AGRICULTURAL PRACTICES AND WATER QUALITY

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CHAPTER THREE

LAND AND WATER MANAGEMENT FOR MINIMIZING SEDIMENT

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SEDIMENTS are primarily soil particles washed into streams by water. They are products of land erosion and are largely derived from sheet and rill erosion from upland areas, and by cyclic erosion activity in gullies and drainageways. It is estimated (Wadleigh, 1968) that at least half of the 4 billion tons of sediment washed annually into tributary streams in the United States is coming from agricultural lands.

Erosion can be natural or can be accelerated by man's activities. Natural or geologic erosion pertains to that occurring under natural environmental conditions. Man-made or accelerated erosion is that induced by man through reduction of natural vegetative cover and improper land use, and occurs at a rate greater than normal for the site under natural cover.

Although sediment yield and soil erosion are not synonymous, they are closely related—and occasionally used interchangeably. Sediment yield can be defined as the quantity of soil material transported into a stream. Soil erosion refers to detachment and movement of soil particles on site, but does not imply movement into stream channels. Thus, soil erosion is a primary requisite for sediment production. The most logical and direct approach to solving our agriculturally related sediment problem is the stabilization of the sediment source by controlling soil erosion through the use of proper land and water management practices or structures. In short, to minimize sediment yield, soil erosion must be minimized.

Soil erosion occurs in two basic steps (Smith and Wischmeier, 1962): (1) detachment of soil particles from adjacent particles by raindrop impact and splash, and (2) transport of detached particles by flowing water. Only when conditions for these steps exist does soil erosion become a serious problem as a direct source of sediment. Soil erosion by water is a physical process requiring energy, and its control involves the dissipation of energy—that of falling raindrop impact and splash, and that due to elevation differences which affect the flow velocity of water.

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The present state of knowledge concerning the mechanics and hydrology of soil detachment and transport have already been adequately reviewed (see Chapter 1). The properties of sediments from agricultural lands have been described and interpreted (see Chapter 2). It is the purpose of this chapter to briefly review management practices for controlling soil erosion to minimize consequent sediment production from agricultural lands. Emphasis will be on sediments derived from sheet-rill or microchannel erosion. This does not imply that sediments resulting from gully or macrochannel erosion are not serious contributors to total sediment yield. However, it has been shown that the best method of controlling gully erosion is to minimize runoff and sheet erosion above a gully or potential gully site (Jacobson, 1965).

FACTORS AFFECTING SOIL EROSION BY WATER

The Universal Soil Loss Equation (Smith and Wischmeier, 1962) provides a framework for discussing erosion control measures. In this equation, soil erosion is described as a function of rainfall, soil properties, slope length and steepness, cropping sequence, and supporting practices.

At present, little can be done to readily change the amount, distribution, and intensity of rainfall per se, but measures can be adopted to modify its erosiveness—that is, to decrease raindrop impact and splash energy or to decrease the amount and velocity of overland flow, or both—to minimize sediment production.

Soil properties affect both detachment and transport processes. Detachment is related to soil stability, size, shape, composition, and strength of soil aggregates and clods. Transport is influenced by permeability of soil to water which determines infiltration capabilities and drainage characteristics, aggregate stability which influences crusting tendencies, porosity which affects storage and movement of water, and soil macro-structure or surface roughness which creates a potential for temporary detention of water.

The slope factor determines the transport portion of the erosion process since flow velocity is a function of hydraulic gradient which is influenced by slope length and steepness. The remaining two factors, cropping sequence and supporting practices, serve to modify either the soil factor or the slope factor or both, as they affect the erosion sequence.

Water runoff and accompanying soil erosion resulting from rainstorms are inversely related to the water infiltration capacity of soil, plus any surface storage capacity. Hence, one way to prevent erosion would be to maintain high water intake rates and surface ponding capacities at levels sufficient to prevent runoff from all rainstorms (Meyer and Mannering, 1968). This is seldom possible, but any increase in infiltration capacity and surface and subsurface storage capacity can greatly reduce erosion as well as benefit crop water supply. In most cases water intake and storage capacities are not sufficient to prevent runoff. Soil erosion then becomes a func-

TABLE 3.1. Effect of rates of applied wheat straw mulch on runoff, infiltration, and soil loss from Wea silt loam with 5% slope.

