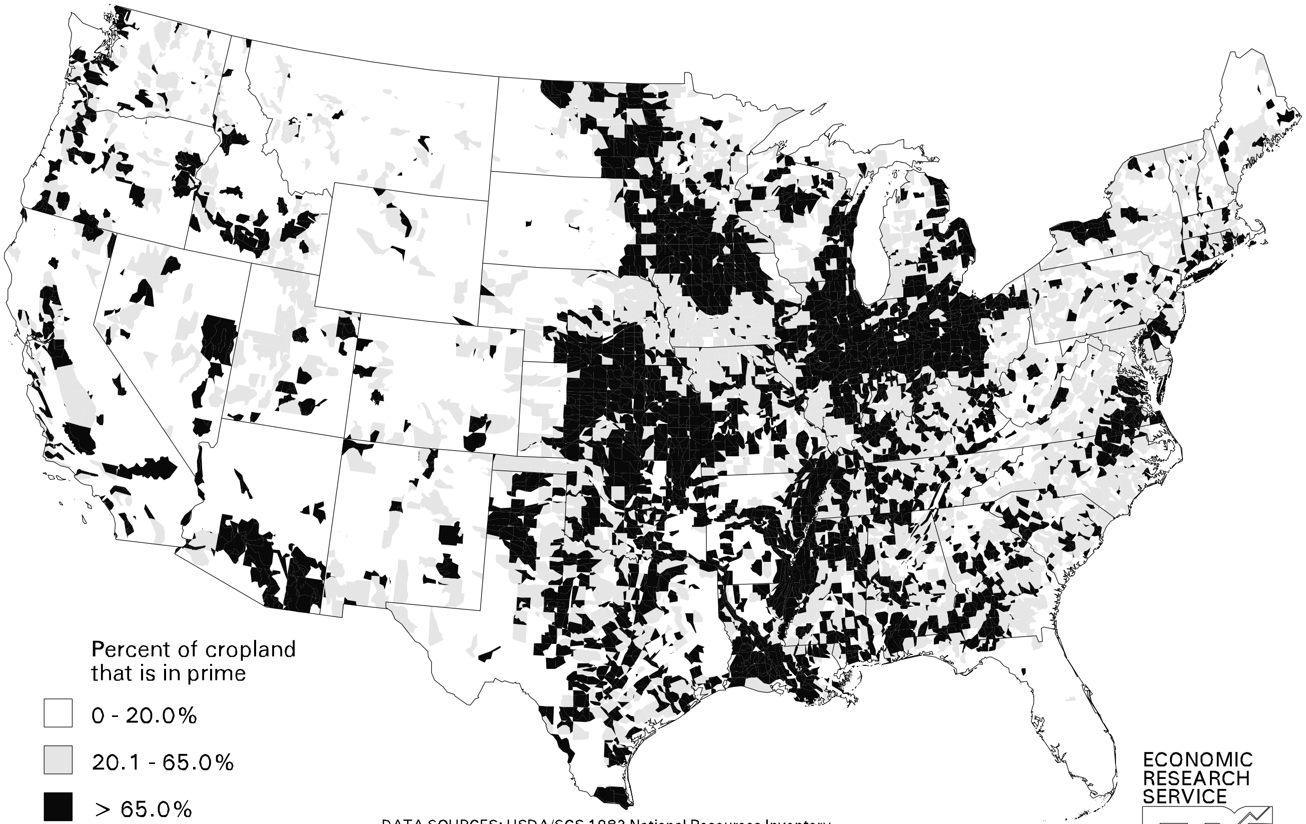


ECONOMIC
RESEARCH
SERVICE

DATA SOURCES: USDA/SCS 1982 National Resources Inventory
and SOILS-5 Databases
ANALYTICAL METHODOLOGY: National Center for Resource Innovations
GIS SOFTWARE: ARC/INFO (Environmental Systems Research Institute)

