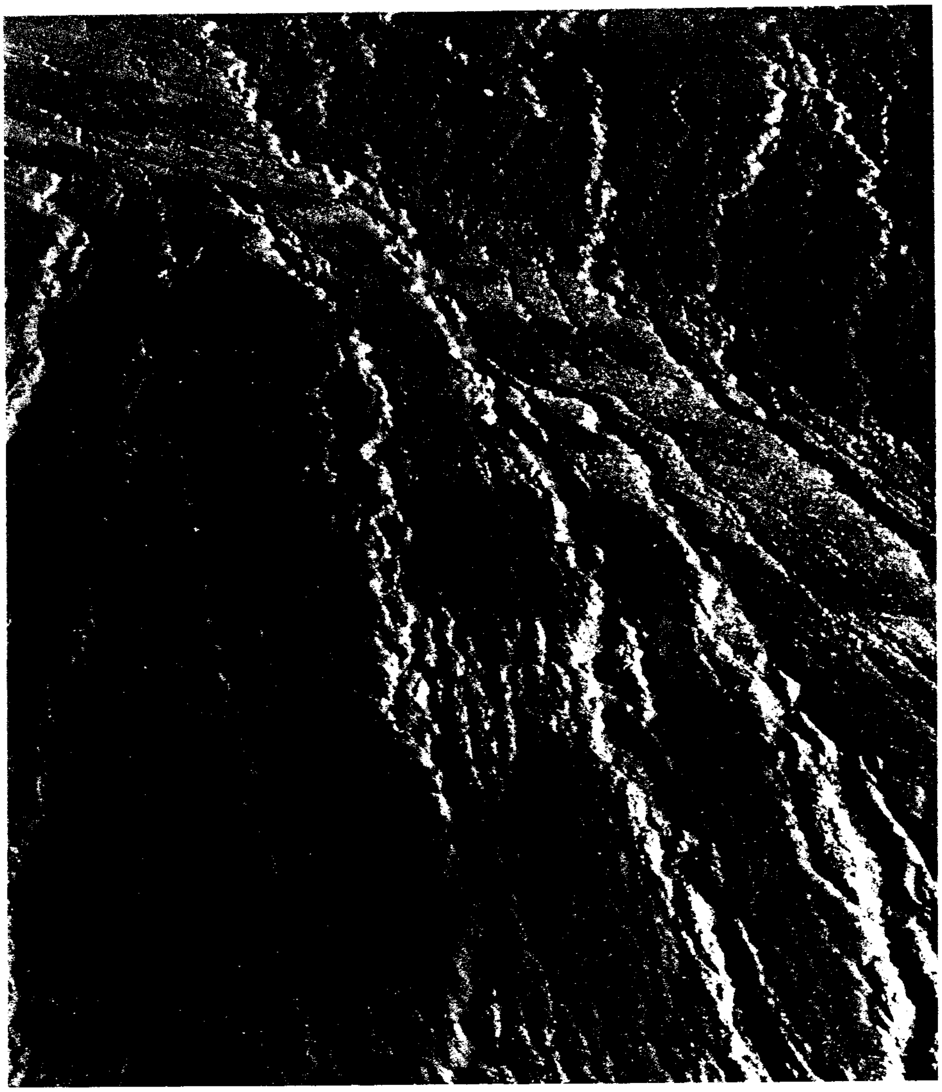

The concept of soil loss tolerance—T value—rests upon assumptions that some soil scientists feel must be challenged

Soil loss tolerance: Fact or myth?

By Leonard C. Johnson

THE concept of tolerable soil loss, as now applied in soil conservation programs, does not serve the long-term interest of mankind in assuring the indefinite productive capability of cropland. Why? Because soil loss tolerances—T values—presently assigned to cropland soils are based on faulty premises concerning rates of topsoil development and mineral weathering processes.

The concept of soil loss tolerance rests upon two assumptions: first, that soil scientists can assess reliably and objectively the maximum rates of soil erosion that can be tolerated and, second, that policymakers can objectively weigh that assessment against countervailing interests or needs, however these may be defined. Both assumptions should be challenged.

