Solutions to Environmental and Economic Problems (STEEP)

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STEEP (Solutions to Environmental and Economic Problems) is a multidisciplinary research effort to develop new techniques and strategies to control soil erosion on the croplands of Washington, Oregon, and Idaho (Fig. 1). The STEEP concept is that erosion control requires major modifications in tillage practices, the development of new crop varieties, and different methods of weed, insect, disease, and rodent control—all of which must be acceptable to farmers.

Summary. This article describes one model for organizing and mobilizing scientific resources to address the highly complex and costly problem of soil erosion in the Pacific Northwest. With a U.S. Department of Agriculture grant to the agricultural experiment stations in Washington, Oregon, and Idaho, as well as supplementary state and federal funds, STEEP awards intermediate-term (15 year) grants for research in five areas: tillage and plant management, plant design, erosion and runoff predictions, pest management, and socioeconomics of erosion control. Most of the research projects require collaboration across disciplines and, in some instances, across state boundaries. After 6 years of effort the results obtained with STEEP indicate that the model might be applicable to other regions and problems.

The innovators of STEEP were the wheat producer organizations in the Pacific Northwest. Producer groups arranged the initial discussions and obtained the supplemental congressional funding, and they continue to support and monitor STEEP's progress. Funds for STEEP research have been made available each year since 1976 by a special U.S. Department of Agriculture (USDA) grant to the agricultural experiment stations at the universities of Washington, Oregon, and Idaho, and by appropriations to the USDA-Agricultural Research Service (ARS).

The high rate of erosion in the croplands of the Pacific Northwest is caused by a combination of factors, including heavy winter rainfall, unusually steep topography, and a prevalence of winter wheat cropping with conventional management. In spite of decades of conservation efforts by concerned farmers, absentee landowners, and various government agencies, the productive capacity of relatively large areas of land is continually reduced because of topsoil losses, and because of environmental damage to land and water resources. The annual rate of soil erosion in the Columbia River drainage system is estimated at 110 million tons, of which approximately 30 million tons are deposited in Northwest streams, rivers, lakes, and harbors. The silt accumulations in reservoirs is shortening the life of critically needed hydroelectric generating facilities, reducing the capacity to store irrigation water, and impairing the water quality of rivers and reservoirs. Removal of silt from roadsides and ditches in eastern Washington, Oregon, and western Idaho costs several millions of dollars each year.

Conservation tillage, which includes no-till and reduced tillage practices, is generally recognized as an effective method for reducing erosion and has been the subject of considerable research over the years. The value of conservation tillage to farmers, however, has varied widely from area to area. Tillage practices that work in one area often do not work in another area because of differences in environmental characteristics. For example, seasonal precipitation, weeds, insects, and diseases frequently vary and can produce effects that override the benefits of conservation tillage.

Characteristics of the STEEP Approach

STEEP represents a mode of research organization and implementation that differs from either the Cooperative State Research Service (CSRS) or competitive grant models of the USDA that guide national research efforts on agricultural problems. The CSRS distributes funds to land grant universities on the basis of a formula that was established by Congress. These federal funds are combined with state dollars to support programs of agricultural research of state, regional, and national interest.

Competitive grants are used by several federal agencies to meet specific program objectives. They are allocated for fixed periods of time to investigators whose proposals are reviewed and scored by peer panels as a basis for recommending whether or not the proposals get funded (*1*). Competitive grants complement and supplement the formula funded research system and assist other scientists whose main responsibility may be to educate undergraduate and graduate college students. However, the competitive grants program has been criticized for several reasons. One is that national agricultural problems that demand the continuity of long-term research programs involving several disciplines are regularly threatened by the vicissitudes of the peer review system. Another reason is that scientists who would otherwise use long-term approaches to the study of problems are often forced to develop truncated research designs without the support of needed expertise from other disciplines.

Neither the competitive grant nor the formula fund model are effective in stimulating multidisciplinary research across state boundaries with the aim of solving regional or national agricultural problems. More often, they bring together members of a single discipline for research projects with quite modest objec-

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tives that can be accomplished through a rather loose form of coordination as opposed to a concerted team effort. Also, because most of the funds for agricultural experiment stations are provided by the legislatures of individual states, regional research is often given a low priority.

STEEP is organized on the basis of intermediate-term (15-year) special grant incentives. This has made it possible to bring together the efforts of scientists from at least ten disciplines in an attempt to find a solution to the soil erosion problems in the Pacific Northwest. Such a program could, presumably, be used to solve other agricultural and environmental problems.

