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EROSION AND SOIL PROPERTIES

The effects of wind and water erosion on soil are a function of the original soil properties; the sorting and transport processes of erosive agents; and interactions with management practices, climate and landscape position. The relation of erosion to soil productivity is a part of a broader issue. To be able to predict relationships between soil properties and productivity requires that we identify soil properties that are important to productivity, measure those soil properties, and then integrate those measurements into a productivity function. Management practices ameliorate to various degrees the properties of eroded soils and often influence productivity separate from its effects on soil properties. This makes it difficult to quantify erosion-soil property-productivity relationships.

Soil properties comprise a continuum from those easily modified to those nearly unchangeable. One property that is relatively easy to manage is soil nitrogen (N). Fertilizer additions can frequently mask a reduction in soil N resulting from erosion. A more difficult to manage soil property is available water holding capacity that may be modified by topsoil loss. Particle size distribution is another property that is difficult to manage, yet may be significantly modified due to erosion or deposition. In some cases, surface soil properties that are easy to modify or amend are nearly impossible to alter if they occur deep in the soil body. For example, a root-restrictive layer may be easy to modify if it lies near the surface but much more difficult to modify if it is deep in the soil or occurs throughout a major portion of the soil. Properties like nitrogen that are now managed easily may become more difficult to manage in the future, if inputs are reduced to protect water quality. These examples illustrate that soil properties associated with an eroded soil can result in various effects on the ultimate productivity of the soil. The relationship of these properties to soil productivity is dependent to a large extent on our ability to manage a less than ideal, root environment.

This paper is divided into five sections describing past research and future needs in erosion and soil property—productivity research. These include: I. SOIL PEDOLOGIC EFFECTS; II. EROSION EFFECTS ON SOIL CHEMISTRY AND FERTILITY; III. SOIL PHYSICAL PROPERTIES MODIFIED BY MANAGEMENT; IV. WIND EROSION EFFECTS ON SOIL PROPERTIES; and V. IRRIGATION EFFECTS ON EROSION. Each section is followed by a statement of problems that describes some of the issues that were discussed at the workshop. A final section, VI. RESEARCH OBJECTIVES, lists five research objectives that summarize the conclusions of Workgroup 2—Erosion and Soil Properties.

I. SOIL PEDOLOGIC EFFECTS—B.F. HAJEK

Various soil physical and chemical properties have been studied in an effort to quantify and understand yield reductions occurring on eroded soils. As for any interdependent system such as soil-crop relations, there seem to be few clear-cut answers. Properties of the A horizon are important in determining plant productivity because a large percentage of the root system occurs in this horizon. These properties are determined in large part by properties of the original soil profile. However, erosion generally results in two characteristic changes: (1) a thinner A horizon and (2) the incorporation of subsoil properties, such as more clay, into the surface soil. Langdale et al. (1979a) described these two factors as primary indicators of erosion on Alfisols and Ultisols in the southeastern United States. As topsoil thins and clay increases, bulk densities are often altered (Frye et al., 1982 and Skidmore et al., 1975); available water-holding capacity decreases (Puckett et al. 1985; Frye et al., 1982); organic matter content decreases (McDaniel, 1985); calcium, potassium, and magnesium content change (McDaniel, 1985), and available phosphorus is reduced (McDaniel, 1985; Frye et al., 1982; National Soil Erosion-Soil Productivity Research Planning Committee, 1981; Phillips and Kamprath, 1973).

Recently, landscape position has been identified as a soil property that should be considered in relation to erosion and productivity. Studies of slope position indicated a reduction in yield on shoulder positions (Onstad et al., 1985). Stone et al. (1985) found similar trends, with yield correlating better to landscape position than erosion class. In the North Carolina Piedmont, Daniels et al. (1985) concluded that productivity was affected as much by landscape position as by degree of erosion. In addition, they concluded that erosion appeared to be random on the landscape, although it was related to some landscape features or past treatment. Onstad et al. (1985) found that most accelerated erosion took place on shoulders of interfluves. Landscape position has influenced soil development which in turn partly determines soil properties that influence soil productivity. Soil properties associated with landscape positions are further modified through the sorting and transport processes of erosion. Reduced soil development and increased erosion on the shoulder position of interfluves also may interact to reduce productivity. Although many studies of soil productivity are in the literature, few quantitative investigations of the effects of erosion on soil properties associated with stable, erosional, or depositional landscape positions have been conducted in the United States.

A major concern wherever accelerated erosion takes place is loss of topsoil rich in organic matter. The effects of topsoil loss are increased whenever the soil has root-restrictive horizons or low natural fertility. Examples are the soils of low nutrient status that occur in the southeastern United States. These soils usually have sandy surface horizons; are relatively low in organic matter and base saturation; and vary in thickness to a relatively acid, low base, low-water-holding capacity, argillic horizon.

