# A research strategy for assessing the effect of erosion on future soil productivity in the United States

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John Denver, the noted American balladier, became involved a few years back with the Presidential Commission on World and Domestic Hunger. He subsequently wrote a song titled "I Want to Live" expressing his feelings about the great whales, the dolphins, and other aspects of what he considers to be intelligent life on this planet. The album cover conveys most of his feelings:

> I want to live, I want to grow, I want to see, I want to know, I want to share what I can give... and I, each of us has something to give. It ought to be shared; it's what we in the world need from you. It is the most that you can give us. Having been born into this world, you have the right to live. Human rights are much more than just freedom of speech, freedom of press and religion. It is the right to breathe the clean air; it is the right to drink and fill yourself, to cleanse yourself with clean water. It is a right that is denied millions of people today from before their birth. To me, that is the one obscenity in the world, and this song is a positive expression, a humanistic expression against that obscenity.

Such an emotional plea could set the stage for this entire conference. It sets a strong tone for research initiated by the Agricultural Research Service (ARS) to quantify the impact of soil erosion on future soil productivity and to develop conservation practices that help ameliorate potential irreversible consequences of soil erosion on producing food and fiber.

The U.S. Congress in 1977 passed the Soil and Water Resources Conservation Act (Public Law 95-192), commonly referred to as RCA. The law directs the secretary of agriculture to make periodic appraisals of soil, water, and related resources and their conservation on agricultural lands, and to make informed, long-range policy decisions regarding the use and

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protection of these resources. A National Soil Erosion-Soil Productivity Research Planning Committee was appointed within the U.S. Department of Agriculture (USDA) and given three objectives: (1) determine what is known about the problem by (a) defining it, (b) identifying research accomplishments, and (c) identifying current research efforts; (2) determine what additional knowledge is needed; and (3) develop a research approach for solving the problem.

Hagen and Dyke (3) developed a crop yield-soil loss relationship for use in RCA. The relationship provided information for a linear programming model to determine the best national management policies. Although their efforts proved noteworthy as a first attempt to develop a nationally applicable crop yield-soil loss relationship, it was determined that much additional work was needed (*8*).

## Need for erosion-productivity research

Numerous reports conclude that soil losses will reduce future agricultural production (*6, 7, 9*). Most soil and water conservation programs begun in the 1930s remain in place today, although in modified form. Heady (*4*) summarized the history of the soil erosion issue as follows: Following major technological advances in the 1940s, the farm public's concern over soil erosion and degradation declined during the 1950s. However, because of environmental concerns over increasing runoff that caused water pollution and siltation of dams and waterways, concern over soil erosion returned in the late 1960s and early 1970s. Most recently, there has been growing concern within the general public about increasing soil erosion and loss of U.S. soil productivity because of high exports and all-out grain production. Thus, in contrast to the previous decade, when public concern over soil loss was environmental, recent concern is over the soil productivity aspects. The ability of U.S. agriculture to produce increasing amounts of crops while restraining soil erosion and sustaining long-term soil productivity depends largely upon the willingness of society to invest in research and for the farm sector to use improved soil conservation and crop production technology in the future.

Soil productivity basically is the ability of a soil to produce crops. Specifically, it is defined as "the capacity of soil, in its normal environment, for producing a specified plant, or sequence of plants, under a specified system of management" (*11*). Productivity is a function of the soil's chemical, physical, and biological properties as well as climate, management, and other noninherent factors used to produce crops. Under good management, maximum use is made of a soil's fertility status, whether natural or artificial, and physical properties, such as available water-holding capacity, bulk density, and permeability. Recent research (*6*) indicates that as erosion occurs soils with unfavorable subsoil and parent material characteristics exhibit drastic reductions in productivity through the loss of each erosion increment. On other soils, erosion does not rapidly damage their nonreplaceable attributes as a rooting medium, even though they are eroding at extremely high rates.

One of the more dangerous characteristics of the soil erosion-soil productivity problem is the difficulty of detection and whether or not technological advancements have masked soil productivity declines resulting from soil erosion (*4*). Erosion may reduce the productivity of a soil so slowly that it is not recognized until the land becomes economically unsuitable for crop production. At the same time, technologies, such as fertilizers or improved hybrid varieties, may mask soil productivity losses.

