#762

PROCEEDINGS OF SOIL EROSION AND PRODUCTIVITY WORKSHOP

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762

4

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TOOLS FOR CONSERVATION

STATEMENT OF PROBLEM: Field and soil management systems are needed to control erosion, to achieve production on soils damaged by erosion, and to manage successfully the heterogeneous mixture of soils that has been created. Research information from a variety of sources must eventually come together in a package(s) that can be used in assessments and for management decisions. This work group listed and acknowledged the management techniques and considered how the information should be packaged. Certain assumptions must be made on future technology related to digital elevation models, hydrologic, erosion, deposition, and sediment yield predictions, or if assumptions can't be made, the work group should identify the capability that such technology might embody.

Based on the assumptions that the work group made concerning the erosion prediction technology, the group made recommendations on how the *productivity information* or technology should be packaged in analytical procedures that can be used to express conservation planning goals. These packages might be simple mathematical expressions, physically-based simulation models, expert systems, and qualitative expressions.

INTRODUCTION

With the approach of the 21st Century only a decade away, projections regarding "What life will be like" and " What we can expect in different segments of our environment" have become popular topics. Because many of us are concerned with some aspects of agriculture, articles such as those in the November 1988 issue of DISCOVER (Volume 9, Number 11) merit thought and discussion regarding their "Agriculture 2001" article. In other predictions such as those in OUTLOOK '85, the Annual Agricultural Outlook Conference sponsored by USDA, emphasis involved economic projections, farm policy, trade issues, etc. Conspicuously absent from these projections are discussions of technology for conservation and specifically, those associated with how future farming practices might affect erosion, protect the soil resource for future food and fiber production, minimize the off-site consequences of erosion, transport of agricultural chemicals, and preserve the quality of water.

The tools for conservation are numerous and involve agronomic, mechanical and engineering practices that alter the hydrologic and erosion cycle. These conservation tools are more or less site specific because their success varies for different climate, soils, topograph, crop conditions, and management preferences. Furthermore, the tools vary for cropland, irrigated land, range and forest land, and disturbed land. Finally, discussions of tools for conservation must address current and future assessments of conservation programs using analytical tools: with simple tools like the Universal Soil Loss Equation (USLE), and the Wind Erosion Equation (WEE), and varying to more complicated physically based models such as WEPP, EPIC, PI, WEQ (the acronyms will be explained later).

SOIL MANAGEMENT SYSTEMS FOR EROSION CONTROL

The conservation movement in the U.S. had much of its beginning during the "dust bowl era" of the early 1930's under the enthusiastic leadership of H.H. Bennett. The conservation ethic evolving during that era, continues even today despite intervening peaks and troughs in funding support at the federal and local levels. Recent public opinion polls reveal that a large majority of the public has concerns about the environment, especially water quality. Whereas much of the early work was sponsored in the U.S. Department of Agriculture, subsequent work has included other federal departments such as the Department of Defense, the Department of Interior, and the Environmental Protection Agency. At the same time, state and local conservation agencies have been created to enforce federal and local legislation for erosion control and water quality protection.

The evolution of legislation for conserving natural resources, protecting the environment, and controlling pollution has led to a proliferation of research approaches and the development of many agronomic practices and mechanical tools to promote infiltration and control soil erosion. Engineering approaches to erosion control are generally appropriate for off-site applications such as those associated with movement of excess water in channels and the associated control of water velocity to control erosion of channel bank and bed. Table 1 lists some commonly used erosion control practices for land use such as are encountered on cropland, irrigated land, rangeland, forest land, and disturbed areas. The table includes vegetative, structural, and management approaches for erosion control.

Vegetative

Agronomic practices are among the first used in control of water erosion since crop rotation, cover crops, and strip crops are easily implemented, and usually have a favorable benefit/cost ratio. With increased use of commercial fertilizers and specialization of farm enterprises, these practices were gradually abandoned in favor of higher income row crops. The cycle, however, seems to be returning to these agronomic practices due to increased fertilizer and pesticide costs and to the increased attention to low input agricultural systems. Crop residue use, conservation tillage, crop rotations, buffer strips and field windbreaks are now regaining popularity as management practices that both control erosion and increase profitability.