In addition to organic matter, several surface and subsurface soil properties also affect productivity. Hajek and Williams (1987) through regression analysis, means, and standard deviations evaluated soil properties relative to yield differences between areas with different erosion levels within fields in the Coastal Plains and Tennessee Valley regions of Alabama. These researchers reported that surface thickness, surface and subsurface clay content, free iron oxides, organic matter, and surface layer phosphorus content most frequently were related to yield differences between eroded areas within fields (Tables 1, 2 and 3).

All of these properties have been related previously to erosion (Langdale et al., 1979b; Frye et al., 1982; National Soil Erosion-Soil Productivity Research Planning Committee, 1981). Surface soil thickness and percent clay in the surface (Ap) and subsurface horizons were correlated best with yield differences. Eroded areas with low yields had thin surface layers (A) with high clay contents and abrupt boundaries to relatively clayey, Bt subsurface horizons.

Table 1. Weighted means and standard deviations of soil properties from slightly (1) and moderately (2) eroded soil areas in fields where yields were significantly lower on moderately eroded areas (α 0.10).

	A Thickness		Clay Surface		Clay Subsoil		Fe_2O_3 Surface		Fe_2O_3 Subsoil	
	1	2	1	2	1	2	1	2	1	2
	cm		%							
	Coastal Plain*									
Mean	23	13	10	16	23	29	1.6	2.0	2.9	3.3
SD	3	3	4	5	6	5	0.4	0.6	0.9	0.9
	Tennessee Valley**									
Mean	18	11	25	34	35	45	2.8	3.5	3.6	4.2
SD	3	3	6	6	6	8	1.1	1.3	1.4	1.6

*Coastal Plain weighted means represent data from Paleudults with fine-loamy texture, siliceous mineralogy, thermic temperature regimes, and include two soils from each of three subgroups: Typic, Plinthic, and Rhodic.

**Tennessee Valley weighted means represent Paleudults with clayey texture, kaolinitic mineralogy, thermic temperature regimes, and one soil from each of two subgroups: Typic and Rhodic.

Table 2. Weighted means and standard deviations of organic matter from slightly (1) and moderately (2) eroded soil areas in fields where yields were significantly lower on moderately eroded areas (α 0.10).

	Organic Matter				P	
	Surface		Surface		Surface	
	1	2	1	2	1	2
	%				kg ha^{-1}	
			Coastal Plain*			
Mean	1.35	1.06	0.63	0.47	56	25
SD	0.49	0.84	0.22	0.14	27	15
			Tennessee Valley**			
Mean	1.20	1.08	0.58	0.52	50	34
SD	0.35	0.35	0.23	0.12	25	19

*Coastal Plain weighted means represent data from paleudults with fine-loamy texture, siliceous mineralogy, thermic temperature regimes, and include two soils from each of three subgroups: Typic, Plinthic, and Rhodic.

**Tennessee Valley weighted means represent Paleudults with clayey texture, kaolinitic mineralogy, thermic temeprature regimes, and one soil from each of two subgroups: Typic and Rhodic.

Table 3. Surface soil and characteristics and correlations obtained by multiple regression analysis.

	Clay	Free Iron Oxides	P	pH	Organic Matter	Yield
	(r^2)					
Surface thickness	0.57	0.45	0.50	0.22	0.12	0.61
Clay	1.00	0.58	0.42	0.36	0.32	0.48
Free iron oxides	—	1.00	0.54	0.10	0.48	0.44
P	—	—	1.00	0.34	0.10	0.28
pH	—	—	—	1.00	0.15	0.17
Organic matter	—	—	—	—	1.00	0.31

The dynamic changes in soil properties resulting from the factors of soil formation (time, biologic, geologic, climatic, and landscape) must be included in any description of erosion effects on soil properties. Prediction of erosion effects on soil properties and subsequent management require a thorough understanding of their relationships with soil-forming factors and production of biomass. Research must address the prediction of long- and short-term effects of erosion, climatic change, and other soil-degrading factors on productivity.

Current productivity indices range from estimates of yields for soil series to potential yields based on empirical equations. A process-based productivity index would provide better predictions of productivity changes caused by wind and water erosion and subsequent restoration. Process-based models could provide a tool for evaluating short- and long-term effects of soil degradation on productivity and establishing local and regional standards for assessments of erosion effects and costs. Sensitivity analysis of input data and validation of models for productivity index application will require regional research efforts.