Short-term political considerations may demand that public policy allow soil resources to degrade, gradually but unceasingly, to a state of agricultural uselessness. But continued support of such a policy must clearly acknowledge the extent and quality of known information about soil development rates under agricultural conditions. Soil loss tolerance values are too important to continue to be based on what amounts to quasi-scientific folklore.

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The T-value concept

The intense nationwide soil conservation movement, initiated in the United States in the 1930s, included a strong quest for practical knowledge about why and how soil erodes and about practices and techniques for preventing or controlling soil erosion. Many governmental agencies and other institutions implemented a massive effort to seek knowledge from various sources. Their goal was to develop a sound foundation in science and technology for the vital work of soil conservation.

Through numerous, comprehensive research and development studies, it increasingly became possible to describe soil erosion and its control more or less accurately and quantitatively. Professional soil conservationists realized that a quantitative standard was needed to evaluate the effectiveness of erosion control measures. This standard is commonly known as the "tolerable soil loss rate" or "T value," usually expressed in tons per acre per year or equivalent dimensions.

Dwight Smith was probably the first student of soil erosion and erosion control to express the need for such a quantitative erosion control standard and to give intellectual substance to the concept of permissible soil loss (*30*). He stated that the maximum allowable rate of soil loss should be "that rate which will permit at least a constant or preferably an increasing time gradient of soil fertility." Focusing his concern on soil fertility maintenance as the critical determinant of soil loss tolerance, Smith tacitly recognized that allowable soil loss rates could vary depending upon the economic feasibility of treating the soil with fertilizer to replace mineral nutrients lost through erosion.

However, he also expressed a concern for the threat posed by mass wastage, stating, "Four tons soil loss per year may be too great for maintenance of soil fertility... when erosion has progressed to the point that plowing is diluting the surface soil with thin layers of subsoil."

O. E. Hayes and N. Clark also concluded that a practical limit should be placed on soil erosion rates (*12*). They suggested that farmers would regard an annual soil loss rate of 3 tons per acre per year on Fayette silt loam as reasonable. Citing geologists' estimates, they stated that to produce a foot of residual soil material from limestone would require the decay of at least 100 feet of rock and thousands of years. The researchers concluded that even at the rate of 3 tons per acre per year, soil losses would greatly exceed the production of soil material by natural weathering processes.

In further developing the concept of allowable soil loss, Smith and D. M. Whitt said, "The ultimate objective of soil conservation is to maintain soil fertility and hence crop production, indefinitely. Any soil loss that permits a decline in fertility must be avoided" (*31*). They believed soil organic matter content was the critical determinant or indicator of soil fertility, and assigned maximum permissible soil loss rates to selected Missouri soils using graphic plots of yearly changes in organic matter content against annual soil loss rates.

Permissible soil loss featured prominently in the deliberations of a 1956 conference of the Agricultural Research Service, the Soil Conservation Service, and certain university faculty members (*35*). At this conference a committee recommended that "...in no case should a permissible soil loss of more than 5 tons per acre per year be allowed." This recommendation was based in part on a $2 average value of nitrogen and phosphorus nutrients in a ton of soil and the subjective belief that "plant nutrient losses of more than $10.00 per acre per year may be excessive for any farmer." The committee also recognized that soil loss tolerance values should be based on considerations more fundamental than the cost of fertilizer materials and the shifting profitability of crop production. Therefore, they set forth the following items "of prime importance in considering permissible soil loss rates:"

► Maintenance of soil depth adequate for crop production.

► Value of mineral nutrients lost.

► Maintenance of the capacity and effectiveness of water control structures and control of floodplain sedimentation.

► Prevention of gully development.

► Crop yield reduction, per inch of topsoil loss.

► Water losses as surface runoff.

► Seedling losses.

The proceedings of a later SCS workshop (*2*) reformed these seven items into three general criteria or broad objectives for establishing T values:

► Soil loss should be reduced to a level that will maintain an adequate soil depth favorable for crop and timber production over a long period of time.