Figure 1.3.2

Distribution of prime cropland on rural, nonfederal land

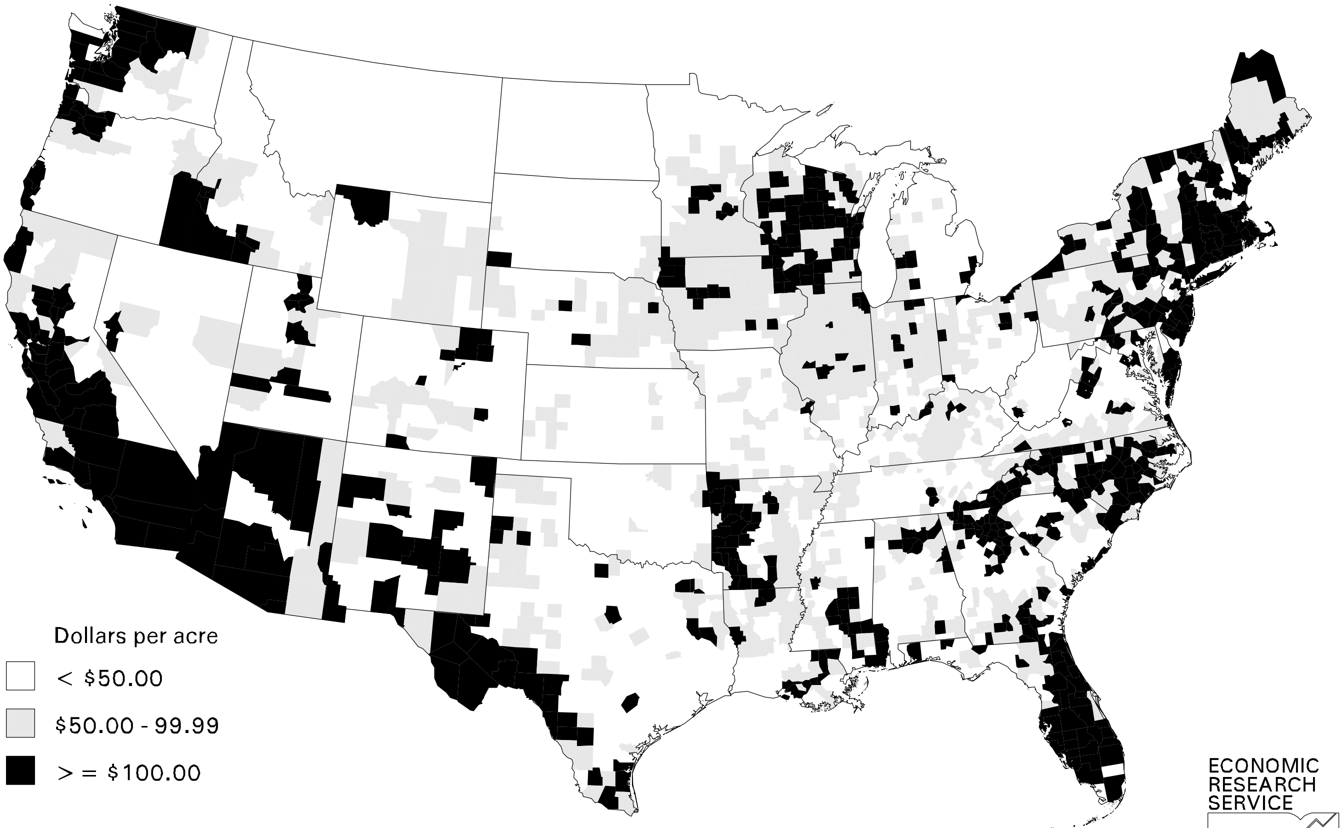


ECONOMIC
RESEARCH
SERVICE

DATA SOURCES: USDA/SCS 1982 National Resources Inventory
and SOILS-5 Databases
ANALYTICAL METHODOLOGY: National Center for Resource Innovations
GIS SOFTWARE: ARC/INFO (Environmental Systems Research Institute)