The extent of acceptable annual soil removal is usually defined in relation to expected rates of soil development. However, these expected rates are not scientifically based. A soil development model is needed to determine soil formation rates and to predict the ability of soil to regenerate lost components and attributes, either naturally or by man-induced practices. The model should address both surface (A horizon) and subsoil (B horizon) development. When based on the five soil forming factors, the model will unify generalizations that can be made about environmental changes from cultural and geological erosion.

Statement of Problems

1. A better understanding of topsoil development rates are needed in terms of the kinetics and energetics of formation and/or reclamation. What are the rate controlling steps in topsoil formation, what soil properties limit this process, and how do management practices affect these soil properties?
2. We need to better quantify the relationship of subsoil attributes and reduced organic matter in the surface horizon to those factors (biological, chemical, and physical) that are important for development of improved soil structure (e.g., the formation and stabilization of macropores).
3. We need to quantify the relationship of subsoil properties to root growth and development below the A horizon.
   a. To what extent can development of macropores alleviate the effects of a root restrictive layer or horizon?
   b. There are various degrees of restriction to root growth that occur in the soil profile. What is the critical reduction in root mass or surface area with depth of the soil profile that will result in a loss of soil productivity for specific crops and climatic regions?
4. The degree of measurement accuracy that is acceptable for crop yield and soil properties in process-based productivity models, and for data layers in information systems must be determined.

II. EROSION EFFECTS ON SOIL CHEMISTRY AND FERTILITY—J.F. POWER

Soil erosion is a selective process in which soil particles and aggregates are selectively sorted and removed from surface soil. Because this process occurs at the soil surface, eroded materials are normally high in organic matter and nutrient content (Table 4). Selective removal of these nutrient-rich soil particles by

Table 4. Mean composition of surface soil and eroded material from a group of six watersheds in Indiana with an average soil loss of 19.7 Mg ha^{-1} yr^{-1} (Stoltenberg and White, 1953).

	Organic matter	N	P	K	$CaCO_3$ and $MgCO_3$
	---------- % by				weight
Surface horizon	3.3	0.16	0.02	0.01	1.0
Eroded material	4.1	0.28	0.04	0.06	1.5

erosion leaves behind a surface soil depleted, to various degrees, of plant-available nutrients. This phenomenon has been documented (Aguilar et al., 1988; Barrow and Kilmer, 1963; Zobeck and Fryrear, 1986).

The soil erosion process also changes the environment in the remaining surface soil (Foster et al., 1985). If soil texture is not significantly changed by erosion, depletion of organic matter and organic-rich soil aggregates by erosion may result in a higher bulk density in the remaining surface soil, with less total porosity, especially macroporosity (over 30 m in diameter). Water infiltration rate frequently is reduced by erosion. As a consequence of these changes, the erosion process may greatly alter the degree of water saturation and drainage of remaining soil pores. Often, erosion results in a shift in the pore size distribution toward smaller diameter soil pores. This could reduce internal soil drainage and decrease air filled porosity. A reduction in air filled porosity provides greater opportunity for populations of anaerobic (including denitrifying) organisms to increase in eroded soils (Larson et al., 1985). A consequence of this change can be greater potential for denitrification, thereby reducing nitrogen-use efficiency. Linn and Doran (1984) showed that about 60% water-filled pores (WFPS) was near optimum for aerobic processes (respiration, nitrification, plant root activity) and that anaerobic processes such as denitrification dominated when WFPS exceeded about 80%. Thus, with a given water input from rainfall or irrigation, soils with greater bulk density tend to remain at or above 80% WFPS for a longer period of time than soils with lower bulk density (unless macroporosity is significant, as often occurs in sandy soils). Because soil erosion selectively removes organic-rich high porosity aggregates and tends to slow internal drainage, the likelihood of significant denitrification losses is greater in eroded than in noneroded soils. However, other factors such as soluble organic carbon also influence denitrifying microbial populations.

Other soil environment factors that affect microbial activity and subsequent nutrient cycling (especially for nitrogen, phosphorous, and sulfur) include temperature regimes, soluble organic carbon concentrations, and aeration. To a large extent, aeration is controlled by soil water regimes because soil pores are occupied by either air or water. Thus, WFPS largely defines aeration regimes as well as water regimes. An exception may occur in carbon-rich zones of soil (near decaying crop residues for example) where prolific growth and respiration by aerobic soil organisms may temporarily deplete soil oxygen levels more rapidly than oxygen can diffuse to the soil microsites.