Agronomic practices protect against soil loss by maintaining cover of the bare soil during the erosive periods, and maintaining organic matter and soil structure.

Table 1. Wind and water erosion control practices.

Land Use	Vegetative	Management	Structural
CROPLAND	Cover crops Rotations Conservation tillage Wind breaks Filter strips Crop residue management	Tillage equipment Slot mulch Contour farming Surface roughening Emergency tillage Bank stabilization	Terraces—graded, level Grass waterways Detention basins Grade control Mechanical plantings
IRRIGATED	Cover crops Rotations Conservation tillage Wind breaks Filter strips Crop residue management	Level basins Drip irrigation Sprinkler irrigation Subsoiling Land forming practices	Grade control Turnout structures Water conveyance structures
RANGE	Cover crops Brush management Range seeding Deferred grazing Proper grazing use	Subsoiling Grazing land Mechanical treatment	Grade control structures Water spreading Detention basins
FOREST	Brush management Forest land management Cover crop after fire	Brush Windrows Clear cutting Balloon/helicopter harvest	Grade control Detention basins
DISTURBED	Reseeding Grass establishment Fertilization Mulching Critical area planting	Topsoil replacement Contour roughness	Grass waterways Detention basins

Cover crops or surface mulches protect the soil surface against the forces of wind and rain drop impact, and the delitereous effects of surface runoff by reducing water velocity. Cover crops and surface mulches also help to maintain high infiltration rates. Additionally, field wind breaks provide vegetative barriers to the force of wind. Crop rotations with close grown crops as part of the rotation help reduce long term average soil loss. Erosion may continue to be serious during row crop years but is reduced by increased aggregate stability and humus in the tilled zone.

Conservation tillage has become popular because of high fuel costs for other systems and resistance of farmers to engineering practices such as terraces. Contour farming continues to be used in certain areas for control of erosion. It is most effective when combined with strip crops and residue management practices. Crop rotations, use of sod crops on earthworms and other soil biota improve soil macroporosity and thereby increase infiltration. Surface roughening is another management practice for control of wind erosion.

Most structural practices are for control of water erosion. These include graded and level terraces, grassed waterways, detention basins, subsurface drains, and grade and bank stabilization structures. These engineering practices deal mostly with control of surface runoff water and are normally used in conjunction with the mechanical and agronomic measures to control water erosion.

Irrigation

Agronomic practices for control of erosion on irrigated land are the same as those listed previously for cropland except for strip crops. Mechanical and engineering practices that deal with the control of water flow or application of water, include irrigation practices such as level basins, drip, sprinkler; dams and dikes; and land forming practices. Conveyance systems relate to delivery systems and erosion control associated with the irrigation systems but not necessarily to erosion due to crop production.

Range

Brush management and range seeding practices are used to control erosion and improve soil moisture on range lands by increasing surface cover of desired species and increasing infiltration. Proper grazing practices increase the quality and quantity of range vegetation which results in increased infiltration and less runoff. Mechanical practices such as subsoiling and grazing land management help increase infiltration by loosening the upper soil layers. Management of riparian areas on rangeland prevent gully formation and bank sloughing. Engineering practices relate to control of surface runoff and in some areas, to spreading surface water over broader areas to increase infiltration of the otherwise excess water.

Forest

Forest management practices include forest establishment, stand management, pest management, grazing management, water conservation, and fire management practices, all of which maintain or improve forest productivity and indirectly control water erosion. Mechanical practices involve brush control and harvesting procedures to minimize soil disturbance and erosion. Engineering practices again relate to control of surface runoff and include, in addition to diversions, proper road construction and harvesting procedures.