Figure 1.3.3

County average net cash return per acre of cropland

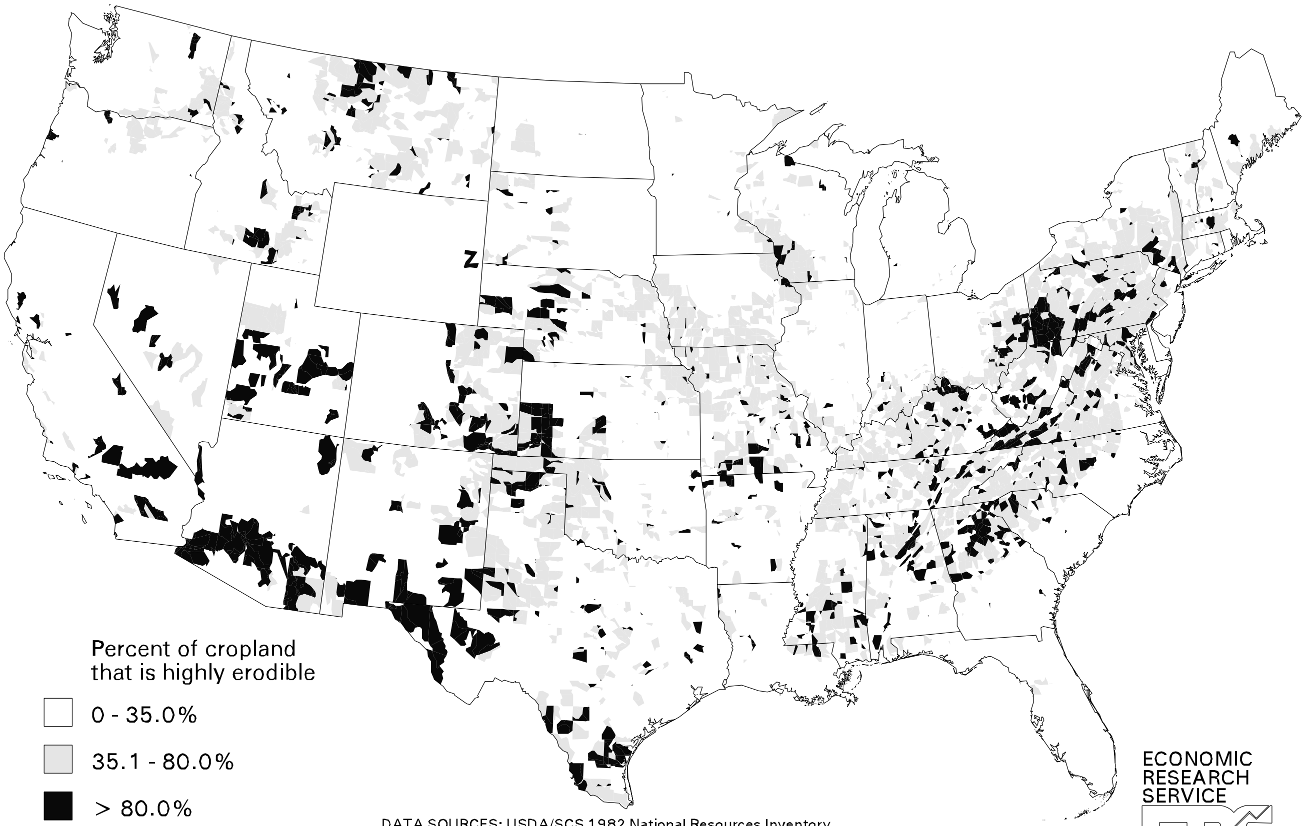


DATA SOURCE: 1987 Census of Agriculture

ECONOMIC
RESEARCH
SERVICE

Figure 1.3.4

Distribution of highly erodible cropland on rural, nonfederal land



DATA SOURCES: USDA/SCS 1982 National Resources Inventory
and SOILS-5 Databases
ANALYTICAL METHODOLOGY: National Center for Resource Innovations
GIS SOFTWARE: ARC/INFO (Environmental Systems Research Institute)

ECONOMIC
RESEARCH
SERVICE

conservation methods are used with appropriate crop residue management, and if supporting conservation practices are employed.

An assessment of erosion needs to consider both the physical potential for erosion and the erosion rates resulting from management choices. Unchanging physical factors associated with sheet and rill erosion are rainfall pattern, soil texture, and topography, measured by the R,K, L, and S factors of the Universal Soil Loss Equation.[3] In the Wind Erosion Equation, the climatic (C) and soil erodibility (I) factors reflect unchanging physical conditions. These parts of the two most commonly used soil erosion predictive equations constitute measures of erosion potential, abstracted from the management of crops and soils.

The erodibility index (EI) divides potential erosion (sheet and rill, or wind) by the soil loss tolerance factor (T-level, the rate of soil erosion above which long-term soil productivity may be depleted) to reflect erosion potential relative to vulnerability to productivity loss (Heimlich and Bills, 1989; McCormack and Heimlich, 1985). Highly erodible land is defined by USDA as land with a natural erosion potential of at least eight times its T-level. Nationwide, 29 percent of cropland is classified as highly erodible (fig. 1.3.4 and table 1.3.1). USDA's Soil Conservation Service classifies about 149 million acres of cropland as HEL for purposes of the conservation compliance provisions of the 1985 and 1990 Farm Acts.[4]