The effects of soil erosion on soil temperature and soluble organic C supply are highly variable. Soil temperature regimes are affected to a large extent by soil water content, with wet soil experiencing fewer extremes in temperatures than dry soil. Also, evaporation of water from a wet soil has a cooling effect, often providing wet soils with lower temperatures than dry soils. In early spring, reduced soil temperature in the surface of a wet, eroded soil may be sufficient to significantly reduce microbial activity and mineralization of N, P and S for plant use. An eroded soil surface, compared to a non-eroded soil, may contain less soluble organic C to serve as an energy source for soil organisms because of lower organic matter content and less growth of crops to serve as a source of organic C.

The effects of soil erosion on soil productivity are highly dependent upon landscape position. For example, Jones et al. (1989) showed for five different soil catenas in Nebraska that most or all the topsoil had been eroded from soils located on the shoulder, upper linear, or lower linear parts of hillslopes. On interfluve or footslope positions, they usually found 20 cm or more of topsoil. For these mollisols, they found little relationship between soil thickness and soil nutrient status, but topsoil thickness was related to crop yields and net income. A number of other studies likewise have shown a close relationship between topsoil thickness and crop yield (Mielke and Schepers, 1986; Power et al., 1981; Carlson et al., 1961; Olson, 1977; Olson and Nizeyimana, 1988). These and additional studies suggest that the quantity of organic C in a soil is the one soil property that has an overwhelming effect on soil productivity.

Fertilizer applications to eroded soils often result in large responses in crop yield, but maximum yields attained on eroded soils are frequently 10 to 20% less than those obtained on non-eroded soils. Such results suggest that growth factors in addition to nutrient availability restrict crop growth—most likely soil physical properties affecting aeration, water relations, and soil strength. Again, these are soil properties that are influenced by organic C content.

Soil erosion is a major mechanism by which nutrients are lost from soils. Larson et al. (1983) estimated that 9.5, 1.7, and 7.9 Gg of N, P and K, respectively, were in the sediments eroded annually from United States soils. The quantity of N removed by erosion is approximately equal to the quantity added each year in fertilizer, but exceeds the quantity of N removed annually in harvested crops (Power and Papendick, 1985). These figures illustrate very well the magnitude of the consequences of soil erosion on the fertility of United States soils.

Soil management practices used to control erosion also dramatically influence soil nutrient balance and nutrient availability. A common method of controlling soil erosion is to maintain crop residues on the soil surface. Larson et al. (1978) showed that removal of crop residues hastens depletion of soil N. For Major Land Resources Area 105 in the midwestern Corn Belt, removal of corn residues resulted in a loss of 65 kg N ha^{-1} plus 110 kg N ha^{-1} lost from soil erosion (a total loss of 175 kg N ha^{-1}), compared to soil erosion losses of only 45 kg N ha^{-1} when residues were maintained on the soil surface (Table 5). Cover crops could be used to increase the amount of crop residue available. As mentioned earlier in this report, maintaining crop residue on the soil surface also greatly alters the soil environment and subsequent nutrient cycling. This subject is discussed in more detail in Power and Doran (1988). From this information, one might again conclude that practices that enhance soil organic C content are likely also to enhance productivity.

Table 5. Calculated quantity of N removed from soil as affected by corn residue management for two Land Resource Areas in Minnesota. (Larson et al., 1978).

Management system	Land Resource Area 102	Land Resource Area 105
	- - - - - - - - kg N ha^{-1} - - - -	
Residues removed		
N in residues	38	65
N in sediment	50	110
Total	88	175
Residues retained		
N in sediment	20	45

Soil erosion results in direct nutrient removal with sediment and may change nutrient availability by altering the biology of the soil environment. Eroded soils are usually low in organic matter and often poorly aggregated. These conditions result in lower soil water retention and less biomass production, which subsequently reduces the amount of energy provided for microbial activity. This lack of soluble carbon, couples with a less favorable habitat for most soil organisms, often limits cycling and availability of soil nutrients in eroded soils.

Statement of Problem

1. Development of a more quantitative relationship between the soil physical environment and microbial population dynamics is needed in order to understand the effects of erosion on nutrient cycling.
   a. If erosion changes the distribution of macropores in the surface horizon, what is the relationship of changes in macropore/micropore spatial distribution on microbial populations and nutrient cycling?
   b. Which soil physical properties are the most critical to nutrient cycling, and when are the relations critical?
2. We need to quantify the influence of erosion on the flow of energy and carbon in the soil system. What is the significance of reduced soluble carbon compounds on nutrient cycling in eroded systems?
3. We need to determine energetics of aggregate formation and stabilization, since aggregates are the primary determinants of soil structure, particularly in fine-textured soils.
4. A better understanding is needed of the role of biological organisms in determining nutrient availability, especially phosphorous and organic N, in an eroded soil.