The keystone of the STEEP model is a special USDA grant to the Washington, Idaho, and Oregon experiment stations to supplement the direct appropriations to ARS for STEEP-oriented erosion research. The funding has been modest for an effort of this magnitude: a special grant of $250,000 was made to the three state experiment stations when the project was first approved in 1976, and this was raised gradually to $648,000 in 1982; a total of $435,000 has been provided annually to ARS for STEEP since 1976. By agreement of the three experiment stations, the special grant funds are divided equally among the three states.

The specific research projects under STEEP are organized into five problem areas: (i) tillage and plant management; (ii) plant design; (iii) erosion and runoff predictions; (iv) pest management; and (v) the socioeconomics of erosion control. Nonfederal scientists from each state experiment station are encouraged to prepare proposals for research in these areas and compete for funds. The proposals are reviewed and arranged in order of priority by a coordinating committee composed of five participating scientists, with the final decision on funding being made by the experiment station directors. Priority is assigned on the basis of criteria as such relevance to objectives, duplication of effort, balance among the objectives, and probability of success. This procedure has resulted in some 35 scientists from ten disciplines gaining financial support for 30 individual projects. The disciplines include soil science, agronomy, plant breeding, agricultural engineering, weed science, plant pathology, entomology, biology, agricultural economics, and rural sociology. Most of these projects have involved collaboration across disciplines and in some cases, across state boundaries.

The USDA-ARS appropriated funds are also directed to research within the five problem areas. Again, guidance is provided by the STEEP coordinating committee. Funds are allocated to general areas where research strengths lie and where contributions to the overall objectives are expected to be the greatest. STEEP has served to direct the research of about 20 federal scientists. Research outlines for specific problem areas are prepared and updated or revised and approved by staff specialists and administrators. Priority for federal research is assigned on the basis of the same criteria as for the state projects as well as relevance to national research programs. The ARS funds are redirected as needed to achieve the program goals. The ARS provides added expertise to STEEP through its national and regional research programs.

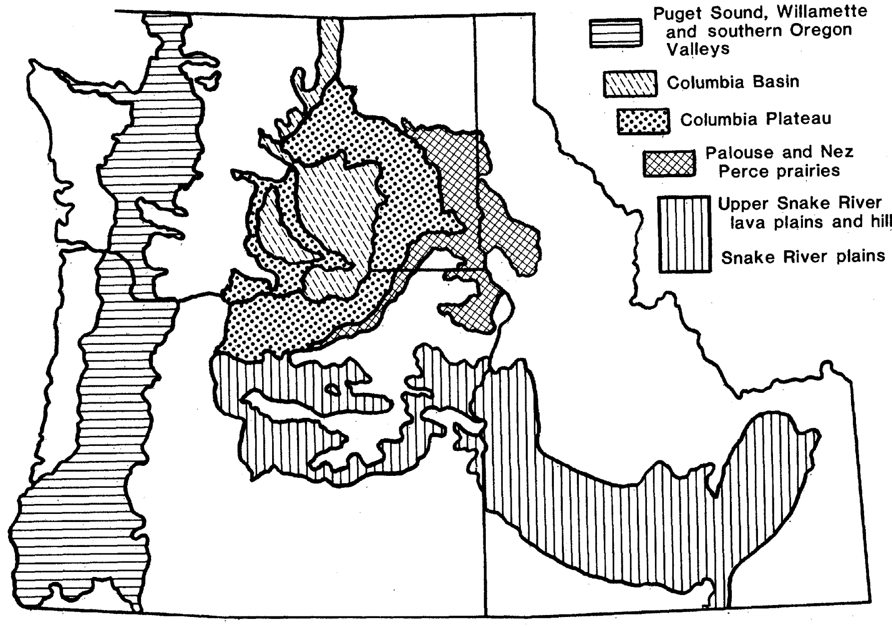

Fig. 1. The major land resource areas in Washington, Oregon, and Idaho.

Funded scientists and their administrators meet annually for 2 to 3 days to discuss their research results and review research needs. Representatives of the wheat-producer organizations, cooperative extension, and regional conservation and environmental agencies also attend these meetings, which take place before the ensuing year's funds are allocated. The STEEP coordinating committee is responsible for organizing the review session and assembling an annual report of the year's research activities.

