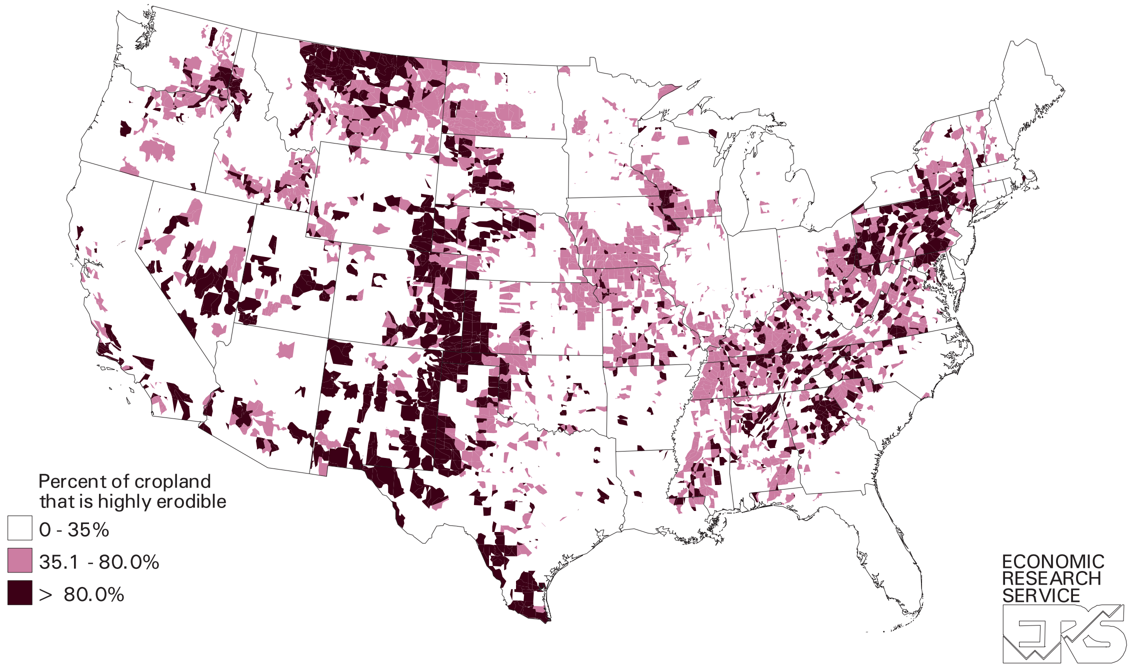
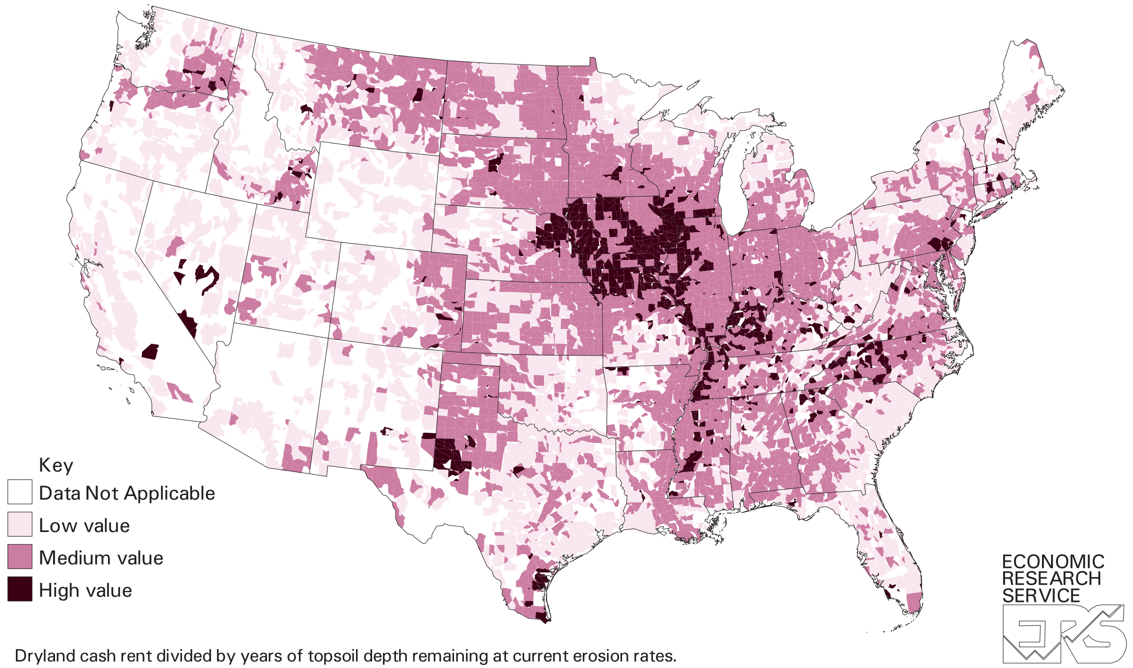
Figure 1.3.4--Distribution of highly erodible cropland on rural, nonfederal land



Source: USDA, ERS, based on NRCS 1992 National Resources Inventory and Soils-5 databases.