III. SOIL PHYSICAL PROPERTIES MODIFIED BY MANAGEMENT—B. LOWERY

Topsoil physical properties are very difficult, if not impossible to restore to the original pre-erosion state. Larson et al. (1983) note that many soils have B horizons that are unfavorable for plant root growth such as horizons with excessive accumulations of clay (argillic), high density and strength (fragic), cement-like qualities (duric), low pH (acidic), salt accumulation (salic), and high aluminum saturation. Soil erosion alters physical, chemical, and biological properties of topsoil and exposes the B horizon. Crop production is reduced because the exposed soil often has properties that are very different from those of the original surface soil and usually require a higher level of management. The need to eliminate soil erosion is foremost, but the second most important problem (which is often overlooked) is how to manage eroded land.

Surface soil properties can be managed to various degrees. The physical environment of soil has been difficult to measure accurately and manage. However, it is possible to change surface soil physical properties through appropriate management systems. This suggests that the physical environment of eroded soils may be amenable to improvement.

Physical properties of the surface horizon of some soils in the United States are similar to those in the B horizon of other soils that are unfavorable for plant root growth (Larson et al., 1983). Examples include: soils with high clay content, such as clay pan soils in Missouri or Clear Lake soil in California; high salt content; and low organic matter surface horizons. This suggests that it may be possible to apply management techniques developed for these soils to improve productivity of some eroded soils. The management techniques used will depend on the ability to identify similarities between the different types of soil.

Many of the physical properties associated with eroded soils can be improved with proper management. Wei et al. (1985) found that when dewatered sewage sludge, a concentrated source of organic matter, was applied to a Kewaunee silt loam soil over a period of 6 years, bulk density decreased, and saturated hydraulic conductivity and aggregate stability increased. Seaker and Sopper (1988 a,b) used municipal sludge to reclaim minespoil. They used microbial populations, organic matter content, and plant growth as measures of the reclamation process. They found that ecosystem recovery, organic matter content, and yield were much greater on the sludge-amended sites than on fertilizer-amended sites.

Low soil water status is commonly indicated as the cause of low productivity on eroded soils (Langdale et al., 1979b; Frye et al., 1982; Andraski et al., 1986; Swan et al., 1987). Potential management techniques that improve soil water availability include surface mulch and irrigation. Batchelder and Jones (1972) artificially removed topsoil from a Typic Hapludult, clayey, mesic soil, and found that non-irrigated corn yields were very low. Corn yields from exposed, irrigated, subsoil sites with and without mulch and from non-irrigated subsoil with mulch were equivalent to those from irrigated surface soil and were significantly higher than those from non-irrigated surface soil. Irrigation of eroded soils can be problematic because they are located on steep slopes conducive to runoff and may have lower infiltration rates and reduced aggregate stabilities.

Improvement of eroded soil must take into consideration the entire array of soil properties and interactions with climate. For example, the use of productivity index models requires adaptation to specific climatic zones and to the presence of gravel layers within the soil profile (Lal, 1988). A management practice designed for its effects on surface soil properties for a specific climatic zone may not have the desired effect on productivity when applied to a similar soil from a different climatic zone, or a soil with different subsoil properties.

Statement of Problems

1. We need to identify types and amount of organic materials (i.e., crop residues, green manure, sewage sludge, etc.) that can be used to alter physical properties of eroded land.
2. Evaluation is needed to determine the accuracy of characterization methods, such a soil test calibration, for eroded land.
3. We need to evaluate the potential use of management practices such as conservation tillage, cropping systems, and irrigation to improve storage and plant water availability in eroded soils.
4. A better understanding of organic matter by clay complex interaction is needed to better quantify the organic compounds that are most important in improving soil structure of eroded soils, especially those properties associated with water transport and root growth.

IV. WIND EROSION EFFECTS ON SOIL PROPERTIES— E.L. SKIDMORE

Potential for wind erosion is severe in arid and semiarid areas, because dry soil surfaces are devoid of vegetative cover and strong winds commonly occur.

Agricultural areas most susceptible to wind erosion include much of North Africa and the Near East, parts of southern and eastern Asia, the Siberian Plains, Australia, southern South America, and the semiarid, and arid portions of North America.