Procedures set in motion by the STEEP program operate in subtle but effective ways to redirect research efforts within the agricultural experiment stations. The normal method of allocating research funds is by discipline, whereby department heads interact with research administrators to approve scientists' projects and budgets for those projects. Under this method, the concerns of a single discipline and the specific departmental goals are the major factors determining the allocation of the research funds. The STEEP model, in contrast, uses research objectives deemed important to solving a particular problem, in this case, erosion control, that transcends departmental boundaries.

The research budgets for agricultural experiment stations are spent mostly on fixed costs, scientists' salaries, technicians, and secretarial support. By providing funds for specific research activities (few of the STEEP funds are used for scientists' salaries), STEEP tends to draw the base resources of departments toward efforts that the stations and the coordinating committee have defined as high priority. The same is true of ARS research. For example, ARS weed science research at Pullman, Washington, although not funded by STEEP, has redirected a substantial part of its program to weed control in conservation tillage systems as a result of the STEEP program. The overall result is that total funds spent on STEEP research are at least triple the amount that is actually allocated. Finally, the annual reporting and interaction requirements mandated by STEEP ensure that research under the program is not placed on the back burner and ignored by scientists with multiple projects.

Some of the types of research and technology development that have been initiated by STEEP are outlined below.

Tillage and Plant Management

Considerable effort has been devoted since the onset of STEEP to research on new and improved agronomic methods for erosion control. Several approaches have been used, but most in some way emphasize the development of no-tillage and reduced-tillage technology for the production of cereals and grain legumes. Reduced tillage planting, which usually involves no more than one or two cultivations for seedbed preparation (compared with four to seven for most conventional planting systems), and no-tillage, where the crop seeds are sowed directly on the land without any prior seedbed preparation, are both highly effective for soil erosion control. For example, an annual soil loss of 56 metric tons per hectare (25 tons per acre) or more, which is common on many conventionally cropped fields of the Palouse region, can be lowered to 11 metric tons per hectare or less with reduced tillage or no-till methods (*2*). This level of control, according to most workers, is sufficient to maintain the long-term soil productivity and minimize the adverse environmental effects of soil erosion. However, crop yields with these conservation tillage systems are often less than with conventional tillage planting. The reasons for this are not fully understood, although crop growth under the reduced tillage and no-till methods may be retarded because the residues of the previous crop, which may range in amount from 4 to 11 metric tons per hectare, are conserved on the soil surface and the seedbed soil is either more cloddy or harder. The subsequent crop must take root and grow in the rough seedbed and in the presence of slowly decomposing surface cover.

STEEP research shows that crop residues left on the soil surface benefit overwinter storage of precipitation. For example, compared with clean fall tillage, overwinter water storage in intermediate precipitation areas was increased by 20 percent when the crop stubble was left undisturbed (*3*). In a higher precipitation area (35 to 45 centimeters annually), surface residues increased water storage by about one-third on slopes and ridgetop positions of the field where runoff generally occurs (*4*). However, the additional water saved with surface residues often does not result in higher crop yields. This may be because phytotoxins are produced in the slowly decomposing surface stubble which, upon leaching into the soil, inhibit seed germination or cause root and shoot injury to newly established wheat seedlings. Studies of wheat straw extracts showed the presence of short fatty acids that may account for the frequently observed temporary stunting of winter wheat planted under the no-tillage system (*5*). Other unidentified toxins are probably responsible for the more severe and permanent type of injury that often occurs in crops planted over heavy residues.

Physically removing the crop residues away from the seed row was shown to improve seedling establishment and early growth and to increase crop yields where phytotoxicity was a problem (*4*). Such treatment also appears to alleviate the abnormal "high crown set" of wheat which often occurs with direct sowing into heavy crop residues. A high crown set impairs development of secondary roots and subjects the young plants to additional environmental stress caused by inadequate water and exposure to herbicides applied for weed control. Consequently, engineers have designed no-till planting equipment that removes straw and chaff from the seed row through use of specially designed drill openers (*6*).

Another related approach for crop residue management in dryland areas is the concept of strip-till-plant (*7*). Wheat is planted in narrow tilled strips (10 centimeters, about 0.5 meter apart) with the interrow area left untilled. This once-over planting technique incorporates the crop residues in the seed row, reduces tillage energy requirements compared with conventional planting, conserves seed zone moisture, and provides good erosion control.

A novel engineering approach for crop residue management developed from STEEP research is the slot-mulch concept (*8*). This technique has the potential for reducing runoff and erosion from frozen soils and for enhancing the feasibility of no-till planting in cereal stubble fields. Crop residue is compacted into a narrow continuous slot, approximately 5 to 10 centimeters wide by 25 to 30 centimeters deep, formed approximately on the field slope contour every 10 to 16 meters. The residues of straw and chaff are left well exposed above the soil surface. Field trials and theoretical analysis show that during runoff, water will flow into the slot and readily move downward through the residue into the soil profile.