A national ARS research planning conference[1] was held in September 1981 at Lafayette, Indiana, to identify the most pressing needs in four thrust areas associated with the problem. The thrust areas were (1) models of soil erosion-soil productivity, (2) experimentation to define the erosion-productivity relationship, (3) water and wind erosion mechanics, and (4) research on conservation tillage. Subsequent material in the conference report discussed the plans, approaches, and progress made in these thrust areas.

**Soil erosion-soil productivity modeling**

In contrast to other thrust areas, a short deadline exists to produce a working model for the 1985 RCA planning process. A working, validated model was needed within 15 months of the Lafayette workshop. The group of scientists/engineers now have a working model referred to as EPIC, the Erosion Productivity Impact Calculator (*13*).

The objective of research for this thrust is to develop a mathematical model for determining relationships between soil erosion and soil productivity. Requirements are (1) to develop an operational model by January 1, 1983, to provide information for the 1985 RCA Report; (2) to expand and refine the 1982 model, mostly developed by linking state-of-the-art components, as research data becomes available; and (3) to emphasize technology transfer so that the model is available to users with documentation to explain its use.

The model is (1) physically based and uses inputs from large data bases, such as those in Soil Conservation Service soil files; (2) capable of continuously, simultaneously, and realistically simulating the processes involved, using a practical time step; (3) generally applicable in the United States; (4) capable of computing management effects and changes; (5) able to interface with economic models; (6) computationally efficient and permit-

[1]Report of the Soil Erosion Soil Productivity Research Planning Workshop, September 22-23, 1981, USDA-ARS, Lafayette, Ind.

ting simulation of a variety of management strategies; (7) capable of simulating long periods (hundreds of years) because erosion processes occur slowly; (8) designed to make decisions for adjusting management strategies as soil productivity changes; (9) designed to allow easy component replacement with improved algorithms; and (10) designed to provide convenient technology transfer to agricultural decision-makers, planners, and researchers.

Model components include the following:

*Climate:* Output consists of daily rainfall, maximum and minimum temperature, solar radiation, and wind.

*Hydrology:* Output from the climate routine is used to compute runoff volume and peak flow, evapotranspiration, percolation, and soil water budgets.

*Erosion-sedimentation:* Using outputs from other model components, wind and water erosion are computed on a daily basis.

*Soil properties.* Soil profiles are divided into layers based upon their pedon description. Properties considered are plant-available water, field water-holding capacity, hydraulic conductivity, bulk density, temperature, slope length and steepness, pH, texture, cation exchange capacity, aluminum concentration, organic carbon, salinity, and exchangeable sodium percentage.

*Nutrient cycle:* The model describes the N cycle processes, including leaching; runoff; immobilization; denitrification; mineralization; crop uptake; inputs from rainfall, fertilizers, and crop residues; and N fixation. Similarly, for the P cycle, processes associated with runoff, crop uptake, fertilizer input, adsorption-desorption, organic transformations, and inorganic P chemical reactions are described.

*Plant growth:* The 11 different crops simulated in EPIC are corn, grain sorghum, wheat, barley, oats, sunflowers, peanuts, soybeans, cotton, alfalfa, and nonlegume forage. The plant growth simulator is temperature-based; it computes leaf-area and total biomass (above and below ground) and considers water extraction, nutrient availability, and daylight length. Growth is limited by the most severe stress caused by water, nutrients, or temperature. Root growth considers soil temperature, oxygen content, bulk density, toxicity, and water content.

*Tillage:* The model accounts for mixing of fertilizers, plant residues, and pesticides in the soil. Further, the model accounts for soil loosening or compaction and fertilizer placement.

*Economics:* The model keeps crop cost budget data and yield, or revenue data essential to decision-making.

*Policy:* The EPIC model can be linked to national analytical policy models, river basin studies, and/or commodity models. Its physical basis, adaptability to new conditions and crops, and widespread testing should afford considerable confidence to policymakers.

Because most tasks developed at the Lafayette workshop have already been accomplished, they are not being enumerated here. As experience with the model is gained, further improvements will become obvious.

**Erosion/productivity experimentation**

At the research planning conference in Lafayette, Indiana, the following objectives for erosion/productivity experimentation were identified: (1) describe techniques and experimental procedures relevant to elucidating the cause of productivity loss associated with erosion, (2) design and develop experiments to quantify soil productivity loss from erosion, and (3) obtain experimental results useful in improving the predictive capability of mathematical models quantifying the extent of productivity loss from varying degrees of erosion.