► Soil losses should be lower than those causing severe gullying in fields or serious siltation in waterways, terrace channels, drainage ditches, and road ditches.

► Plant nutrient losses should not be excessive.

Others have defined the T value at least partially in economic terms; that is, with reference to the monetary costs of ameliorating productivity declines associated with soil erosion. The initial attempt in 1956 to broadly define permissible soil loss (35) took into account the costs of replacing the mineral nutrients lost through soil erosion. Smith and Walter Wischmeier wrote, "Both physical and economic factors are considered in establishing soil loss tolerance values. The concept is to limit soil loss to levels that will allow economical maintenance of soil productivity" (*32*). This view was also expressed in *Agriculture Handbook No. 537:* "The term 'soil loss tolerance' denotes the maximum level of soil erosion that will permit a high level of crop productivity to be sustained economically and indefinitely" (*39*).

The agricultural productivity of soil is a function of relationships between the soil itself, in all of its manifold physical, chemical, and biological aspects, and the life processes of plants. Degradation of cropland soils occurs principally through two general mechanisms: loss of soil material through erosion and qualitative degradation of edaphic properties through tillage-induced wastage of organic matter and alteration of desirable physical features. Some soils never possessed, or have lost through misuse or mismanagement, the capacity to sustain "a high level of crop productivity," however that property may be defined. The costs of goods and services may influence substantially decisions on whether and how to control erosion or counter its adverse effects on crop production. Conditioning soil loss tolerance on present-day costs of mineral fertilizers, for example, implies little appreciation for the importance of guarding the vital edaphic qualities of healthy topsoil against mass wastage or tillage-induced organic matter oxidation. It does not allow for our lack of knowledge about future costs of fertilizers and other remedial measures.

In practice, the soil loss tolerance concept appears to be focused on preserving agricultural productivity of soils in situ. Preventing excessive reduction in topsoil depth has become the predominant operational criterion of erosion control practice effectiveness, with consideration of total soil profile depth where this seems to be, potentially at least, a secondary productivity-limiting soil factor. A 1977 SCS technical advisory (*37*) cited soil profile depth as the nearly exclusive determinant for selecting T values. Tolerance values were adjusted downward by one ton per acre per year for soils already severely eroded, reflecting consideration of topsoil depth as a secondary determinant.

Additional refinements of the soil loss tolerance concept took place in the 1950s, and tolerance values were assigned to various soils. Donald McCormick and his colleagues, in reviewing that work, concluded that "current T values were based largely on considerations of the rate of formation of A horizons, with adjustments based on the thickness or other aspects of the quality of the entire soil depth accessible to plant roots" (*22*).

Thus, T values have evolved largely

through short-term economic considerations of declining agricultural productivity due to excessive soil erosion. Key elements in attempts to relate soil losses to diminished productivity have been topsoil depth and available mineral nutrient levels.

Soil formation rates

In recent years concerns about rates of soil formation have re-emerged, especially in relation to prevalent soil erosion rates under intensive agricultural use. Writers have cited various supposed sources of information on rates of soil formation, with a proliferating array of secondary and tertiary sources being cited as though they were primary sources.

It appears that many published references on soil formation rates can be traced to two sources: A speculative guess by geologist T. C. Chamberlin and certain speculative deductions by Hugh Hammond Bennett. These two scientists, separated by a generation in time but both addressing deep and widespread concerns about the threat of rampant soil erosion, attempted to cast some light on the vitally important question of soil formation rates.

Chamberlin, then head of the University of Chicago Department of Geology, expressed his concerns at the 1908 White House Conference on Conservation of Natural Resources. He said, "We have as yet no accurate measure of the rate of soil production. We merely know that it is very slow.... Without any pretension to a close estimate, I should be unwilling to name a mean rate of soil formation greater than one foot in 10,000 years on the basis of observation since the glacial period. I suspect that if we could positively determine the time taken in the formation of the 4 feet of soil next to the rock over our average domain, where such depth obtains, it would be found above rather than below 40,000 years. Under such an estimate, to preserve a good working depth, surface wastage should not exceed some such rate as 1 inch in a thousand years" (*6*).