Studies of crop sequence effects show that the highest overall yields of winter wheat with no-till are obtained where the wheat follows a low-residue crop such as peas or lentils. This procedure is now becoming a common commercial practice in eastern Washington. Crop yields equal or sometimes exceed those obtained with conventional tillage planting. Yields are often much lower when the wheat is planted without tillage following a cereal crop, unless the cereal crop was sparse or the residues were removed by harvesting or burning.

No-till management offers possibilities for more intensive cropping in the low to intermediate precipitation areas (35 to 45 centimeters average annual precipitation) where alternate wheat and fallow is the more traditional practice. One scheme, which is under investigation through the joint efforts of agronomists and weed and soil scientists, is to control weeds chemically and allow the stubble of the previous crop to stand overwinter. In most years, overwinter water storage is greater than when fall cultivation is used. Instead of the usual fallow cultivation, a crop of barley or spring wheat is planted without tilling, as early as conditions permit, thus minimizing soil erosion and water loss.

A significant technological advance resulting from STEEP research is the no-till method of planting cereal crops in killed grass sod (*9*). A considerable area of bluegrass for seed production (approximately 80 percent of the nation's seed supply) is grown in northern areas of the Palouse region on steep hills. Soils in sod are well protected and there is virtually no erosion. When the sod is removed by the usual practice of plowing and cultivation for seedbed preparation, the erosion hazard is increased. Studies showed that the registered herbicide glyphosate [*N*-(phosphonomethyl)glycine], when applied at an economical rate in early spring, would kill the bluegrass. Wheat or barley that is then planted by the no-till method produces yields equivalent to conventionally planted crops. This first crop can then be followed by winter wheat, a grain legume, or another spring crop and a rotation established that continues no-till planting on the undisturbed sod. The protection against erosion that is provided by the sod remains highly effective for several years.

The design of planting equipment has received considerable emphasis in the STEEP program. Several versions of no-till or reduced tillage planters for one-pass operations were developed and tested by researchers in all three states, with varying degrees of success. A chisel-type planter resulted in yields of winter wheat on commercial fields that were 107 percent of conventionally seeded yields and reduced soil erosion by 84 percent compared with conventional planting (*10*). A planter with a hoe-type opener was designed to operate in heavy residues and provide for the precise vertical separation of seed and fertilizer, the fertilizer being placed below the seed to minimize damage to seedling roots from fertilizer burn (6). Another type of drill designed in the early years of STEEP is now in limited commercial use in the Palouse region. It appears that several different drill designs will be necessary for no-till planting because of the diverse soil, slope, crop residue, and moisture conditions that occur across the wheat region.

Plant Design

Prior to STEEP little was known about the breeding of wheat varieties adapted to reduced- and no-tillage management systems. Breeding efforts had focused exclusively on clean tillage and traditional wheat-fallow culture. Since 1977, extensive studies of wheat genotypes under different cultural practices have been conducted to select wheats specifically adapted to reduced- and no-tillage management. The genotypes have been grown on various residues, with the use of split plots maintained under conventional and conservation tillage. Under contrasting tillage treatments, wheat genotypes responded differently for traits such as yield and weight in about 35 percent of the tests. These results indicate that certain genotypes have several traits that are particularly advantageous for growth under conservation tillage. These include deep crown placement, early spring recovery, prolific tillering, early maturity, strong straw, and consistently high seed weights. No features have been identified that would limit the breeding of wheats adapted to conservation tillage.

A primary objective of Vogel and coworkers (*11*) in their pioneering work on semidwarf wheat varieties grown in the Pacific Northwest was to breed strains that could efficiently use high levels of inorganic fertilizer, withstand lodging, and yet be sown early enough to provide maximum vegetative cover for erosion control. Early seeding has long been recognized as a practical way to prevent erosion of fall-sown wheat under summer fallow culture. However, there are several problems associated with early seeding, such as weeds, diseases, insects, poor stand establishment, excessive plant growth, and cold and water stress.