An alternative measure of productivity loss due to erosion converts total erosion from tons per acre per year to inches per year using the soil bulk density. The rate of expected soil loss in inches is divided into the topsoil depth (the A horizon) recorded in the Soil Interpretation Record (SOILS 5) (USDA, 1983). This measures how many years it would take to remove the topsoil at the current rate of erosion (on the extreme assumption that all the eroded soil is removed from the field). Combining these physical features of soils with economic information highlights the different perspective economics brings to these measures. Multiplying the inverse of this measure by the cash rental rate for cropland reflects the relative economic value of soil productivity loss due to erosion. Three factors are reflected in this measure: erosion rates, soil depth, and rental values of land. The physical measures (soil erosion and depth) provide a quantitative view of soil characteristics, while the rental rate provides an indication of the economic value of the soil for agricultural production. Low erosion rates or deep, longlasting topsoils are given less weight, and highly productive (high rental rate) but vulnerable soils (thin topsoil, high erosion rate) are given more weight (fig. 1.3.5).

This indicator suggests four regional concentrations of vulnerable soils, the largest centered on Iowa, Illinois, and Missouri in the Corn Belt. This region's index values are largely driven by the region's relatively high rental rates. While erosion rates are moderate, the soil is relatively valuable. A second concentration of vulnerable soils is the eastern bluffs of the Mississippi River in western Kentucky, Tennessee, and Mississippi, along the eastern edge of the Mississippi Delta. A third concentration is the irrigated cotton area of the Texas Panhandle, stretching up to the eastern edge of Colorado. The final concentration is a band of highly erodible and highly valued land in eastern Washington and Oregon around the Palouse.

One major onsite effect of soil erosion is the impact on soil productivity. Research conducted in the 1980's has improved our understanding of the long-term relationship between erosion and productivity (AAEA, 1986). The 1987 RCA estimated that agricultural productivity would decline about 3 percent over the next 100 years, due to soil erosion, under 1982 management conditions. Productivity loss would be concentrated on soils eroding at high tolerance values or on very fragile soils where even slight erosion can result in large declines in yields (USDA, 1989). Soil erosion also contributes to off-farm sediment damages. USDA has estimated that soil erosion causes \$2-\$8 billion annually in offsite damage (Ribaudo, 1986).

Vulnerability

Other land and soil quality indicators have been developed that reflect both physical attributes and the consequences of production practices on soil quality and on the potential to sustain agricultural production. Interest in soil erosion and its associated costs has been coupled with an increasing interest in measuring the loss of nutrients, pesticides, and

---

[3] The Universal Soil Loss Equation is: A = RKLSCP, where A is the estimated soil loss. R, K, L, and S represent the climate, soil, and topography conditions at the measured site. C and P estimate the degree to which use and management of the soil reduce erosion (USDA, 1989).