ANALYTICAL TOOLS TO EVALUATE SOIL EROSION CONTROL

Most scientists and engineers concerned with soil erosion are familiar with the many developments in personal computers since the first modern personal computer (PC) came on the market in 1975. As DISCOVER (1988) points out, the original system was primitive considering the capability of present day PCs. These technological advances have contributed significantly to our ability to address wind and water erosion process prediction and the planning for and evaluation of conservation programs. Yet at the same time, many conservationists lag seriously behind in computer literacy with the result that planning conservation programs for erosion control by wind and water are hampered by an inability to use the best technology available. Extensive training programs will be required to train staff(s) in the use of new process based models such as RUSLE, WEPP, and WEPS. These models require the use of computers to integrate and solve process related mathematical expressions. At the expense of creating a wrong impression, computers do not control erosion. Rather computers afford the opportunity to estimate where erosion or pollution might be a problem and assist the conservationist and producer in evaluating possible soil management strategies that control erosion, sustain productivity, and provide economic returns. While computer hardware has been dramatically increasing in capability and affordability, software has been making similar, although not as obvious, strides. One of the most exciting developments has been in the area of artificial intelligence (AI). The possibilities opened up for using qualitative as well as quantitative reasoning are obvious in the areas of hydrology, erosion, and water quality. Through the use of AI and a concept known as "blackboarding", knowledge and databases can be combined with simulations, GIS, and other programs to produce an overall "expert" where there was none.

It seems fairly safe to say that erosion prediction and control technology has not kept abreast with developments in the computer area. Whereas personal computing power (measured by calculations per second) has increased by a factor of 10,000 since 1975, wind and water erosion are still generally estimated by simplistic regression models such as the Wind Erosion Equations (WEE) (Skidmore & Woodruff, 1968) and the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978). This technology was based on research prior to the advent of modern computing capability and was designed for easy use by conservationists in the field. The technology is currently being upgraded by ARS scientists working with other government agencies and university cooperators. Data with which to parameterize and validate the models is still a problem. The anticipated deadline for widespread use of the new technology is early in the 1990's when land management agencies anticipate having computers at the local planning level.

Table 2 lists, sequentially, the technology available for estimating water and wind erosion for conservation planning. Of special interest are the current development of new technology to upgrade the USLE and WEE.

In the water erosion technology, the original USLE has been modified by Williams (1975) to produce a sediment yield estimating tool, i.e., the rainfall-runoff erosivity term R was replaced by a runoff term, $aQ(q_p)^m$, and by Foster and Onstad (1977) where R was replaced by a term $E = (aR + bQq_p^m)$ with $a + b = 1$ to better quantify splash derived erosion and runoff derived erosion. (a and b are coefficients; R = EI as estimated by Wischmeier and Smith, (1978); Q = runoff volume; and q_p = peak runoff rate.) Furthermore, the USLE was revised by

Wischmeier and Smith (1978). Other changes in each of six factors in USLE and computerization are being made in another revision called RUSLE, the 1990 revised USLE.

Table 2. Water and wind erosion prediction technology

Abbreviation	Title and Reference	Date
USLE	Universal Soil Loss Equation Agric. Handbook #282 and #537	1965, 1978
MUSLE	Modified Universal Soil Loss Equation ARS-S-40	1975
Foster et al. USLE	Runoff erosivity factor USLE Trans. ASAE 20(4):683-687	1977
ANSWERS	ANSWERS: A model for watershed planning Trans. ASAE 23:938-944	1980
CREAMS	Chemicals, Runoff, Erosion and Agricultural Management Systems USDA-SCS Conservation Research Report #26	1981
RUSLE	Revised Universal Soil Loss Equation USDA-ARS & SCS	1990
WEPP	Water Erosion Prediction Project Hillslope version Watershed version Grid version	 1989 1990 1990
OCP-WEPP	Operational computer version WEPP (hillslope)	1990
WEE	Wind Erosion Equation Agriculture Handbook #346	1968
WEQ	Revision of Wind Erosion Equation USDA-SCS Agronomy Manual #190-V-NHM	1988
WERM	Wind Erosion Research Model USDA-ARS	1991
WEPS	Wind Erosion Prediction System	????

In the case of the WEE, there have not been any major revisions or updates of the technology except for professional papers proposing additional values of individual factors to permit applications to additional crops or new geographic areas. Some minor improvement have been included in the USDA-SCS Agronomy Manual 1988.