Results obtained through the STEEP project have shown that several of the barriers to early seeding can be removed. In particular, it is possible to breed for resistance to the diseases of early seeding, such as certain rusts and strawbreaker foot rot. By using several approaches, breeders have obtained wheats with stable resistance to stripe rust. Most varieties now recommended for early seeding have genes for nonrace-specific resistance or genes for both specific and nonspecific resistance to the fungus. In another breeding strategy, similar wheat lines that have different genes for resistance are being blended. The mixture of divergent, genetic forms of resistance almost precludes the possibility of a new stripe rust biotype causing serious damage to early-sown wheat. Although progress has been slower, similar approaches are being used in the development of wheats resistant to leaf rust.

Achieving adequate cold hardiness in early-sown wheat came about through STEEP-sponsored research. Most wheats are particularly vulnerable to freezing temperatures and deacclimate readily after the five- to eight-tiller stage. After several cycles of breeding and selection, a few wheat lines were identified with the needed balance among crown placement, tiller number, heading date, and yield potential that could withstand unusually cold temperatures of moderate duration. Daws, a recently released variety, forms a deep crown and is the most cold hardy of currently grown soft white winter wheat varieties.

Recent research under the STEEP program has produced results that may explain why winter wheat seedlings develop poorly under conservation tillage. Roots of wheat plants grown under reduced tillage were found to be colonized by a species of bacteria that markedly inhibit plant growth. Bioassays with these microbes indicated that some wheat genotypes were inhibited less than others, suggesting that wheat varieties tolerant of these inhibiting bacteria can be developed.

Thus far, results show that wheat varieties that do well under conventional tillage do relatively well under conservation tillage. However, all currently tested germplasm has been developed under conventional tillage systems, and experiments are now under way to determine whether segregating wheat populations derived from early varieties grown exclusively under conservation tillage systems will yield progeny with features that are specially adaptive to conservation tillage.

Disease Management

Winter wheat in the Pacific Northwest probably suffers from more diseases than wheat in any other region of the same size in the world. Winter wheat is grown at elevations ranging from near sea level in the Puget Sound–Willamette Valley regions of western Oregon and Washington to 2100 meters above sea level near the Teton Mountains in eastern Idaho. Temperature and moisture vary greatly with elevation, and these influence disease development.

Changing technology, especially the extension of irrigation and efforts to reduce tillage, have accentuated the demands on research in plant pathology. Researchers face the disease problems of historic, conventional farming plus those of the experimental systems just reported. Therefore, the STEEP research has included studies of disease management in new and changing systems.

Stand establishment is often a severe problem in crops grown under the no-tillage system, especially when crop refuse is heavy. *Pythium ultimum* and *P. aristosporum* fungi attack under cool, wet conditions (*12*), and decomposing fragments of straw in the drill row stimulate the development of these pathogens. Toxins that are leached from masses of rotting straw (*13, 14*) weaken seedlings directly, predisposing them to attack by *Pythium*. Investigators found that Ridimil [*N*-(2,6-dimethylphenyl)-*N*-methoxyacetyl)alanine methyl ester], when used as a seed treatment or as granules in the drill row, reduces or controls the stand establishment problem caused by *Pythium*.

The most widespread, chronic soilborne disease in the region is strawbreaker foot rot, caused by *Pseudocercosporella herpotrichoides*. This fungus rots the base of the wheat stem and survives from year to year on infested stubble. Crop infestation occurs in late fall and early spring. STEEP-sponsored research advanced the use of benomyl (Benlate) [methyl 1-(butylcarbamoyl)-2-benzimidazolecarbamate] as a stopgap means of reducing losses in early-seeded fields. In Washington alone, over 80,900 hectares were sprayed with the chemical during 1980 and 1981, with considerable increases in yields.

Wheat breeders in all three states are working cooperatively to incorporate the best known foot-rot resistances into adapted wheat varieties. Investigators in Washington are concentrating on more efficient means of testing materials for resistance. Studies in Oregon on tillage management show that burning the crop residues does not materially reduce foot rot. Oregon state and ARS (*15*) researchers have established that, compared to use of the moldboard plow, surface mulch does not significantly increase foot rot.

Studies in Idaho show that use of the no-tillage method increases stripe rust, which is caused by *Cephalosporium* *gramineum*. This fungus enters injured roots and infects wheat stems. In cool wet weather, the fungus sporulates on the straw left on the soil surface and water washes the spores into the soil. STEEP researchers are now attempting to breed wheat varieties that will resist the disease and to develop chemical control methods.