Mulch Rate	Surface Cover	Water Applied*	Runoff	Infiltration	Soil Loss
(tons/a)	*(%)*	*(inches)*	*(inches)*	*(inches)*	*(tons/a)*
0	0	6.25	2.83	3.42	12.42
¼	40	6.25	2.50	3.75	3.23
½	60	6.25	1.58	4.67	1.42
1	87	6.25	0.30	5.95	0.30
2	98	6.25	0.09	6.16	0.00
4	100	6.25	0.00	6.25	0.00

Source: Adapted from Mannering and Meyer (1963).
* Water applied at constant intensity of 2.5 inches per hour.

tion of runoff velocity and the resistance of the soil to the forces of flowing water.

Laboratory studies have shown that the amount of energy required to initiate runoff was a function of clod size (Moldenhauer and Kemper, 1969). Rough, cloddy surfaces enhanced water intake and contributed to surface detention of water, even after water intake was reduced by pore sealing. It was apparent that large clods created many steep micro-slopes. Dispersed particles from soil peaks eroded into depressions, leaving exposed areas still receptive to water.

A vegetative cover or surface mulch is one of the most effective means of controlling runoff and erosion (Duley and Miller, 1923; Borst and Woodburn, 1942; Baver, 1956; McCalla and Army, 1961; Smith and Wischmeier, 1962). Wheat straw mulch applied on freshly plowed land at a rate exceeding one ton per acre almost completely eliminated runoff from, and controlled erosion on, a 5% slope, as shown in Table 3.1 (Mannering and Meyer, 1963). Mulch on the surface protected it from raindrop impact energy, reducing detachment of soil particles and surface sealing. In so doing, high water intake rates were maintained. The effectiveness of mulch in maintaining high intake rates was correlated with the proportion of the surface covered. In addition, the mulch created barriers and obstructions that apparently reduced flow velocity and carrying capacity of runoff. This was evident especially at the ¼- and ½-ton mulch applications where total runoff was 87 and 56%, respectively, of the zero mulch treatment. In contrast, soil loss was 27 and 11%, respectively, of the zero rate.

In another study (Meyer and Mannering, 1968), runoff velocity was measured as a function of mulch rate. Five inches of simulated rain were applied at a constant intensity of 2.5 inches per hour to soil treated with straw mulch at various rates. Data shown in Table 3.2 indicate that small amounts of surface mulch caused considerable reduction in flow velocity. Moreover, large reductions in erosion rates were associated with relatively small reductions in flow velocity. This was not unexpected because the quantity of material moved is considered proportional to about the fourth power of velocity.

In a laboratory study, Kramer and Meyer (1968) studied the effects

TABLE 3.2. Effect of applied wheat straw mulch on runoff velocity, and soil loss from Wea silt loam with 5% slope.

Mulch Rate	Runoff	Runoff Velocity*	Soil Loss
(tons/a)	*(inches)*	*(ft/min)*	*(tons/a)*
0	3.3	26	14.5
¼	2.8	14	5.8
½	2.4	12	3.7
1	2.0	7	1.7

Source: Adapted from Meyer and Mannering (1968).
* After application of about 5 inches of rainfall when runoff rates were essentially constant.

of mulch rate, slope steepness, and slope length on soil loss and runoff velocity. Using a glass bead bed to simulate a soil slope, they showed that less than a ton of mulch on the surface reduced erosion on slopes greater than 70 feet long at 4% slope. Mulch rates of less than 1 ton reduced erosion from moderate to steep slopes (4 to 6%). However, on slopes of 3 and 10%, ⅛- and ¼-ton mulch rates did not greatly decrease erosion compared to no mulch. Erosion more than doubled as slopes increased from 8 to 10%. Again, mulch rates ¼ ton or greater reduced runoff velocity considerably. It was noted that for some conditions low mulch rates increased erosion as compared to no mulch. This was attributed to increased flow velocity and turbulence around mulch pieces, causing particle movement.

In some area soil wettability is considered a factor in soil erodibility. Water repellency, often developed as a result of fires on some soils, can cause much sediment production by curtailing infiltration and encouraging runoff. Reduction in erosion is effected by modifying the wetting characteristics of hydrophobic soil. By mechanical or chemical means, soil wettability can be increased so that infiltration rate is increased (Osborn and Pelishek, 1964; De Bano, 1969).