The Water Erosion Prediction Project (WEPP) consists of three distinct models: a hillslope version, a small watershed version, and a grid model. Whereas the USLE (and RUSLE) has many conceptual problems (being a regression model), the WEPP model is physically based and includes a hydrologic/climate model as drivers of the process-based erosion mechanics. Furthermore, whereas USLE is applicable only to slope segments to the point where deposition begins, the WEPP model uses fundamental equations for sediment detachment, transport, and deposition so that the sediment can be routed (and mass balance maintained) to a point on a permanent stream system. Thus it will be possible to estimate sediment yield at some point in the stream system without the empiricism of using the USLE with a sediment delivery ratio. This new technology, in addition to being conceptually more sound than the USLE, permits combining hillslope erosion with ephemeral gully and channel erosion in such a way that the processes of erosion/transport/deposition will be estimated with a hydrologic model as a driving mechanism. The intensive data requirements and calculations needed to accomplish the more detailed assessments, are made possible with a personal computer (PC) or a minicomputer. The entire conceptualization, parameterization, and documentation have been done in such a way that the model is robust and applications can be made to prototype solutions where the experimental work might not have been performed.

Major enhancements in WEPP over the USLE are the inclusion of a hydrology component based on the Green and Ampt (1911) infiltration equation, kinematic routing of precipitation excess over the land surface and in concentrated flow areas, and partitioning of precipitation excess between interrill and rill areas. Furthermore, WEPP uses plant growth and residue accumulation and decay components, tillage routines, and their affect on soils, and water balance calculations. A major improvement has also involved the use of disaggregation of rainfall data. Whereas daily rainfall is the major climatic variable available in most places, the model requires rainfall intensity data, and procedures were developed to disaggregate daily rainfall amounts into individual storms and intensity patterns.

The technology currently used for predicting wind erosion in the U.S. is based on variations of the Wind Erosion Equation (WEE), Table 2. This technology uses erosion loss estimates that are integrated over large fields and long time scales to produce average annual values. The technology is mature and not easily adapted to new or untested conditions or to address new problems associated with new legislation. As in water erosion, widespread availability of personal computers has led to research to adopt flexible, process-based technology to assess and plan conservation practices for wind erosion control.

As in the water erosion technology, USDA has a major program underway to develop new wind erosion technology. But unlike the water erosion, the model development for wind erosion has two major stages: the first stage is to develop a wind erosion research model (WERM) which will lead to a second stage, the wind erosion prediction system (WEPS, Table 2). In this second stage, the submodels of WERM will be reorganized to increase computation speed, data bases will be expanded in size, and a user-friendly input-output section will be added to make the technology of greater utility to users.

WERM is modular and consists of a supervisory program and five submodels (climate, hydrology, decomposition, crop, tillage, soil, and erosion), along with a data base, reflecting the fundamental processes occurring in the field. The submodels permit easy testing and updating during the technology development. Finally, as in the WEPP technology, extensive experimental work is being carried out simultaneously with model development and is devoted to delineating parameter values that facilitate application of the algorithm to both measured and unmeasured processes (Hagen, 1988; Hagen et. al. 1988).

FUTURE ISSUES WITH CONSERVATION TOOLS

To fully utilize the erosion control options available for conservation planning and to couple wind and water erosion predictions models based on landscape, soils and climate data attributes, with predictive capacity and management optimum control and profit requires additional developments. The devel required include: (1) data base development to validate prediction model permit evaluation of agronomic, mechanical, and engineering practices in prediction technology such as WEPP and WEPS; (2) analytical tools and dures such as geographic information systems, expert systems, digital e models, fuzzy set models, climate data, and probabilistic representation of r (polygon) characteristics; and (3) economic evaluation models to permit a of appropriate conservation practices that optimize return within the con individual producers while meeting environmental/pollution risk criteria to the environment and natural resources. Such technology must be packaged the land manager/owner working in concert with the conservationist can e the suite of conservation systems and can query the system with a series o if' situations that meet both legislative and management constraints. Th quirements present a formidable challenge whose solution rests with devel of expert systems that integrate causal effects of conservation practices erosion to the economics of producing a crop and to subsequent effects o quality/quantity. With the tremendous advances in computer technolo considerable effort of research scientists and conservationists, such a system be practical by the turn of the century.