Seeding directly into undisturbed stubble increases "take-all," which is caused by the fungus *Gaeumannomyces graminis* var. *tritici*. This fungus persists on the roots and in the stubble of harvested crops, and is more severe if the host remains are unbroken. With conventional tillage the wheat residues are fragmented and the fungus is less effective in transmitting the disease. Both take-all and *Pythium* root infections are favored by weakened plants. The proper nutrition of crops planted without tillage is a critical factor in preventing spread of the disease, and this requires the application of fertilizers near the seed, a problem that in turn requires advances in machinery and knowledge.

Bacteria antagonistic to the take-all pathogen and adapted to life on the surface of the wheat root have been applied to wheat seeds prior to planting. The bacteria colonize the surfaces of emerging roots and grow with the root as it ramifies the soil. Take-all lesions are reduced to minute, nondamaging size and the disease is controlled. This method has promise for commercial adoption. The bacteria are strains of *Pseudomonas fluorescens*.

Fusarium avenaceum is another pathogen that has increased in importance with the use of conservation tillage. This fungus causes severe losses in lentils (*Lens culinaris* Medic.) that are seeded directly into sod of Kentucky bluegrass killed by herbicide (*16*).

The most destructive airborne diseases of the region are stripe and leaf rust, caused by *Puccinia striiformis* and *P. recondita*, respectively. Serious losses due to these rusts occurred in the 1980–1981 season. Both of these rusts have increased as a result of crop irrigation. Precipitation in July and August is normally so low that little green, herbaceous foliage existed in the region prior to irrigation. The rusts, as well as the cereal aphids that transmit barley yellow dwarf virus, require green leaves to survive over the summer in quantity, and these are now available.

The number of races of both *P. striiformis* and *P. recondita* is increasing rapidly (*17, 18*) and resistance to specific races is becoming less reliable. Means of detecting nonspecific resistance, or resistance effective against many races, are being developed.

Epidemiological studies of stripe rust have shown that on the basis of the cumulative degree days during winter and early spring it is possible to predict outbreaks of stripe rust well in advance. Warm winters and cool springs made for severe losses in susceptible varieties (*19*). The winter of 1980–1981 was mild and the spring was exceptionally cool and wet. Heavy losses were prevented by timely application of Bayleton (triadimefon) (*20*).

The barley yellow dwarf virus causes serious losses in wheat, oats, and barley, and the predominant strains are transmitted by the bird cherry-oat aphid, the greenbug, and the English grain aphid. All corn varieties and hybrids extensively grown in Washington are hosts of barley yellow dwarf virus. The bird cherry-oat aphid reached 1000 individuals per ear of corn in August 1979, and winged adults migrated from the corn to the early-seeded winter wheats. Yellow dwarf losses have increased dramatically in recent years, probably as a result of increased corn production under irrigation. In 1981, spring barley yields were reduced by one-third to one-half in widespread areas by yellow dwarf. No resistant, adapted cereals are available in Washington.

Other workers have discovered that herbicides sometimes alter disease relationships. The expanded use of chemicals to control weeds on untilled fallow ground may result in herbicide-disease interactions of which we have no knowledge.

Research into disease management has provided challenges for other areas of STEEP research. No-till drills are needed for commercial use that will move the straw out of the seed furrow. Fertilizers must be properly placed to give the seedling greater vigor. Crops with increased resistance to several diseases are required so that reliance on chemical controls can be minimized. Methods for bacterial control of take-all must be perfected, and similar efforts must be made to control other diseases. At the same time, diverse breeding programs and germplasm resources must be maintained to insure against unpredicted outbreaks of disease.

Weed Management

The development of conservation tillage systems under the STEEP program required new research on combinations of chemicals and tillage for weed control. Reduced tillage, trashy fallow, and no-till encourage the establishment of wild oat (*Avena fatua*), downy brome (*Bromus tectorum*), and broadleaf weeds in the crop seeded after the fallow season. For the benefits of substituting chemicals for tillage during fallow to be preserved, the use of selective grass and broadleaf herbicides is required.

The chemical control of weeds during fallow can be highly beneficial for water conservation. Tests in Oregon during 1977 to 1981 showed that an additional 0.5 to 2.54 centimeters of moisture was stored in such fields compared to mechanically tilled fallow fields. The resulting extra yield was complemented by a reduction of two tillage operations with a combined net benefit of $62 per hectare. Similar results have been reported in Washington and Idaho.

The herbicides used for chemical fallow in the noncrop phase of each season include cyanazine, atrazine, metribuzin, dalapon, propham, paraquat, and glyphosate. These herbicides are also used for reduced tillage cultures. Herbicides for selective downy brome control in wheat include trifluralin and metribuzin. Metribuzin is a postemergence herbicide that is effective on both grass and broadleaf weeds, and was registered for crop use for the first time in 1979.