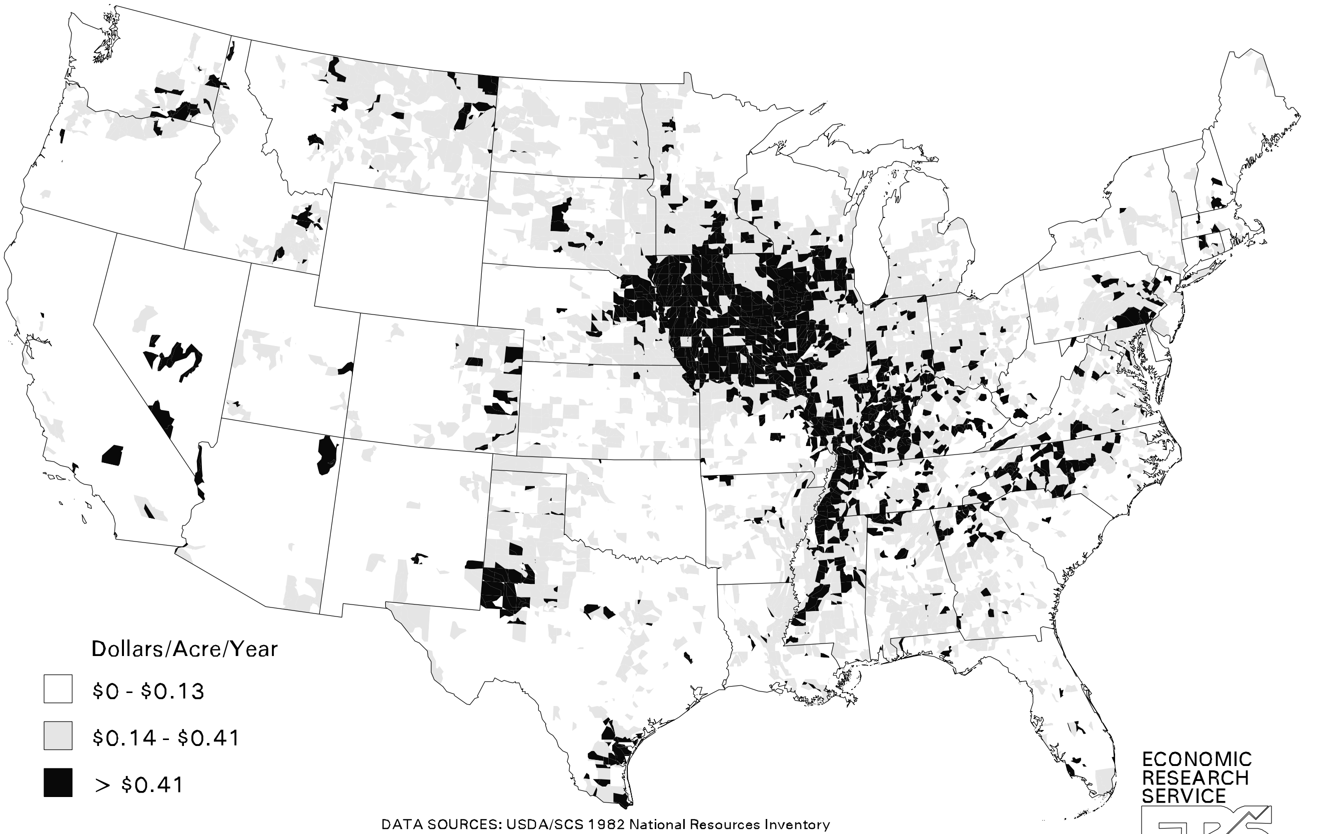
[4] USDA's HEL classification for program purposes includes some cropland in fields that have at least one-third or 50 acres (whichever is less) of soils with an erodibility index of 8 or greater. Thus, the highly erodible soils, 123 million acres in table 1.3.1, are less than the 149 million acres of HEL classifications for program purposes.

salts from farming systems to surface and ground water (National Academy of Sciences, 1993). For example, vulnerability indices have been constructed to assess the potential for groundwater contamination related to agricultural chemical use. These indices, which are discussed in detail by Kellogg, Maizel, and Goss (1992), incorporate variables that reflect the propensity of soils to leach pesticides and nitrates. For example, the Ground Water Vulnerability Index for Pesticides (GWVIP) is a function of soil-leaching potential, pesticide-leaching potential, precipitation, and chemical use. The Ground Water Vulnerability Index for Nitrogen fertilizer (GWVIN) is similar to GWVIP except that a residual nitrogen variable replaces the pesticide use and pesticide-leaching potential variables. Using these measures, the Corn Belt, Southeast, and Lake States have more acreage vulnerable to pesticide leaching, while the Northern and Southern Plains show more acreage with a potential for nitrate leaching (figs. 2.2.4, 2.2.5, p. 62).

While LCC, prime farmland, and HEL are useful in determining how land might be used or the degree and location of erosion, they are limited in that they exclude other important characteristics of soils. Productivity measures, such as yields per acre, or profitability measures, such as cash rents, provide fairly direct indicators of the utility of land for producers wishing to maximize the return on their land investments. But, such measures are limited to those private interests and do not reflect the environmental vulnerability or harm the land may face. Vulnerability indices are useful measures of potential environmental impacts and provide a needed link between soil characteristics and water quality. Vulnerability and HEL indices provide policymakers and natural resource managers with needed information for beginning to design and target policies for resource management. But, as we broaden our understanding of land as a fundamental base for the environment, broader measures are needed to capture the multiple dimensions of soil and land quality.

Figure 1.3.5

Value of onsite soil productivity loss



DATA SOURCES: USDA/SCS 1982 National Resources Inventory and SOILS-5 Databases
ANALYTICAL METHODOLOGY: National Center for Resource Innovations
GIS SOFTWARE: ARC/INFO (Environmental Systems Research Institute)

Comprehensive Soil Quality Measures

Instead of focusing on the land's capability to support specific activities or on a single soil degradation process, such as erosion or chemical leaching, researchers are focusing on how a broad range of physical, chemical, and biological properties determine soil quality.[5] Researchers are also asking how human activities, such as farming, affect the soil and the soil's ability to function in the long run and mitigate offsite effects. Eventually, economic analysis could provide estimates of the on- and off-farm costs of soil degradation and the cost of maintaining soil quality.