Bennett discussed the results of a series of short-term studies (about five years) of erosion rates from small field plots on various soil types at several locations throughout the United States. He observed that under well-established, mature forest or grass cover the land surface appeared to be effectively protected from erosional forces and probably had been stabilized for a very long time (*3*). Based on these empirical studies and observations, Bennett speculatively concluded, "At such a slow rate of planation [0.002 ton per acre year in the case of Cecil sandy clay loam under forest cover] soil probably rebuilds from beneath fast enough to balance surface removal" (*3*). He further stated, "These losses are so small [0.002 ton per acre per year under forest cover; 0.012 under grass] that soil probably builds from beneath as rapidly as it is removed from the surface."

In an introductory chapter of his extensive treatise on soil conservation, Bennett (*3*) presented a general overview of his beliefs about rates of soil formation:

"Soil is reproduced from its parent material so slowly that we may as well accept as a fact that, once the surface layer is washed off, the land so affected is, from the practical standpoint, generally in a condition of permanent impoverishment. As nearly as can be ascertained, it takes nature, under the most favorable conditions, including a good cover of trees, grass, or other protective vegetation, anywhere from 300 to 1,000 years or more to build a single inch of topsoil. When 7 inches of topsoil is allowed to wash away, therefore, at least 2,000 to 7,000 years of nature's work goes to waste. The time involved may be much longer; the building of the second inch may require many more years than the building of the first inch at the surface, and so on downward."

Soil Conservation Service

Hugh Bennett (right) and Kendall Weisiger, Southern Bell Telephone and Telegraph Co., observe erosion on an abandoned South Carolina farm in the early 1940s.

Bennett repeated this statement with only minor variations in both the 1947 and 1955 editions of a less technical, more popular-styled book (*4*). This represents the extent of Bennett's allusions to rates of *topsoil* formation, and he cited no research results or other primary sources of data to substantiate his conclusion.

Today, after several decades marked by continuing, severe cropland erosion, the vital question of how rapidly soils may form from various parent materials is being raised again in various quarters. Unfortunately, the torch of scientific knowledge still sheds only a dim and flickering light on this question.

David Pimentel and associates, citing Norman Hudson (*13*) as their source, wrote, "Under ideal soil management conditions, soil may be formed at a rate of 1 inch (2.54 cm) in about 30 years" (*26*). Citing Bennett (*3*), A. F. Gustafson (*9*), and Oliver Owen (*25*) (misrepresented as O. Olivers), Pimentel and his colleagues further stated, "... and under natural conditions at a rate of 1 inch in 300 to 1,000 years" (*26*).

Later, Dave Schertz, citing Pimentel and associates, stated, "Several scientists have suggested that under natural conditions soil forms at a rate of 1 inch in 300 to 1,000 years" (*27*). S. A. Schumm and M. D. Harvey (*28*) also cited Pimentel and associates as authorities who "... consider that under ideal soil management conditions 25 mm of soil can form in 30 years (0.8 mm yr^{-1})" and "under normal agricultural practice, 25 mm of soil can form in 100 years (0.25 mm yr^{-1})."

Examination of these citations reveals that Hudson (*13*) apparently cited Bennett (*3*) as the basis for his statement: "The rate of formation cannot be precisely measured, but the best estimate of soil scientists is that under undisturbed conditions it will take on the order of 300 years to produce 25 mm of top soil,...." In a second edition of his book, Hudson repeated the statement and also made the puzzling assertion that topsoil formation can be hastened ten-fold by tillage-induced aeration and leaching (*14*). In this later edition, moreover, Hudson completed the circle by citing Pimentel and associates instead of Bennett as the source of undergirding data. But, as noted above, Pimentel and colleagues cited Bennett, Gustafson, and Owen, in addition to Hudson.

Pursuing this trail a bit further shows that Gustafson, in his brief treatment of this important question (9), simply quoted and subscribed to Chamberlin's conclusion that "the formation of soil is an extremely slow process...." The contribution of Owen (*25*) to the body of knowledge about the rate of soil formation is a nonspecific citation of certain authorities [presumably Bennett (*3*), Jenny (*15*), and Kellogg (*17*), listed in a bibliography at the end of his third chapter, "Nature of Soils"].