Weedy grasses such as downy brome are difficult to control with the use of stubble mulch fallow, sweep fallow, trashy fallow, and no-till practices, and sometimes with conventional tillage. Successful programs for downy brome control in winter cereals could increase yields by 35 percent on average in the Pacific Northwest. Chemical herbicides are not only essential for selective weed control in the crop but also are vital for nonselective control in the fallow period.

Tillage costs increased by 9 percent in 1978, 14 percent in 1979, 15 percent in 1980, and 16 percent in 1981. Mechanical tillage costs for weed control have escalated at a much faster rate than herbicide costs. The concept of reduced tillage by the use of chemical fallow and selective weed control in the crop can be of great economic value at a time when conservation practices are essential, and when energy and production costs are increasing.

Socioeconomic Considerations

Unless farmers adopt some of the soil conserving methods that are developed, the STEEP program will not have accomplished its objectives. Rural sociology and economic components were added to STEEP to contribute an understanding of the acceptance and rejection of soil-saving innovations. Recent evidence suggested that the adoption process for environmentally related technology might differ from the traditional pattern observed in the Midwest for technology primarily aimed at improving the farmer's economic well-being (*21*).

STEEP agricultural economists have studied both the short- and long-term effects of using erosion control practices, and the effects of improved technology on short- and long-term scenarios. The question farmers consider is the trade-off between short-term costs of erosion control practices, measured largely by reduced yields, and long-term benefits, measured by maintaining productivity over time.

Studies of the economics of conservation practices (*22, 23*) revealed that the short-term (annual) cost of conservation is approximately $10 per acre. The annual reduction in soil loss with conservation practices varied from 5 to 8 tons per acre. Analyses of long-term costs related to the use or non-use of conservation practices (*24*) indicated that over a 75-year period, farmers would receive an additional $8.50 (present value) per acre annually for a wheat-pea rotation with the use of conservation tillage. In another study (*25*) it was concluded that the long-term effects of soil erosion and technological progress need to be evaluated together when estimates of future agricultural productivity are being made. The findings indicated that until there are technical substitutes for energy intensive inputs, rates of production will decline.

The rural sociological component of STEEP gave highest priority to conducting an immediate bench-mark survey of current erosion control practices and perceived barriers to greater usage (*26*). This survey was conducted in 1976 in a natural geographical area of exceptionally high erosion potential straddling the Washington-Idaho border. Among the results of this survey was that farmers frequently cite absentee landlords as a major reason for their reluctance to make greater efforts to control soil erosion. The same farmers were surveyed again in 1980, at which time their detailed perceptions of the landowner-farmer relationships were determined. The results showed that absentee landlords were not a significant factor in inhibiting the use or erosion control practices (*27*).

The 1980 survey was conducted jointly with agricultural economists who, over the course of the STEEP program, had developed their own decision-making models for the use of minimum tillage practices. The availability of the 1976 bench-mark survey (*26*) provided an invaluable set of background variables for testing the model. The interaction between the rural sociologists and agricultural economists caused the two groups to examine each other's models and influenced the questions they asked in the joint survey.

Data were thus collected on the ways in which farmers changed their soil erosion control practices between 1976 and 1980, the effects of absentee landowners, and the role of risk aversion in decision-making. On the basis of these data, scientists are now developing models for encouraging the adoption of new soil conserving practices developed by the STEEP program. The first step of diffusion has already been realized. The surprising discovery (*27*) that absentee landowners are primarily females of retirement age who do not participate in farm decisions has led to the realization that farm operators themselves must make the necessary improvements. This finding has provided the basis for nearly 20 extension education programs for soil conservation service personnel and farmers.

Conclusions

The STEEP research program has directed the work of 55 scientists in the ARS and the agricultural experiment stations of Washington, Oregon, and Idaho toward a solution of the erosion problem in the Pacific Northwest. The success of the effort, now 6 years old, must ultimately be judged on the basis of whether soil erosion in this part of the United States is brought under control within the next 5 to 10 years, the expected life of the STEEP program.

The USDA special grant to the three universities and an appropriation to the ARS which, since 1976, has provided annual funding for the research, has resulted in long-term multidisciplinary research across state boundaries. Results from the STEEP program have shown that significant reduction in soil loss occurs when crops are grown without tillage or with minimum tillage and have identified some of the factors responsible for the decreased yields that are associated with these practices.