The experimental approaches identified to quantify effects of soil erosion on soil productivity are physical simulation techniques, including the use of greenhouses and lysimeters; soil removal (scalping); accelerated erosion using field-simulated rainfall and runoff; and use of tracer techniques. Each approach has certain disadvantages for the simulation of the erosion process on soil properties. Cost and possible artificial effects are disadvantages of *greenhouse and lysimeter techniques;* the advantage is that many soil variables and ambient conditions can be controlled, thus permitting study of cause and effect relationships. With *soil removal or scalping techniques,* the mechanical removal of soil is not characteristic of the erosion process because there is no selective sorting of soil materials, which occurs in the natural erosion process, nor is there mixing of materials within the tillage zone. However, well-designed field experiments are possible within a limited range of soil conditions. *Simulated rainfall and runoff techniques* as a means to accelerate the erosion process are feasible at locations having rainfall and/or runoff simulation equipment. This approach can potentially eliminate some objectionable aspects of other techniques used to quantify productivity loss from erosion. For wind erosion, wind tunnels would be used for soil removal. *Tracer techniques* for quantifying soil erosion measure depth from the soil surface to some definable soil profile layer, such as a $CaCO_3$ layer, specific soil horizon, change in parent material, etc. Although economical and rapid, these techniques lack precision, and some soils lack a distinctive soil layer, or the layer is irregular in depth. Another technique is to compare $^{137}Cs$ concentrations in a given depth of eroded soil to that of a comparable noneroded soil. Although promising, use of these techniques requires further development.

Research needs to be designed to meet the needs of objective 2 and/or objective 3 by quantifying effects of erosion on productivity under natural conditions and by quantifying changes in soil physical, chemical, and biological properties caused by erosion for major (benchmark) soils.

Where feasible, determinations of inputs and their costs to compensate for losses in productivity from erosion should also be determined.

Quantifying erosion's effects on soil productivity using natural areas as experimental sites incorporates effects of past management and progressive erosion on productivity. Landscape position for experimentation is a major consideration. A major problem is determining how much erosion occurred previously. Carefully designed experiments are needed because so many factors influence productivity. Minimum experimental information needed includes detailed descriptions of soil profiles at the site, water supply and soil water relations, soil chemical and physical properties, plant measurements, temperature conditions, and soil and plant management details.

Quantifying changes in soil physical, chemical, and biological properties as a result of erosion and how these changes influence productivity requires a careful, coordinated effort for the selection of soils and experimental research sites. This phase of the research is targeted on representative benchmark soils selected from major land resource areas (MLRAs) on which erosion's effects are most severe (*10*). When possible, existing plots established for universal soil loss equation (USLE) research, or plots selected so that as much previous cropping, erosion, and management information are available, are to be used. Wind erosion is being evaluated under ustic and aridic moisture regimes. Major agronomic cropping systems, crop selection, and cultural practices are being coordinated.

Of increasing importance to policy and other decisions at national and state levels are the inputs required to compensate for loss of soil productivity from erosion and the cost of these inputs. It may be possible to maintain crop yields or even increase them by the addition of inputs that compensate for potential productivity losses. Types of costs incurred by losses in productivity involve consideration of crop sequence, residue management, water infiltration rates, water-supplying capacity, soil fertility, changes in soil chemical and physical properties, pesticide use, and energy requirements. Research is needed on costs and inputs for control of soil erosion in crop production systems and inputs necessary to maintain soil productivity as erosion progresses.

Participants at the Lafayette workshop determined tasks for each of the research approaches for the erosion-productivity experimentation and developed a national plan. A total of 29 tasks in 19 states were identified. MLRAs were well represented, as were national issues, with some tasks developed specifically for national or regional laboratories.

Although initiation of research following the workshop has been slow because of resource limitations, encouraging research projects are in progress. The urgency of such research is obvious because the duration associated with climatic sampling is often great.

### Water and wind erosion mechanics

Soil erosion by wind and water have been recognized as major problems for agricultural resource management for decades. Much research to quantify the magnitude of erosion as a function of climate, soil, topography, and alternative management systems has been completed. However, today's needs are not being met. For example, complex topography often is ignored in favor of making measurements on a uniform slope.