Contrary to the interpretations of some writers, Bennett did not adduce from his observations an affirmative finding of rates of topsoil development. Rather, he suggested it seemed *reasonable to assume* that subsoil material was being produced by bedrock weathering as rapidly as surface soil was being removed by erosion *under a very stable condition of long-standing, complete vegetative protection*. Bennett's opinions in this matter do not provide any basis for the five-ton-per-acre-per-year maximum soil loss tolerance now firmly fixed in erosion control programs and policies. Somehow, his tentative assessments of probable rates of development of soil materials from parent material have become transmuted into positive suggestions, if not assertions, that topsoil is being or can be formed at certain rates on cultivated cropland.

Soil development processes

To speak of topsoil formation without further rational analysis is to imply that a process of net gain occurs. Actually, topsoil develops through *transformation* of subsoil into topsoil, a process characterized by a net loss of mineral matter through dissolution and leaching and, under minimal physical disruption (no tillage), by either a net gain or no discernible change in organic matter content. The overall result of this process, however, is a net loss of mass from the soil profile.

Charles Kellogg (*16*), in a seminal work on soil development, portrayed this phenomenon as resulting from both "destructional" and "constructional" processes. He described the unconsolidated mineral material, produced from rock by "destructional" and "essentially sterile" chemical and physical weathering processes, as the parent material from which soils form. Kellogg considered the introduction of organic material as the progenitor of the constructional phases of soil development; essentially the process of topsoil formation and the additional chemical and physical processes and reactions are associated with the "biological constructional forces in soil development" (*16*). However, considering the quantities of mineral materials retained in situ, both topsoil and subsoil formation can be viewed as destructive because of the additional dissolution of soil minerals through biochemical reactions occurring in topsoil and the subsequent loss of those minerals through leaching.

Noting that "numerous reviews have been made of reports on the rate of rock weathering," Donald McCormack and associates (*22*) found that "data on the rate of development of a favorable root zone from weathering of parent material are not yet conclusive." They considered a renewal rate of one-half ton per acre per year to be "a useful average for unconsolidated materials.... For most consolidated (rock) materials, rates are much lower" (*22*). (Actually, this is a residual soil material accumulation rate, rather than a renewal rate.) In their analysis of criteria for determining soil loss tolerance values, McCormack and his colleagues noted that "the rate of soil formation simply will not compensate" for soil erosion at the rate of currently accepted T values. They concluded, "Political expediency and short-sighted environmental or economic demands cannot be allowed to determine tolerable levels of soil erosion" (*22*).

Scientists generally consider the accumulation of organic matter at the surface the initial step in topsoil development on mineral soil profiles. G. F. Hall and associates (*10*) reviewed the results of several studies on organic matter accumulation in soil materials under both forest and grass vegetation: "All these studies suggest that organic matter can accumulate very rapidly under either forest or grass vegetation. Accumulations that can qualify as an A or Al horizon take place in a matter of 10s of years, and a steady state between gains and losses can be reached in a few hundred years" (*10*).

Such a suggestion about unquantified rates of organic matter accumulation under undisturbed vegetative cover can hardly provide a basis for Schertz's conclusion that "...formation of the A horizon exceeds 1 inch in 30 years" (*27*). Nor can it be a basis for any conclusions about rates of topsoil development under annual or rotational cropping systems.

Terry Logan (*20*) emphasized two points relative to rates of topsoil renewal: rates of rock weathering are not necessarily similar to rates of topsoil renewal, and whatever the rates of soil renewal are, they are probably lower than present T values. Observing that "most estimates of soil renewal are 0.5 metric ton/ha/year (<0.2 ton/acre/year)" Logan concluded, "We are in essence mining the soil in order to produce food and fiber in the same way that we mine our coal resources" (*20*).

Using land for intensive, annual grain crop production results in a gradual and persistent decline in soil organic matter content. Given the relationship of oxygen supply and temperature to microbial activity and the decomposition of organic materials and the relationship of tillage to soil aeration and soil warming, such a result is virtually inevitable (*1, 5, 8, 33, 34*).