As a result of the STEEP program, some scientific resources that were previously devoted to other concerns have been mobilized toward the higher priority research problem, soil erosion. This mobilization was accomplished, in part, by supplementing the traditional cooperative research model with special, intermediate-term grants.

Experiences with STEEP suggest that this model may be useful for research aimed at the solution of other important regional and national agricultural problems and perhaps problems in other sectors. However, a proliferation of STEEP-type programs might result in the diversion of scientific effort away from other priority problems, and the model should therefore be subjected to additional testing both within and outside the agricultural sector.

References and Notes

1. D. W. Krogmann and J. Key, *Science* **213**, 178 (1981).
2. U.S. Department of Agriculture, *Palouse Co-operative River Basin Study* (Government Printing Office, Washington, D.C., 1979).
3. R. E. Ramig, P. E. Rasumssen, R. W. Rickman, J. Kraft, in *STEEP Annual Report, 1980* (Univ. of Idaho Press, Moscow, 1980), p. 135.
4. V. L. Cochran, L. F. Elliott, R. I. Papendick, in *STEEP Annual Report 1979* (Univ. of Idaho Press, Moscow, 1979), p. 143.
5. V. L. Cochran, D. L. Bikfasy, L. F. Elliott, R. I. Papendick, *Agronomy Abstracts* (American Society of Agronomy Annual Meeting, Detroit, 1980).
6. D. E. Wilkins, in *STEEP Annual Report, 1979* (Univ. of Idaho Press, Moscow, 1979), p. 114.
7. F. E. Bolton, in *STEEP Annual Report, 1980* (Univ. of Idaho Press, Moscow, 1980), p. 64.
8. K. E. Saxton, D. K. McCool, R. I. Papendick, *J. Soil Water Conserv.* **36**, 44 (1982).
9. L. F. Elliott and R. I. Papendick, in *STEEP Annual Report, 1979* (Univ. of Idaho Press, Moscow, 1979), p. 141.
10. C. L. Peterson, in *STEEP Annual Report, 1980* (Univ. of Idaho Press, Moscow, 1980), p. 29.
11. O. A. Vogel, J. C. Craddock, Jr., C. E. Muir, E. H. Everson, C. R. Rohde, *Agron. J.* **48**, 76 (1956).
12. R. J. Cook, J. W. Sitton, J. T. Waldher, *Plant Dis. Rep.* **64**, 102 (1980).
13. L. F. Elliott, D. E. Miller, A. W. Richards, *ibid.* **63**, 882 (1979).
14. J. M. Wallace and L. F. Elliott, *Soil. Biol. Biochem.* **11**, 325 (1979).
15. R. J. Cook and J. T. Waldher, *Plant Dis. Rep.* **61**, 96 (1977).
16. Y. S. Lin and R. J. Cook, *ibid.*, p. 752.
17. R. F. Line, in *Proceedings of the Fifth European and Mediterranean Cereal Rust Conference, 1980.* (European and Mediterranean Cereal Rusts Foundation, Rome, 1980), pp. 163–166.
18. A. E. Milus and R. F. Line, *Plant Dis. Rep.* **65**, 78 (1980).
19. S. M. Cookley and R. F. Line, *Phytopathology* **71**, 461 (1981).
20. R. F. Line and R. Rakotondradona, in *Proceedings of the Fifth European and Mediterranean Cereal Rusts Conference, 1980* (European and Mediterranean Cereal Rusts Foundation, Rome, 1980), pp. 239–241.
21. F. Pampel and J. C. Vanes, *Rural Soc.* **42**, 57 (1977).
22. J. M. Harker and E. L. Michalson, *Soil Conservation and Farm Management Planning* (University of Idaho Research Bulletin No. 104, Moscow, March 1978).
23. S. Berglund and E. L. Michalson, *J. Soil Water Conserv.* **36** (No. 3) (May–June 1981).
24. D. J. Walker, paper presented at the Western Agricultural Economics Association Meetings, Las Cruces, N.M., July 1980.
25. D. Taylor and D. Young, paper presented at the Western Agricultural Economics Association Annual Meeting, Lincoln, Neb. 19 to 21 July 1981.
26. J. E. Carlson, D. A. Dillman, W. R. Lassey, *The Farmer and Erosion Factors Influencing Use of Control Practices* (Agricultural Experiment Station Bulletin 601, University of Idaho, Moscow, April 1981).
27. D. A. Dillman and J. E. Carlson, *J. Soil Water Conserv.* **37** (No. 1), 37 (1982).
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