Digital computers permit large amounts of data to be handled and multiple computations to be performed efficiently. Thus, new experimental erosion programs, not envisioned in experiments leading to development of the USLE (*14*) and the wind erosion equation (WEE) (*9*), are required.

Objectives for this research thrust include the development and improvement of mathematical relationships to (1) estimate erosion and deposition rates, (2) describe the soil property changes caused by soil erosion as they relate to plant growth, and (3) describe the selective removal, by erosion, of key soil constituents (soil fines, organic matter, and nutrients).

A series of short-term wind and water erosion tasks were identified that were needed for development of the EPIC model. These tasks, now completed, have been incorporated into the model. The specific tasks were to facilitate use of the USLE and WEE in EPIC. Some examples of the types of problems included the following: Modifying the WEE for integration into the daily mode used in EPIC; developing the soil loss ratio relationships used in the USLE for daily simulation, using an algorithm to reflect tillage roughness and crop stage; developing and evaluating residue decomposition algorithms that give realistic C factors for the USLE; and participating in the evaluation of the water and wind erosion simulations for EPIC.

Tasks identified as essential to accomplish the objectives over a longer time frame are:

*Task 1.* Improve wind erosion prediction and control technology.

*Task 2.* Improve water erosion prediction and control technology.

In both tasks 1 and 2, there are pressing needs to reassess problems of using current hydrodynamic relations as a replacement for the USLE and WEE. In many instances, new experiments are needed to define model parameters for current agronomic and conservation practices. Although time-consuming, such an approach has great potential for improved resource management and conservation. Erosion model development using the fundamental physical laws is required when erosion loss estimates are needed from individual storm events.

*Task 3.* Develop improved ways to assess erosion effectively and efficiently over complex areas. Opportunities for improved assessment technology include the use of remote sensing and geomorphic relationships, and work is being initiated.

*Task 4*. Relate the processes of soil detachment by raindrop impact and surface flow to stress-deformation properties of soils. Development of improved rill and interrill detachment equations is needed to quantify more accurately the effects of tillage, cropping sequences, and residue management on a variety of soil physical and chemical properties.

*Task 5*. Develop improved relationships for sediment transport and deposition by overland flow. Current technology generally has resulted from experiments where the hydraulic roughness was small relative to the flow depth. Thus, transport relationships must be developed for specific application to the shallow flow phenomenon.

*Task 6*. Determine the effect of water and wind erosion on soil properties important for crop growth. Eroding soil generally carries significant amounts of agricultural chemicals that are lost for subsequent crop production. Research must define how erosion affects soil fertility with different management practices.

Although the short-term objectives have been accomplished, research on the long-term objectives needs to be implemented immediately. Perhaps of greatest urgency is the need to develop second-generation erosion equations that will replace the USLE and WEE. These new erosion relationships are especially important for applications involving erosion estimates for complex topography and from individual storm events.

## Conservation tillage

Conservation tillage is perhaps the most significant technology developed for producing crops while controlling erosion. Conservation tillage was used on about 35 million ha of U.S. cropland in 1980, up from 12 million ha and 1 million ha in 1972 and 1963, respectively (*15*). Yet, such tillage systems are being accepted much slower than is consistent with the need. Here, we define conservation tillage as "any tillage system that reduces loss of soil or water compared to unridged or clean tillage (clean tillage is cultivation of a field so as to cover all plant residue and to prevent the growth of all vegetation except the particular crop desired)" (*11*).

As action agency efforts intensify to encourage acceptance of conservation tillage, increased emphasis on cultural techniques that retain protective amounts of residue mulch year-round and increased roughness on the soil surface is likely, and these criteria may become an accepted part of the definition of conservation tillage. But conservation tillage is not a panacea for solving all soil erosion problems. For example, the flat, dark soils of Indiana, Ohio, and Illinois produce lower crop yields under surface residue systems than under conventional tillage.[2] Other erosion con-

[2]Moldenhauer, W. C. 1976. "Tillage Systems: Scope and Severity of the Problem," a paper presented at the North Central Region Tillage Research Workshop, Council Bluffs, Iowa.

trol measures frequently needed include cover crops, rotations, contour and stripcropping, ridges, terraces, grassed waterways, and permanent structures along waterways. Despite widespread adoption of conservation tillage, some scientists predict that future growth in exports of grains and soybeans will result in gross sheet and rill erosion that is 85 percent more in 2010 than in 1977 (*1*).