The conditions imposed on soils by intensive agricultural practices today do not permit conversion of subsoil into new topsoil through organic enrichment. There can be no progressive downward migration of the subsoil/topsoil zone of transition unless a continuing and persistent annual net gain in soil organic matter content occurs. Such downward translocation of the subsoil/topsoil boundary that may occur in cultivated soils is a consequence of a progressive lowering of the plow layer or tilled zone into the subsoil due to erosional losses and tillage. It is not due to marginal gains in organic matter content. This phenomenon also is marked, of course, by retrogressive dilution of the organic content of the tilled zone through continuing admixture of subsoil mineral matter, which usually further degrades the edaphic qualities of the vital soil zone of seed germination and seedling establishment.

Basing T values on contemporary farming profitability standards or present day costs of fertilizers cannot insure or even address the long-term maintenance requirements of fully productive cropland soils. Moreover, to contend that presently assigned T values approximate natural rates of soil development is to do a grave disservice to both soil science and the ultimate goal of soil conservation.

T values versus reality

In 1909 the chief of the U.S. Bureau of Soils offered the following euphoric assessment of the condition and future of the nation's soil resources: "The soil is the one indestructible, immutable asset that the Nation possesses. It is the one resource that can not be exhausted; that can not be used up" (*36*). It is unlikely that any soil scientist or conservationist today would subscribe to such a sanguine view of soil indestructibility. Yet the concept of tolerable soil erosion rates, as presently defined and applied, is equally unrealistic as a basis for long-term protection and maintenance of soil resources.

In 1948 Kellogg (*18*) asserted, "Through proper cropping systems and soil management practices, erosion of soil under use should be kept somewhere near the normal rate." He defined the normal rate of soil erosion as the rate that would occur without land surface disturbance by agricultural practices.

A similar view, expressed in a report prepared by the Wisconsin Chapter of the Soil Conservation Society of America, stated in part: "Until now, practical and political considerations by the policymakers and program adminstrators have allowed for the ac-

Soil conservation efforts must be directed at protection of the entire plant rooting zone in the soil profile, not just the surface soil layer.

ceptance of 'tolerable' average soil erosion rates of up to 5 tons per acre per year.... Even the lowest T value, it should be noted, is many times greater than the rate at which the soil is forming under completely natural conditions. Soil erosion control goals based on T values therefore should be considered as provisional or short-range. Such standards grant license to...'waste' the soil resource to a depth of 5 or 6 inches per century. Accordingly, the long-range goal should be to reduce cropland erosion to a rate no greater than that which would occur through the action of nature alone."[1]

Discussing the dilemma posed by the conflict between desires for short-term gain and the necessity of maintaining soil productivity indefinitely into the future and having "no conclusive evidence that a decline in production caused by soil erosion is recoverable under continued cultivation," McCormack and William Larson (*21*) concluded: "Ultimately, we must squarely face the fact that soil productivity is directly tied to the overall thickness of the rooting zone, which forms much more slowly than the A horizon in cultivated soils. Long-term soil conservation objectives must be consistent with this fact. There is no alternative."

J. R. Williams and associates (*38*), asserted, "There is essentially no research base to support T values; they were established and are revised on the basis of collective judgements by soil scientists." Nevertheless, G. F. Hall and colleagues (*11*) concluded, "An upper limit (to allowable soil loss] of 11 mt/ha [about 5 tons per acre per year) is generally accepted since it approximates the *maximum rate* of A horizon development *under optimum conditions*" (emphasis added). It must be noted, however, that optimum conditions for organic matter accumulation and, hence, for topsoil development do not even come close to occurring on cultivated cropland as a general rule.