Many definitions of soil quality include both environmental factors and measures of crop productive capacity or productivity. For example, soil quality has been defined as "the ability of a soil to produce safe and nutritious crops in a sustained manner over the long-term and to enhance human and animal health without impairing the natural resources base or harming the environment" (Parr, Papendick, Hornick, and Meyer, 1992). Similarly, soil quality can be defined as the "sustaining capacity of a soil to accept, store, and recycle water, minerals, and energy for production of crops at optimum levels while preserving a healthy environment" (Arshad and Coen, 1992). A National Academy of Sciences (NAS) report defines soil quality as "the ability of a soil to perform its three primary functions: to function as a primary input to crop production, to partition and regulate water flow, and to act as an "environmental filter" (1993). In addition, the NAS report recommends that "the concept of soil quality should be the principle guiding the recommendations for use of conservation practices and the targeting of programs and resources." Currently, conservation compliance plans and, until recently, eligibility for the Conservation Reserve Program relied primarily on one soil quality indicator–soil erosion index as measured by the erodibility index.

A soil's quality is determined by a set of many highly correlated physical, chemical, and biological properties such as soil depth, water-holding capacity, bulk density, nutrient availability, potential capacity, organic matter, microbial biomass, carbon and nitrogen content, soil structure, water infiltration, and crop yield.[6] Because of the correlation across properties, a few key attributes could be selected as soil quality indicators and these indicators, or indices, could be used to help predict a soil's ability to perform the three primary functions suggested in the NAS report. Many such combinations of soil attributes have been suggested as indicators of soil quality (Olson, 1992; Hornsby and Brown, 1992; Alexander and McLaughlin, 1992; and Arshad and Coen, 1992). For example, Parr and others (1992) suggest a soil quality index that includes such factors as soil properties, productivity potential, environmental factors, health (human/animal), erodibility, biological diversity, food quality/safety, and management inputs. Many of these factors, such as food quality or biological diversity, are complex indicators themselves but may be important to understanding the full breadth of soil quality. And while the components of soil quality appear quite complex, some soil properties can be estimated without collecting detailed attribute information. For example, Larson and Stewart (1992) use crop residue data and a simple regression model to estimate changes in soil organic matter for several U.S. soils (see Larson and Pierce, 1991, for a review of simple methods that estimate changes in soil properties using minimal, and available, data).

Change in soil quality is a function of many factors, including agroclimatic factors, hydrogeology, and cropping and cultural practices. Soil quality can be degraded through three processes: (1) physical degradation such as wind and water erosion and compaction; (2) chemical degradation such as salinization, acidification, alkalinity, nutrient depletion, and chemical or heavy metal contaminants; and (3) biological degradation, which includes declines in organic matter content and the amount of carbon from biomass and reduced activity and diversity of soil fauna. (National Academy of Sciences, 1993). Selected examples of these processes include:

Physical degradation. Erosion has long been considered an important agent of soil degradation worldwide (National Academy of Sciences, 1993). Erosion has been shown to reduce onfarm soil productivity and contribute to water quality problems as eroded soils carry agrichemicals and byproducts or

---

[5] Physical properties include soil tilth, wind and water erosion, aggregate stability, surface soil thickness, and organic carbon; chemical properties include pH, total plant nutrients, and salinity; and biological properties include microbial and natural processes of respiration, mineralization, and denitrification.

[6] While yield is considered an important component of soil quality, lands of very poor quality as measured by erosion, compaction, salinization, etc., can produce very high yields. Yield per se may mask important environmental or health components of soil quality.

residuals into waterways. Compaction is typically caused by heavy machinery and livestock trampling; soils with low organic matter are particularly vulnerable (World Resources Institute, 1992). "Compaction can make tillage costly, impedes seedling emergence, and decreases water infiltration, causing higher runoff of rainwater and increasing water erosion" (World Resources Institute, 1992). As Arshad and Coen (1992) point out, an optimal degree of compaction is needed for maximum yield growth: high rates of compaction can substantially reduce yields, affecting productivity. For example, Eradat and Voorhees (1990) show that the value of yield losses from compaction in Minnesota, Wisconsin, Iowa, Illinois, Indiana, and Ohio could be as high as $100 million annually.