Data Bases

To facilitate use of the new wind and water erosion prediction techn model parameter values must be developed and the necessary attribut collected. Techniques need to be developed to relate model parameters to phy measured finite combinations of climate, soil, cropping systems, and conser practice factors. However, the model inputs and attribute data needed m within the resources of agencies to collect or verify.

Data collected during the National Cooperative Soil Survey represen vidual pedons (laboratory data and descriptions), soil series (soil interpret record, official soil series description), and map units (file map unit interpre record). The data must be supplemented, integrated, and extended to rep specific map units or polygons for use in geographic information systems and systems. Additionally, a central or representative value for each attribut measure of dispersion is needed to generalize the more specific data at the se map unit component level to the areal polygon or field level.

Local county data bases should be developed to collect the temporal s properties that are critical to erosion prediction such as crusting, bulk densit surface aggregates with respect to climate, crop management, and time of ye these time variant data are accumulated, systems and procedures to summari properties are needed to satisfy the input requirements of the predictive mo

Analytic Tools

Parallel to the developments in computer hardware have been developme computer software such as geographic information systems (GIS), digital elev models (DEM), and expert systems (ES). These tools will allow developmen display of alternatives by conservationists/operators. Combining digital elev models with soil maps should permit 3-dimensional views of soils on lands and display wedges of soil that could be lost as predicted by WEPP and W However, these software tools are stressing the attribute data of present d databases such as the soil map which is the base from which all models run. More robust methods of representing the variability of soil properties within polygons (delineations) must be developed, perhaps to present a probabilistic representation of the properties. This same approach could then be extended to fields or watersheds. Combined with climatic probabilities, systems could be developed according to erosion risks and systems designed to control the risks similar to flood control systems.

The analytical tools and expert systems must be able to integrate all ramification of a resource management system such as the effects of erosion control practices and crop management systems on water quality and the soil ecosystem. These ramifications are so extensive that only a computer will be able to sort them out and present tradeoffs for each conservation system and crop management system.

ECONOMIC EVALUATION

In many cases, criteria for an economic analysis of erosion control strategies are not available. In other instances, factors such as esthetics criteria or constraints, and associated legislative mandates or social concerns make it difficult to assess alternatives. Tools such as the Erosion Productivity Impact Calculator (Williams et al., 1983) and productibility indices (PI) as proposed by Pierce et al. (1983) provide methods for developing an improved and scientifically based tolerance limit of erosion for both on-site and off-site situations. Other methods or models will be required to develop limits for off-site erosion/sedimentation and for water quality/quantity concerns. Likewise water conservation may not be compatible with flood control. In short, the problems inherent in planning and management of complex socio-technical systems involving imprecise and usually vague data must be minimized by the tools developed. A possible tool to assist with such problem definition is the 'fuzzy-set' theory in systems engineering or probabilistic and risk management approaches used by the National Weather Service and the EPA, respectively. Planning goals may require multiple standards for soil erosion depending on the resource concerns such as on- or off-site, water quality, sediment movement, or other environmental impacts; and risks that society is willing to adopt for these concerns.

SUMMARY

The expanding computer technology and associated software is providing the opportunity to design more comprehensive and complex procedures for assessing erosion and presenting alternatives for control of erosion and protection of air and water quality. New models for wind and water erosion will require additional attribute data for map units and will require additional research data for parameter development. Databases to collect and facilitate the summary for time and space variant data are required for accurate prediction of erosion. These models and databases must be integrated in an expert system to adequately assess all interactions and to provide appropriate economic analysis of resource management systems. Additional requirements of soil erosion tolerances or other criteria for defining conservation objectives for on- and off-site situations and for water quality must be developed. Expanding technology is providing opportunities and challenges to researchers and conservationists in the development of economically and environmentally sound management systems.

Computers and computer models are not an end but rather a means to an end. They can assist in evaluation and prediction but they cannot prevent erosion nor manage the soil resource. Research is needed to develop new tools to control wind and water erosion, promote infiltration, break-up long wind erosion expanses, and generally promote holistic approaches to soil management which preserve and improve soil productivity.

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