Figure 1.3.5--Value of onsite soil productivity loss



Dryland cash rent divided by years of topsoil depth remaining at current erosion rates.
Source: USDA, ERS, based on NRCS 1992 National Resources Inventory.

Highly erodible lands are more vulnerable to soil quality problems, but if erosion is controlled, they may be productive soils. Any soils that are eroding are considered to have lower quality than similar soils that are protected from erosion. Soil quality suffers on eroding soils, but simply controlling erosion does not necessarily translate to high-quality soils since compaction, acidity, salinization, and biological factors play a part in the quality of the soil (Mausbach, 1997).

The 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 (HEL) is defined by USDA as cropland with a natural erosion potential of at least eight times its T-level. According to the 1992 NRI, 124 million acres of cultivated cropland and CRP land are highly erodible from water, wind, or both (table 1.3.1). However, for purposes of administering the conservation compliance provision of the 1985, 1990, and 1992 Farm Acts, USDA's NRCS has classified 146 million acres as HEL, which includes some 22 million acres of other soils in fields that are primarily highly erodible soils (for more information on Conservation Compliance, see chapter 6.4). Highly erodible soils are found in all States (fig. 1.3.4).

Another measure of productivity loss due to erosion converts total erosion from tons per acre per year to inches per year. 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). 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. Low erosion rates or deep, long-lasting 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 in this region, the soil is relatively valuable. A second concentration is the eastern bluffs of the Mississippi River in western Kentucky, Tennessee, and 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 and Central Plateau.

The 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, under 1982 management conditions, agricultural productivity would decline about 3 percent over the next 100 years, due to soil erosion. 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, 1989a). Soil erosion also contributes to off-farm sediment damage, estimated at $2-$8 billion annually (Ribaudo, 1986).

Vulnerability. Interest in soil erosion and its associated costs has been coupled with an increasing interest in the loss of nutrients, pesticides, and salts from farming systems to surface and ground water (NAS, 1993). For example, indices to assess the potential for groundwater contamination related to agricultural chemical use (Kellogg, Maizel, and Goss, 1992) incorporate variables that reflect the propensity of soils to leach pesticides and nitrates. The Ground Water Vulnerability Indexes for Pesticides and Nitrogen are functions of soil leaching potential, pesticide and nitrogen properties, precipitation, and chemical use. 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 (see figs. 2.2.2 and 2.2.4 in chapter 2.2, *Water Quality*).

Land capability classes, prime farmland, and highly erodible land designations are useful in determining how land might be used or the degree and location of erosion, but they are limited in that they exclude other important characteristics of soils and pertain mostly to cropland. 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 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. All these measures can provide policymakers and natural resource managers with 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.

Comprehensive Measures of Quality

Instead of focusing on the capability to support specific activities, such as crop production, or 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. Physical properties include soil tilth, and wind and water erosion; chemical properties include pH, total plant nutrients, and salinity; and biological properties include microbial and natural processes of respiration, mineralization, and denitrification. How do human activities, such as farming, affect the soil and its ability to function in the long run? Eventually, economic analysis could provide estimates of the on- and off-farm costs of soil degradation and the cost of maintaining soil quality.

Most definitions of soil quality include both environmental factors and measures of crop 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 and others, 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, 1993) 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*. 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 rely primarily on one soil quality indicator—soil erosion potential as measured by the EI.

A soil's quality is determined by many 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. Because of the correlation across these properties, a few key attributes can be selected as soil quality indicators (Olson, 1992; Hornsby and Brown, 1992; Alexander and McLaughlin, 1992; and Arshad and Coen, 1992). 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 contributors to 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 information of attributes. 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.

Soil quality is a function of many factors, including agroclimatic factors, hydrogeology, and cropping/production 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 and acidification; and (3) biological degradation, which includes declines in organic matter, carbon from biomass, and the activity and diversity of soil fauna (NAS, 1993).

Physical Degradation. Erosion has long been considered the major agent of soil degradation worldwide (NAS, 1993). Erosion has been shown to reduce onfarm soil productivity and contribute to water quality problems as eroded soils carry agrichemicals and byproducts or residuals into waterways. Another form of soil degradation is compaction, typically caused by heavy machinery and cattle trampling. Soils with low organic matter are particularly vulnerable. Compaction can make tillage costly, impede emergence of seedlings, and decrease water infiltration, causing higher runoff of rainwater and increasing water erosion (WRI, 1992). 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. While salinity problems are often associated with irrigation, salinity problems can also occur in dryland areas where rainfall is insufficient to leach salts from the soil. More than 48 million acres of cropland and pastureland are affected by varying degrees of salinity (USDA, 1989a). 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, 1989a). Crops such as corn, soybeans, rice, and some fruits and vegetables, are quite sensitive to salinity—an increase in salinity can lead to a significant yield reduction. Acidification, another chemical degradation process, can occur when bases (such as calcium, magnesium, potassium, and sodium) are leached from the soil. Aluminum toxicity is also often a problem in acid soils. Acidity may be reduced by the application of basic material, such as limestone. Acidic soil conditions can limit plant growth by supplying insufficient calcium or magnesium, altering the decomposition rates of organic matter, and reducing the amount of nitrogen fixed by legumes (NAS, 1993).