Chemical degradation. Salinity or salt accumulation in soils can be a problem in arid and semiarid regions where rainfall is insufficient to leach salts from the soil. While salinity problems are often associated with irrigation, salinity problems can also occur in dryland areas. According to USDA's Soil Conservation Service, more than 48 million acres of cropland and pastureland are affected by varying degrees of salinity (USDA, 1989). Irrigated areas are particularly subject to salinization because irrigation water contains dissolved salts, which become more concentrated in the soil as water is consumed by crops or lost by evaporation (USDA, 1989). Some crops, such as corn, soybeans, rice, and some fruits and vegetables, are quite sensitive to salinity—an increase in salinity can lead to significant yield reduction. Acidification, another chemical degradation process, can occur when bases (such as calcium, magnesium, potassium, and sodium) are leached from the soil. Acidity may be reduced by the application of basic material, such as limestone. Acidic soil conditions can limit plant growth and reduce productivity because they supply insufficient calcium or magnesium, alter the decomposition rates of organic matter, and can reduce the amount of nitrogen fixed by legumes (National Academy of Sciences, 1993).

Biological degradation. According to NAS (1993), biological degradation is "perhaps the most serious form of soil degradation because it affects the life of the soil and because organic matter significantly affects the physical and chemical properties of soils." Currently, little is known about the potential cost to the food and fiber system due to biological degradation. The decline in organic matter content of cultivated soils as increased mechanical power has become available is often considered an inevitable consequence of production agriculture. But studies show that the decline in soil organic matter associated with tillage can be stopped and reversed by no-till management (Edwards and others, 1988; Langdale and others, 1992; Edwards and others, 1992). Increases in organic matter content of soils ranging from 100 to 2,000 lb/acre have been achieved under no-till management; these increases are of the same magnitude as the decreases in organic matter measured during cultivation in soils monitored during the last century (Odell and others, 1984; Rasmussen and Smiley, 1989).

Soil Quality and Production Practices

Farm management is a crucial factor in improving and maintaining soil quality and many farmers are already adopting practices that improve soil quality. Although there is no comprehensive USDA soil quality initiative, many USDA programs address specific soil quality factors (see chapters 4 and 6). Practices implemented under these programs often address not only the targeted problems, such as soil erosion, but other soil quality goals as well. For example, the increasing adoption of conservation tillage to reduce erosion often improves water use efficiency and increases biological activity and organic matter content (Karlen, Eash, and Unger, 1992). For many farmers, adoption of conservation tillage has reduced costs while maintaining or increasing yields. Similarly, the use of cover crops (see chapters 4 and 6) helps slow runoff, add organic matter, decrease erosion, and reduce leaching of nutrients and pesticides.

Author: Marlow Vesterby, (202) 219-0422.

Contributors: Robbin Shoemaker, Ralph Heimlich, and Margot Anderson.

References

Alexander, E.B., and J.C. McLaughlin (1992). "Soil Porosity as an Indicator of Forest and Rangeland Soil Condition (Compaction) and Relative Productivity." Proceedings of the Soil Quality Standards Symposium, San Antonio, TX, Oct. 1990. Watershed and Air Management Report No. W0-WSA-2. U.S. Dept. Agr., Forest Service.

Arshad, M.A., and G.M. Coen (1992). "Characterization of Soil Quality: Physical and Chemical Criteria."*American Journal of Alternative Agriculture*, Vol. 7, Nos. 1, 2.

American Agricultural Economics Association Task Force (1986). "Soil Erosion and Soil Conservation Policy in the United States." Occasional Paper No. 2, Iowa State University, Ames, IA.

Bills, N., and R. Heimlich (1983). *Assessing Erosion on U.S. Cropland*. AER-513. U.S. Dept. Agr., Econ. Res. Serv.

Edwards, J.H., C.W. Wood, D.L. Thurlow, and M.E. Ruf (1992). "Tillage and Crop Rotation Effects on Fertility Status of Hapludult Soil." *Soil Society of America Journal* 56: 1577-1582.

Edwards, W.M., M.J. Shiptalo, and L.D. Norton (1988). "Contribution of Macroporosity to Infiltration into a Continuous Corn No-tilled Watershed: Implications for Contaminant Movement." *Journal of Contaminant Hydrology* 3:193-305.

Eradat, O., and W.B. Voorhees (1990). *Economic Consequences of Soil Compaction.* ASAE Paper No. 90-1089. St. Joseph, MI: American Society for Agricultural Engineers.