Wind erosion significantly alters soil physical and chemical properties. In extreme cases, soil may or may not exist at a point in the landscape because of wind erosion. Loess soils are aeolian deposits that were formed by wind erosion, but the area that supplied the loess suffered a negative sediment balance. In addition to total mass removal during wind erosion, soil is selectively removed, thus, changing soil properties. Several studies have noted significantly more organic matter present in wind-eroded sediment compared to the parent soil (Warn and Cox, 1951; Laprade, 1957; Gile and Grossman, 1979; Hagen and Lyles, 1985; and Zobeck and Fryrear, 1986). Although the amount of nutrient eroded varies among nutrients, amounts in eroded soil generally range from 1 to 3 times the amount found in the eroding surface soil (Hagen and Lyles, 1985; Zobeck and Fryrear, 1986). The selective removal of soil particles can also produce dramatic changes in the texture of the soil surface. This is illustrated by an example from southern New Mexico. Replicated samples were taken by Skidmore (unpublished) from three coppice dunes and subdunes in areas which are part of the Desert Project (Gile et al., 1981) and the Jornada Experimental Range. One of the dunes (study area 5b) was bisected with a trench to about 1 meter below ground level. Bisection revealed a clear demarcation between the original ground level and the dune material. Dunes in this area recently originated probably from nearby surface soil. Higher sand content in the dune than in the subdune is in the direction one would expect from winnowing by wind erosion (Table 6). Fine particles are removed, which tend to concentrate sand as erosion continues. Some desert sands of the Sahara are said to have blown so much that all fine material has been removed, and they now blow without even emitting dust. Likewise winnowing has removed essentially all of the silt, and clay-size particles from Jornada interdune sand.

Table 6. Comparison of dune and subdune texture.

Treatment	Site	Sand	Silt	Clay	GMD
		%	%	%	mm
Coppice dune	Study Area 5b*	89.4	4.3	5.9	0.1160
Subdune	Study Area 5b	84.7	7.7	7.5	0.0915
Coppice dune	Study Area 16a*	82.6	10.2	7.0	0.0735
Subdune	Study Area 16a	36.8	40.8	23.0	0.0102
Coppice dune	Jornada B**	89.4	4.6	5.7	0.1093
Subdune	Jornada B	83.7	6.0	9.8	0.0800
Interdune sand	Jornada B	98.3	0.3	1.1	0.2530

*Gile et al. (1981)
**USDA-ARS, Jornada Experimental Range

The Jornada coppice dune is much like the dune in area 5b, with about the same difference (5%) in sand concentration between the dune and subdune (Table 6). However, the dune at study site 16a has a very much greater sand concentration than the subdune. Contrasting features between the dune and subdune indicate that most of the dune materials did not originate locally.

An example of sand accumulating in piles from wind erosion is in the Rio Grande flood plains of the San Luis Valley, south Colorado. At the eastern edge of that valley, which stretches between two mountain ranges, are vast hills of sand. As soil in the arid valley was eroded by wind, the suspended material (<100 um) escaped the valley. But the wind blew the sand across the desert valley, until it was blocked by the Sangre de Cristo Mountain.

An example of textural change of agricultural soils was given by Lyles and Tatarko (1986). They compared the change in particle size distribution in the top 10 cm of soils at 10 sites in western Kansas over a 36 year period between 1948 and 1984 (Table 7). The sand fraction increased at all but one site, with the increase ranging from 0.9 to 23.3 percentage points. The greatest changes occurred in moderately coarse and coarse textured soils.

Table 7. Comparison of change in primary particle size distributions and GMD (Geometric Mean Diameter)* in 1948 to 1984 in the upper 10 cm of the soil at 10 sites in western Kansas. After Lyles and Tatarko (1986).

**Sub-group	Sand 1948	Sand 1984	Silt 1948	Silt 1984	Clay 1948	Clay 1984	GMD 1948	GMD 1984	Change in GMD
	%						mm		-%-
1	8.9	9.8	72.4	67.0	18.7	23.2	0.0065	0.0057	-12.3
2	23.8	27.1	60.4	55.6	15.8	17.3	0.0123	0.0130	5.7
3	13.0	15.6	60.9	59.7	26.1	24.8	0.0056	0.0065	16.1
4	61.7	80.5	30.2	11.3	8.1	8.2	0.0613	0.1169	90.7
5	49.7	49.4	35.9	33.1	14.4	17.5	0.0317	0.0278	-12.3
6	5.8	8.5	69.1	69.3	25.1	22.2	0.0046	0.0056	27.7
7	8.6	11.2	71.9	65.7	19.5	23.1	0.0063	0.0060	-4.8
6	56.9	80.2	31.6	14.7	11.5	5.2	0.0455	0.1295	184.6
8	85.0	93.5	12.0	2.8	3.0	3.7	0.1674	0.2184	30.5
8	76.4	78.8	18.2	11.4	5.4	9.8	0.1132	0.1036	-8.5

*Calculated from: GMD = $Q(x_i)^{m_i}$ where Q is product operator, m_i is the mass fraction represented i=1 by size class i, x_i is the geometric mean diameter of class i, and GMD is the geometric mean diameter.