Biological Degradation. According to the 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 how agricultural activities change a soil's biological properties, and the potential cost to the food and fiber system.

It has been estimated that the number of bacterial species in a gram of soil may exceed 10,000 (Torsvik and others, 1990). Probably less than 1 percent of all bacterial species are presently known and there may be up to 1 million different species on earth (ASM, 1994). Biological degradation is important because if the soil food web is disrupted, the soil may not be able to cycle nutrients and transform harmful chemicals or substances to nontoxic waste or to combat plant pests and diseases (Mausbach, 1997).

The microbial community is continually adapting to the environment, and can function as indicators of changes in soil quality. Changes probably occur more rapidly in the microbial community than in other soil characteristics. Methods to assess soil microbial status need to be explored as indicators to further define and measure soil quality (Kennedy and Papendick, 1992).

Land Quality and Resource Policy

The Natural Resources Conservation Service has recognized the importance of soil quality and has established the Soil Quality Institute to acquire and develop soil quality technology. In addition, many Federal programs address specific soil quality factors such as wind and water erosion and nutrient loss (see chapter 6). USDA programs are directed at conducting research on the relationship between farming practices and soil quality, developing new technologies and practices that conserve and protect soil resources, providing technical and financial assistance to adopt soil conserving practices, and protecting farmland through land retirement and conservation easements.

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References

Acton, D.F., and L.J. Gregorich (1995). "Understanding Soil Health," *The Health of Our Soils: Toward Sustainable Agriculture in Canada*, Acton and Gregorich (eds.). Center for Land and Biological Resources Research, Research Branch, Agriculture and Agri-Food Canada, Ottowa, Ontario.

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, Texas, Oct. 1990. Watershed and Air Management Report No. W0-WSA-2. U.S. Dept. Agr., U.S. Forest Service.

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.

American Society for Microbiology (1994). *Microbial Diversity Research Priorities*. Washington, DC.

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

Doran, J.W., and T.B. Parkin (1994). "Defining and Assessing Soil Quality," *Defining Soil Quality for a Sustainable Environment*, SSSA Spec. Pub. No. 35, Madison, WI.

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

Halvorson, Johnathan J., Jeffrey L. Smith, and R.I. Papendick (1997). "Issues of Scale for Evaluating Soil Quality," *Journal of Soil and Water Conservation* 52(1). Jan/Feb.

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, Texas, Oct. 1990. Watershed and Air Management Report No. W0-WSA-2. U.S. Dept. Agr., U.S. Forest Service.

Karlen, D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F. Harris, and G.E. Schuman (1997). "Soil Qality: A Concept, Definition, and Framework for Evaluation," *Soil Science Society of America Journal* 61(1).

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.

Kennedy, A.C., and R.I. Papendick (1995). "Microbial Characteristics of Soil Quality," *Journal of Soil and Water Conservation* 50.

Larson, W.E., and F.J. Stewart (1992). "Thresholds for Soil Removal for Maintaining Cropland Productivity." *Proceedings of the Soil Quality Standards Symposium*, San Antonio, Texas, Oct. 1990. Watershed and Air Management Report No. W0-WSA-2. U.S. Dept. Agr., U.S. Forest Service.

Mausbach, Maurice J., Director—Soil Quality Institute (1997). Personal correspondence. Jan.

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

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

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

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

Pierce, F.J., and W.E. Larson (1993). "Developing Criteria to Evaluate Sustainable Land Management," *Proceedings of the Eighth International Soil Management Workshop: Utilization of Soil Survey Inforamtion for Sustainable Land Use*, J.M. Kimble (ed.). U.S. Dept. Agr., Soil Cons. Serv., Lincoln, NE. May.

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

Seybold, C.A., M.J. Mausbach, D.L. Karlen, and H.H. Rogers (1997). "Quantification of Soil Quality," *Advances in Agronomy*, B.A. Stewart and R. Lal (eds.). Lewis Publishers.

Torsvik, V., J. Goksoy, and F.L. Daae (1990). "High Diversity in DNA of Soil Bacteria," *Applied Environmental Microbiology* 56.

U.S. Department of Agriculture, Soil Conservation Service (1994). *Summary Report, 1992 National Resources Inventory*. July.

U.S. Department of Agriculture, Soil Conservation Service (1993). *Soil Survey Manual*. AH-18.

U.S. Department of Agriculture, Soil Conservation Service (1989a). *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*. SB-790. Dec.

U.S. Department of Agriculture, Soil Conservation Service (1983). "Application of Soil Information: Soil Interpretations." Part 603. *National Soil Handbook.*

U.S. Department of Commerce, Bureau of the Census (1994). *1992 Census of Agriculture*. AC92-A-51, Oct.

Vesterby, M., and K.S. Krupa (1993). "Effects of Urban Land Conversion on Agriculture." *Urbanization and Development Effects on the Use of Natural Resources*, E. Thunberg and J. Reynold, eds. Southern Rural Development Center and Farm Foundation. SRDC No. 169.

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