Another means of preventing runoff and increasing total infiltration is through surface storage. Rough soil surfaces can retain several more inches of rainfall than smooth surfaces, due to water being trapped in the depressions of the rough topography (Larson, 1964). Available subsurface storage capacity has also been recognized (Holtan, 1965) to be important in the infiltration process. Thus, for soils to have high infiltration capabilities, they must have a high inherent permeability to water, show resistance to crusting, and have a high surface and subsurface storage capacity.

PRACTICES FOR EROSION CONTROL

Practices or structures for erosion control are designed to do one or more of the following: (1) dissipate raindrop impact forces, (2) reduce quantity of runoff, (3) reduce runoff velocity, and (4) manipulate soils to enhance the resistance to erosion (Meyer and Mannering, 1968).

TILLAGE METHODS AND EROSION CONTROL

The relationship between tillage methods and soil erosion has been reported by many investigators. Principles involved have been well documented (Larson, 1964; Mannering and Burwell, 1968). Some tillage methods deter soil erosion by creating rough surfaces which provide surface storage, reduce runoff, and delay or prevent surface crusting. Other tillage methods provide increased subsurface storage, and still others provide both. There are tillage methods that leave all or part of the residue from previous crops on or near the soil surface, protecting the surface from raindrop forces and enhancing water infiltration. Excessive tillage can be a factor in soil erosion, however, because tillage is a source of energy for breaking soil into erodible sizes just as are rainfall and runoff. Tillage-induced soil conditions play a significant role in soil erosion through effects on the infiltration capabilities of soil (Burwell et al., 1966; Burwell et al., 1968).

On a silt loam soil, 6.7 inches of simulated rainfall, applied at a constant intensity of 5 inches per hour, infiltrated a surface created by moldboard plowing before runoff began. When the soil was plowed, disked, and harrowed, only 2.1 inches of water infiltrated before initiation of runoff. Comparable values for untilled and rotary tilled soil were 0.4 and 0.9 inch, respectively. Cumulative water intake was fifteen times greater on rough, plowed soil and three times greater on plowed, disked, and harrowed soil than on untilled soil. These differences were related to plow layer porosity and to surface roughness (Burwell et al., 1966).

Another study conducted on the same soil compared infiltration of simulated rainfall of mulch-tilled and clean-tilled surfaces (Burwell et al., 1968). The soil was previously cropped to oats. Mulch tillage consisted of a pass with a chisel-type cultivator to a depth of 6 inches. This tillage operation incorporated about half of the oat stubble residue, leaving about 0.6 ton per acre on the surface. Clean tillage consisted of moldboard plowing in the fall, with and without secondary disking and harrowing the following spring, and spring plowing alone. Table 3.3 is a summary of this study. Fall mulch-tilled surfaces provided nearly eight times greater infiltration capacity

TABLE 3.3 Influence of tillage treatment on water infiltration.

Tillage		Infiltration	
Fall	Spring	To initial runoff	During 2" runoff
		(inches)	*(inches)*
Chisel	None	6.7	3.8
Plow	None	1.2	1.6
Plow	Disk, harrow	0.9	0.8
None	Plow	2.1	1.5

Source: Adapted from Burwell, Stoneker, and Nelson (1968).

before runoff started and four times greater infiltration capacity during runoff than did fall-plowed surfaces, disked and harrowed in the spring. Infiltration for fall mulch-tilled surfaces was more than three times greater than for spring-plowed surfaces. Fall-plowed surfaces were altered by fall to spring weathering, resulting in little, if any, infiltration advantage over fall-plowed, spring-disked, and harrowed surfaces. Rainfall action, wetting-drying, and freezing-thawing cycles between fall plowing and spring planting act to disperse soil material which seals the surfaces by filling in depressions and open channels created by plowing.

These representative data indicate that the amount of water entering soil can be controlled significantly by soil physical conditions created by tillage operations. Conventional tillage (plow, disk, harrow) usually creates conditions that restrict water movement. Mulch and other so-called minimum tillage systems can produce soil conditions conducive to water intake. Plowing, followed by disking and harrowing, usually leaves the soil clean or void of crop residue. Rain falling on these bare or only partially covered surfaces washes fine soil into depressions and open channels, resulting in progressive soil sealing. Rate of sealing depends on how cloddy or how rough the surface is after tillage. Where clean tillage is practiced, it should create rough, cloddy surfaces that resist dispersion and subsequent surface sealing so as to delay the first runoff event during the spring.