**Soil Subgroups: 1. Aridic Argiustolls; 2. Aridic Haplustolls; 3. Ustollic Haplargids; 4. Udic Paleustalfs; 5. Aridic Haplustalfs; 6. Udic Argiustolls; 7. Aridic Argiustolls; 8. Psammentic Haplustalfs

Soil erodibility as indicated by aggregate status is influenced by past management systems, yearly and seasonal fluctuations, and erosion events. Aggregate formation and degradation involve a complex interrelationship of biological, physical, and chemical reactions. Management systems directly and indirectly affect these inter-relationships. A study conducted in Kansas showed that although residue management had little effect on soil physical properties, crop species significantly affected soil aggregate properties (Skidmore et al. 1986). Soil aggregates from grain sorghum plots were smaller, less dense, and more fragile than those from wheat plots. The soil aggregates from the sorghum plots had lower dry aggregate stabilities (dry sieving technique), but had higher wet aggregate stabilities (moist sieving technique) than those from wheat plots. Differences between crops could not be attributed to differences in soil organic matter content.

Wind erosion ravages the Great Plains and other erosion-prone areas to some extent in each erosion season. The Soil Conservation Service (SCS) surveys and reports land damaged by wind erosion. Last season, SCS reported more than 13 million acres of land damaged. Although on-site damage can be great, Huszar (1988) concluded that offsite costs of wind erosion dwarf on-site costs. Off-site damages include increased need for interior house cleaning and laundry; damaged landscaping; impacts to exterior paint, health, recreation; and road maintenance costs.

Another area of concern is the impact on wind erosion of the climate changes induced by the greenhouse effect. It is uncertain how the projected higher temperatures will affect precipitation patterns, surface soil wetness, surface windspeed, and plant biomass. However, an increase in aridity, as projected for America's heartland, would increase the wind erosion hazard.

In summary, wind erosion physically removes the most fertile portion of the soil from fields and, therefore, lowers productivity. Some soil from damaged lands is suspended and becomes part of the atmospheric dust load. The suspended dust obscures visibility and pollutes the air, causes automobile accidents, fouls machinery, and irritates the homemaker. Blowing soil fills road ditches; buries fences; damages landscapes; reduces seedling survival and growth; lowers the marketability of vegetable crops like asparagus, green beans, and lettuce; and increases the susceptibility and transmission of some diseases.

Although past research on wind erosion has been reasonably accepted and implemented, significant gaps exist in our understanding and technology. The sorting and transport processes of wind erosion can result in significantly different soil properties compared to those resulting from water erosion. Also, the soil properties associated with resistance to wind erosion are highly dependent on dry soil aggregation.

Statement of Problem

1. We need to quantify effects of soil textural change caused by selective removal and deposition on hydrologic relationships and aggregate status.
2. Plant damage, and population reduction caused by wind erosion and impacts on production should be quantified.
3. We should determine the concentration and fate of plant nutrients and agricultural chemicals contributed by wind erosion to the atmosphere aerosol.
4. We need to determine if climate changes induced by the greenhouse effect will alter the extent and severity of global wind erosion.

V. IRRIGATION EFFECTS ON EROSION—R.E. SOJKA

Seventeen western states account for 83% of the 23.9 million hectares that are irrigated in the United States. Sprinker irrigation occurs on 31% of the total land irrigated whereas subirrigation, furrow, basin flood, or other types of overland flow methods account for the remaining 16.4 million irrigated hectares (Irrig. J. 1989). Although irrigation development in the western U.S. was nearly completed by 1944, continued development occurred during the 1960's and 1970's. Further expansion has been impeded by the lower commodity prices of the 1980's (CAST 1988). Although irrigated area represents only 10 to 17% of the total production area in the United States, the proportional value is much larger, because irrigated crops have significantly higher yields and quality, and include higher value vegetable, horticultural, and specialty crops.

Water erosion from irrigated farmlands is a serious problem, especially in the older irrigated area of the West (Koluvek and Tanji, 1989). Erosion commonly removes 5 to 50 t ha^{-1} yr^{-1} from furrow-irrigated fields and as much as 141 t ha^{-1} yr^{-1} from the inlet (upper) ends of fields (Berg and Carter, 1980; Kemper et al., 1985; Fornstrom and Borelli, 1984). As much as 50.9 t ha^{-1} soil loss has been measured from a single 24-hr irrigation set (Mech, 1959). Sediments are the largest single pollutant of surface drainage waters in southern Idaho (Brown et al., 1981). Sediment concentrations have ranged from 0.02 to 15 g l^{-1} in surface irrigation return flows (Brown et al., 1974). In 40- to 80-year old tracts, exposure of calcareous subsoils on the upper one-third to one-half of irrigated fields is common, seriously impairing the productivity of the eroded areas (Carter et al., 1985; Carter, 1989a, 1989b). Organic matter accumulation is extremely slow in the arid West, making soil restoration exceedingly difficult. Because irrigation return flows usually are channeled directly to rivers and riparian areas, erosion on irrigated land carries added pollution risks.