Many forms of conservation tillage, including stubble-mulching, reduced or no-till, rough seedbeds, and similar practices, are excellent methods for soil erosion control. But acceptance of the methods from state to state and region to region varies. Many technical problems reduce or inhibit acceptance. Among these are pest control, poor surface drainage, delayed planting, poor germination and emergence, inadequate machinery design to prevent plugging or to facilitate machinery adjustment to changing conditions, improper fertilizer placement, nonoptimum soil temperatures, soil compaction, excessive time for planting operations, and excessive soil surface acidification.

Three major problems facing conservation tillage research are (1) regional or local autonomy, (2) lack of sufficient unifying concepts to guide conservation tillage research in general, and (3) failure to use multidisciplinary approaches. Inadequate support for such research is also a problem. This support issue must be resolved for conservation tillage technology to be developed effectively and to be accepted as one of the principal solutions to soil erosion.

*Regional or local autonomy.* Workshop participants recommended using tillage-related models, coupled with nationally coordinated field experimentation, to generalize technology. Effects of soils, climate, topography, and cultural systems on the forms of conservation tillage suitable for best management of soils, plants, water, and pests must be understood for effective technological advances and transfer from one part of the United States to another.

*Unifying concept to guide tillage research.* Crosson and Miranowski (*1*) identified a major aspect of many years of conservation tillage research without national focus, unifying concepts, and adequate identification of key researchable issues. Specifically, the distinction between on-farm and off-farm damages from erosion has important implications for the development of conservation tillage technology and the key researchable issues. Thus, selection of target research issues for conservation, based only on gross soil loss, likely will not serve the objective of protecting soil productivity, although off-farm damages may be reduced. Addressing the issue of unifying concepts requires the use of tillage-related models that are coordinated and validated nationally with experimental data from MLRAs.

***Multidisciplinary research approach.*** Scientists participating in the conservation tillage workgroup at Lafayette recognized the importance of multidisciplinary research, and they made recommendations accordingly. Within ARS, conservation tillage research occurs within various national research programs. To coordinate the ARS effort and to encourage teams of scientists to work together on conservation tillage research, a conservation tillage coordinating team has been established within the ARS headquarters staff. The need for multidisciplinary research is great, and programs to facilitate such will continue.

The objectives of the conservation tillage research thrust are to (1) assess potential suitability of conservation tillage nationwide on the basis of existing technology and (2) improve and systemize research techniques for incorporating conservation tillage technology into conservation production systems appropriate to each MLRA.

For the first of the above objectives, the approach is to use model techniques and existing resource information to develop soil productivity indices and to show where conservation tillage is suitable. Then the impact that conservation tillage would have on soil erosion in the United States will be shown. To accomplish the first objective, the following tasks have been assigned:

*Task 1.* Determine the productive potential of soil as affected by removal of surface soil layers.

*Task 2.* Classify soils on the basis of their suitability for conservation tillage.

For the second of the above objectives, tillage-related models will be used with field observations to generalize technology nationwide. Successful task activities will make it possible to account for soils, climate, topography, and cultural system effects on forms of conservation tillage suitable for best management of soil, plant, water, and pests. Tasks contributing to generalized nationwide information include the following:

*Task 1.* Predict and verify the joint effects of soil, weather, tillage, and residue management on soil water content as affected by conventional and conservation tillage.

*Task 2.* Improve planting and fertilizer machinery performance for conservation tillage systems.

*Task 3.* Develop and adopt special-purpose chemicals to assist in conservation tillage.

*Task 4.* Develop algorithms to estimate the C factor in the USLE to reflect the effect of conservation and conventional tillage systems for resource modeling.

*Task 5.* Develop algorithms for estimating soil reflectance as related to color and roughness, impacts of surface residue cover on total reflectance, soil temperature response to reflectance, and erosion effects that expose subsoils of different color.

*Task 6.* Develop technology to define crop residue decomposition and soil microbial relations in tillage systems and relate these to nutrient immobilization and release.