Granatstein, D., and D.F. Bezdicek (1992). "The Need for a Soil Quality Index: Local and Regional Perspectives." *American Journal of Alternative Agriculture*, Vol. 7, Nos. 1, 2. .

Heimlich, R., and N. Bills (1989). *Productivity and Erodibility of U.S. Cropland.* AER-604. U.S. Dept. Agr., Econ. Res. Serv.

Hornsby, A.G., and R.G. Brown (1992). "Soil Parameters Significant to Pesticide Fate." Proceedings of the Soil Quality Standards Symposium, San Antonio, TX, Oct. 1990. Watershed and Air Management Report No. W0-WSA-2. U.S. Dept. Agr., Forest Service.

Karlen, D.L., N.S. Eash, and P.W. Unger (1992). " Soil and Crop Management Effects on Soil Quality Indicators." *American Journal of Alternative Agriculture*, Vol. 7, Nos. 1, 2 .

Kellogg, Robert, L. , Margaret Stewart Maizel, and Don W. Goss (1992). *Agricultural Chemical Use and Ground Water Quality: Are There Potential Problem Areas?* U.S. Dept. Agr., Soil Conservation Service, Economic Research Service, Cooperative State Research Service, and National Center for Resource Innovations. Dec.

Langdale, G.E., L.T. West, R.R. Bruce, W.P. Miller, and A.W. Thomas (1992). "Restoration of Eroded Soil with Conservation Tillage." *Soil Technology* 5:81-90.

Larson, W.E., and F.J. Pierce (1991) . "Conservation and the Enhancement of Soil Quality." *Evaluation for Sustainable Land Management in the Developing World.* Vol. 2: Technical Papers. Bangkok, Thailand: International Board for Science Research and Management.

Larson, W.E., and F.J. Stewart (1992). "Thresholds for Soil Removal for Maintaining Cropland Productivity." Proceedings, Soil Quality Standards Symposium, San Antonio, TX, Oct. 1990. Watershed and Air Management Report W0-WSA-2. U.S. Dept. Agr., Forest Service.

McCormack, D.E., and R. Heimlich (1985). *Erodible Soils: Definition and Classification*. A & P Staff Report No. 85-2. U.S. Dept. Agr., Soil Cons. Serv.

National Academy of Sciences, National Research Council (1993). *Soil and Water Quality: An Agenda for Agriculture*. National Academy Press, Washington, DC.

Odell, R.T., S.W. Melsted, and W.M. Walker (1983). "Changes in Organic Carbon and Nitrogen of Morrow Plots Soils under Different Treatments, 1904-1973" *Soil Science* 137: 160-171.

Olson, K.R. (1992). "Soil Physical Properties as a Measure of Cropland Productivity." Proceedings of the Soil Quality Standards Symposium, San Antonio, TX, Oct. 1990. Watershed and Air Management Report No. W0-WSA-2. U.S. Dept. Agr., Forest Service.

Parr, J.F., R.I. Papendick, S.B. Hornick, and R.E. Meyer (1992). "Soil Quality: Attributes and Relationship to Alternative and Sustainable Agriculture." *American Journal of Alternative Agriculture*, Vol. 7, Nos. 1, 2.

Rasmussen, P.E., and R.W. Smiley (1989). "Long-term Effects on Soil Productivity and Crop Yield in Semi-arid Regions of Eastern Oregon." Station Bulletin 675. U.S. Dept. Agr., Agricultural Research Service and Agriculture Experiment Station, Oregon State Univ.

Ribaudo, M. (1986). *Reducing Soil Erosion: Offsite Benefits*. AER-561. U.S. Dept. Agr., Econ. Res. Serv. Sept.

U.S. Department of Agriculture (1989). The Second RCA Appraisal: Soil, Water and Related Resources on Nonfederal Land in the United States.

U.S. Department of Agriculture, Soil Conservation Service (1989b). *Summary Report, 1987 National Resources Inventory*. SSB-790. Dec.

__________ (1983). "Application of Soil Information: Soil Interpretations." Part 603. *National Soil Handbook.*

Vesterby, M., and K. S. Krupa (1993). "Effects of Urban Land Conversion on Agriculture." E. Thunberg and J. Reynolds, eds. Southern Rural Development Center and Farm Foundation. SRDC No. 169. Mississippi State Univ., Mississippi State, MS.

World Resources Institute (1992). *World Resources, 1992-1993*. Oxford University Press: Oxford, England.