Various measures are used to mitigate erosion of irrigated land (Carter et al., 1989), including settling points (Brown et al., 1981), buried drains and minibasins (Carter and Berg, 1983), straw placement (Brown and Kemper, 1987; Berg, 1984), and sodded furrows (Cary, 1986). However, these measures are often expensive or management intensive. Other methods of management such as conservation tillage need to be examined in the context of irrigated lands.

Many of the factors governing erosion processes from irrigation are either unknown or violate existing water erosion model assumptions (Trout and Neibling, 1989). These processes are further complicated by the characteristics of specific irrigation systems. Salt species and concentrations vary with irrigation water source, time of year, soil and landscape position. Divalent cations such as Ca^{++} or Mg^{++} reduce clay dispersion and aid aggregation, whereas Na^{+} salts increase clay dispersion. The effects of water SAR (sodium adsorption ratios) and soil ESP (exchangeable sodium percentage) on erosion processes and their interaction with clay mineralogy have not been studied. These effects are likely significant, because suspended sediment concentrations affect furrows surface-seals, intake rates, and furrow erosion (Brown et al., 1988; Eisenhauer, et al, 1983), sometimes in contradiction to existing theory.

Infiltration varies systematically in time and space for both sprinkler and furrow irrigation. High application to some areas under center pivot irrigation results in water flow onto soils with a high degree of spatial variation in soil water content. Infiltration of the runoff is dependent on the effects of spatial factors affecting the direction of runoff flow and the soil water content. As water runs downslope in furrow irrigation, the stream attenuates because of infiltration into drier soil, rather than growing larger with runoff accumulated from upslope. The highest initial and lowest outlet flow velocities in furrow irrigation can be associated with the shallowest slopes, as a requirement to push water across a long flat field. This is the reverse of downslope runoff accumulation from rainfall. Furrow shapes are controlled and regular and, unlike rills, are restricted from meandering (Carter, 1989b). Field compaction is often managed spatially to provide rapid water conveyance and more even intake over the length of the furrow, while allowing unimpeded upward and lateral infiltration from the furrow into beds between the furrow. Interrupted flow techniques (surge irrigation) rapidly reduce erosion potential of a given furrow by altering the pore geometry of surface seals and managing water potential distribution in the surface few centimeters of furrow soil to increase resistance to soil detachment. Row width, irrigation set time, crop species, and planting geometry relative to the furrow interactively affect furrow infiltration and erosion (Sojka nd Brown, unpublished data).

Although many of the physical and chemical processes that cause erosion from irrigated land are similar to those occurring with rainfall, the processes occur in combinations or under conditions that are unique to irrigation. These unique conditions and combinations of processes as in the case of water quality considerations, are either totally unaccounted for or are erroneously extrapolated in existing water erosion models. Empirical parameters and model assumptions developed for rainfed conditions often do not apply to erosion under irrigation. The process of irrigation and quality of irrigation water can also result in increased hazard of wind erosion between water applications. Soil erosion under these circumstances may proceed in cyclical events of water erosion exposing and transporting soil materials which is then sorted and further transported by wind.

Statement of Problems

1. We need to better describe the interaction of water quality and soil properties on water and wind erosion of irrigated lands.
2. Process-based models need to be developed to describe the unique physical and hydrological circumstances encountered within the range of commonly used irrigation methodology and their interaction with water quality and water management.
3. Management systems which are less expensive and labor intensive are needed to protect irrigated lands from erosion.

VI. RESEARCH OBJECTIVES

1. Develop a process-based soil genesis model for predicting soil profile development with or without the influence of agricultural activities.
2. Describe the soil aggregation and nutrient transformation processes as influenced by management practices, biological activity, and organic carbon inputs.
3. Develop a process-based productivity index to evaluate soil productivity changes caused by soil erosion and/or restoration by management practices.
4. Quantify wind erosion effects on aerial transport of soil-bound agricultural chemicals, plant abrasion, soil hydrology, and soil aggregation.
5. Describe the interaction of water application techniques, soil properties and irrigation water quality on erosion of irrigated lands.

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