Larson (*19*) proposed a two-level approach to setting T values: a T_1 value reflecting on-site soil productivity maintenance objectives and a T_2 value reflecting broader social purposes and off-site concerns, such as water pollution or reservoir sedimentation. The T_1 values would be set by scientific experts in soils and agriculture; T_2 values would be set by economists, environmental scientists and planners, and public policymakers. Although Larson did not indicate how he thought T_1 and T_2 might be related quantitatively, Peter Nowak and associates (*24*) suggested that T_2 temporarily might be set higher than T_1 where the economic, social, or political costs of reducing current erosion rates to a crop productivity maintenance level were deemed excessive. But deciding whether or not costs are excessive is in every instance an exercise in priority setting. Such a temporary relief could easily become permanent, and the T_1/T_2 approach could become a victim of persistent reluctance to acknowledge that agronomic crops are grown on productive soils, not on the social, political, or economic constraints of the moment.

New commitment needed

The introduction to a report on a recent symposium imagined a trip to a farm in the year 2030. Among other marvelous achievements B. C. English and colleagues posited, "Tillage practices and crop-growing patterns reduce erosion to a level where natural processes of soil formation replace amounts lost to water and wind erosion" (*7*). Some may argue that this futuristic scenario represents an impossible dream; that the need for maximum grain production and monetary profit in the near term is so compelling that reducing soil erosion to anywhere near the "normal" rate cannot be contemplated seriously, much less achieved in the foreseeable future. But such a rationalization cannot be offered or accepted forever.

Reducing cropland and rangeland soil erosion rates virtually to zero or to the nor-

[1]Wisconsin Chapter, SCSA. "Soil Conservation Policies for the 1980s; A report of the Ad Hoc Committee on Land Resources." July 1985.

mal rate must become a firm goal of agriculturists and conservationists. The productive and environmentally sound agriculture that mankind and a great many other of earth's creatures require is not otherwise sustainable. What is needed to effect this essential goal? First, land management policies must severely restrict production of annual crops on highly erodible lands. Second, agricultural crop production systems must be developed and used that retain complete ground cover at all times while permitting all seed placement and other cultural operations with absolutely minimal disturbance of either surface vegetative cover or soil.

The first requirement is beginning to be addressed through the conservation reserve program and similar initiatives undertaken by state governments, for example, the Reinvest in Minnesota reserve program. An approach to addressing the second of these urgent needs was suggested by William Moldenhauer and Charles Onstad, "As the need for reduced erosion becomes more critical, methods of control...should become more innovative" (*23*). Systems that presently seem infeasible, they noted, "may be developed as the pressure to control erosion increases. If mechanical controls in conjuction with residue management are too costly or not feasible on certain soils, then perhaps the only alternative is permanent meadow or pasture."

L.L. Sloneker and Moldenhauer (*29*) sharpened the focus on this approach in observing that "the conventional plow-disk-harrow system became preeminently successful because of the combined efforts of research and educational disciplines and industries working with farmers over many decades." They called for a similar, all-out effort to promote surface residue-retaining systems of crop culture.

McCormack and Larson (*21*) wrote, "Perhaps we can afford to take as long as 25 years" to acquire the knowledge needed about "rates of formation of favorable root zone in various...parent materials, about methods of tillage that will hold soil erosion to very low levels, and about restoring the productivity of severely eroded soils." Unrelenting emphasis must be focused, first and foremost, on the second of these three categories. Undoubtedly, some eroded soil profiles can be restored to a productive state if sufficient depth of suitable soil material remains. The profitability of such restorations depends upon the costs of correcting or overcoming the deficiencies in productive capacity resulting from excessive erosion. These costs will not remain constant over time, nor can their trends be predicted accurately. Costs that may seem economically justifiable today are likely to be unacceptable in a century when cropland soil depths will be diminished by an additional four to six inches or more.

A new order of commitment is needed. The goal of achieving soil erosion control compatible with a sustainable agriculture will require efforts driven by a zeal at least equal to that which motivated the all-out crop production programs of the past. Time is short for realizing the year 2030 scenario described earlier. The 25-year horizon posited by McCormack and Larson is even nearer. It can be done, but policies, programs, and technologies cannot achieve the needed soil protection level if the performance standard is rooted in erroneous beliefs and institutionalized deceptions concerning the process of soil development. Acquiescence in unceasing soil resource degradation is not an acceptable public policy choice.

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