*Task 7.* Soil compaction may impair the success of conservation tillage systems. Information is needed to assess the ultimate impact of compaction on water flow, aeration, and packing susceptibility in conservation tillage systems.

*Task 8.* Phenology schemes will be used to trace the early development of major annual crops and for identification of stresses in crop growth with conservation tillage.

Because much field research and validation are necessary and because the experimental phases of this research are only now being initiated, actual data on a nationwide basis cannot be reported.

Although some research to fulfill the objectives of this thrust are underway, they are largely site specific and lack a unified thrust. New research to overcome these objections is being initiated to overcome the limitations described above and to aid in the widespread acceptance of conservation tillage for erosion control.

## Summary

Demographic projections into the 21st century, for both the United States and planet Earth, indicate increasing needs for food and fiber production. Furthermore, if the United States continues to export greater amounts of grain, most available land will eventually be farmed. Maintenance of soil productivity must therefore be ensured.

The research described to quantify soil erosion-soil productivity is formulated to provide a national perspective for the problem. Some facets of the new research are already underway; others are being planned or require availability of new resources. The EPIC model, which is in its final phase of testing, will allow for significant improvement in projections for the 1985 RCA report over those in the 1980 report.

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## REFERENCES

1. Crosson, P., and J. Miranowski. 1982. *Soil protection: Why, by whom, and for whom?* J. Soil and Water Cons. 37: 27-29.

2. Davis, R. M. 1977. *Soil conservation on agricultural land: The challenge ahead.* J. Soil and Water Cons. 32: 5-8.
3. Hagen, L. L., and P. T. Dyke. 1980. *Merging resource data from disparate sources.* Agr. Econ. Res. 32(4): 45-49.
4. Heady, E. O. 1982. *Trade-offs among soil conservation, energy use, exports, and environmental quality.* In H. Halcrow, E. O. Heady, and M. L. Cotner [eds.] *Soil Conservation Policies, Institutions and Incentives.* Soil Cons. Soc. Am., Ankeny, Iowa.
5. Langdale, W. W., and W. D. Shader. 1982. *Soil erosion effects on soil productivity of cultivated cropland.* In *Determinants of Soil Loss Tolerance.* Am. Soc. Agron., Madison, Wisc.
6. Larson, W. E., F. J. Pierce, and R. H. Dowdy. 1983. *The threat of soil erosion to long-term crop production.* Science 219 (4584): 458-465.
7. Larson, W. E., L. M. Walsh, B. A. Stewart, and D. H. Boelter. 1981. *Soil and water resources: Research priorities for the nation.* Soil Sci. Soc. Am., Madison, Wisc. 229 pp.
8. National Soil Erosion-Soil Productivity Research Planning Committee. 1981. *Soil erosion effects on soil productivity: A research perspective.* J. Soil and Water Cons. 36: 82-90.
9. Schmidt, B. L., R. R. Allmaras, J. V. Mannering, and A. I. Papendick. 1982. *Determinants of soil loss tolerance.* Spec. Publ. No. 45. Am. Soc. Agron., Madison, Wisc. 153 pp.
10. Skidmore, E. C., and N. P. Woodruff. 1968. *Wind erosion forces in the United States and their use in predicting soil loss.* Agr. Handbk. 346. U.S. Dept. Agr., Washington, D.C. 42 pp.
11. Soil Conservation Service, U.S. Department of Agriculture. 1981. *Land resource regions and major land resource areas of the United States.* Agr. Handbk. 296. Washington, D.C. 156 pp.
12. Soil Conservation Society of America. 1976. *Resource conservation glossary.* Ankeny, Iowa.
13. Williams, J. R., K. G. Renard, and P. T. Dyke. 1983. *EPIC: A new method for assessing erosion's effect on soil productivity.* J. Soil and Water Cons. 38(5): 381-383.
14. Wischmeier, W. H., and D. D. Smith. 1978. *Predicting rainfall erosion losses: A guide to conservation planning* Agr. Handbk. 537. U.S. Dept. Agr., Washington, D.C. 58 pp.
15. Wittwer, S. 1982. *New technology, agricultural productivity, and conservation.* In H. Halcrow, E. O. Heady, M. L. Cotner [eds.] *Soil Conservation Policies, Institutions, and Incentives.* Soil Cons. Soc. Am., Ankeny, Iowa. pp. 201-215.