In a recent summary (Burwell and Larson, 1969) it was shown that prior to initial runoff, tillage-induced roughness accounted for most of the variation in infiltration, whereas differences in pore space caused only minor variations. In contrast, during a 2-inch runoff period, water intake was little affected by roughness or porosity—indicating that surface seals were already formed when runoff started, and overshadowed roughness or porosity changes induced by tillage.

Mulch tillage—a tillage system that loosens the soil without soil inversion—leaves all or most crop residue on the soil surface. This creates a condition highly resistant to raindrop and runoff forces. A comparison of runoff and soil loss from conventional and mulch tillage is typified in Table 3.4. In each instance the benefits of this type of tillage are apparent.

Deep tillage or subsoiling of some soils can reduce soil losses by increasing volume of subsurface storage available for infiltrated water. If deep tillage shatters or fractures a soil pan, this increased storage may be much greater than indicated by the increased depth of tillage. However, subsoiling generally has not been effective unless channels were kept open to the soil surface. If subsequent tillage obliterates subsoiler slots in the surface few inches, little difference in soil loss or infiltration can be expected (Meyer and Mannering, 1968).

Postplanting tillage is used with most tillage systems. If a surface seal has developed, cultivation to break it may materially increase water intake. In a 5-year tillage study (Mannering et al., 1966), cultivation of minimum tilled treatments reduced average runoff from 3.5 to 2.1 inches and soil loss from 16.3 to 9.5 tons per acre as compared to the same treatments uncultivated. Under some condi-

TABLE 3.4. Effect of mulch tillage on runoff and soil losses in the Corn Belt.

Location, Soil, and Slope	Field Practice	Tillage	Runoff	Soil Loss
			(inches)	*(tons/a)*
Wisconsin				
Miami sl, 6%	Noncontoured	Conventional	3.1	22.3
		Mulch	2.5	6.7
Miami sl 9%	Contoured	Conventional	0.8	1.4
		Mulch	0.06	0.01
Fayette sl, 16%	Contoured	Conventional	0.6	2.0
		Mulch	0.05	0.03
Ohio				
Muskingum sl, 9–15%	Contoured	Conventional	1.14	7.8
		Mulch	0.05	0.03
Indiana				
Russell sl, 5%	Noncontoured	Minimum	3.12	10.7
		Mulch	2.24	0.5

Source: Adapted from Mannering and Burwell (1968).

tions, cultivation of rough, cloddy surfaces may increase erodibility by decreasing soil aggregate size, decreasing surface roughness, and reducing existing crop residue surface cover.

SLOPE MODIFICATION FOR EROSION CONTROL

Contour planting and tillage function to control runoff and soil loss from storms that are moderate in extent, or until capacity of soil to hold or to conduct runoff is exceeded. In field practice, rows are oriented on the contour, generally with a slight grade toward a waterway. On slopes of moderate steepness and length, average annual soil loss can be reduced by about 50% (Smith and Wischmeier, 1962). Runoff is ponded and flows slowly around the slope rather than downslope. However, when smooth tillage is used, or when infiltration rates are low, runoff from high intensity rains may overtop rows, reducing runoff and erosion effectiveness. In addition, because contouring generally results in point rows and irregular field shapes, its use as an erosion control practice is declining. Large farming equipment and narrow rows are not compatible with point row farming.

Contour strip-cropping is the practice of alternating strips of a close-growing meadow or grass crop with strips of grain or row crops across a hillside. The erosion control aspect of strip-cropping is the reduction in length of slope of land in row crop. In addition, flow velocity of runoff water is reduced as it moves through the close-growing grass strip, causing sediments to drop out. The sod literally acts as a filter strip. The reduction in soil erosion from a strip-cropped slope is proportional to the fraction of the slope that is in grass strips (Wischmeier and Smith, 1965).

Terracing is one of the oldest practices used to control erosion. Terraces are combinations of ridges and channels laid out across the slope to trap water running downslope, and to conduct the water to suitable surface or subsurface outlets at a nonerosive velocity. The primary benefit of terracing is the reduction in slope length. Since erosion is approximately proportional to the square root of slope length (Smith and Wischmeier, 1962), reducing slope length in half can reduce erosion by more than 20%. Bench-type terraces also provide for a reduction in slope steepness. Terracing with contour farming is generally considered more effective as an erosion control practice than strip-cropping, but it is also more expensive. With both practices soil loss is confined within field boundaries. In strip-cropping the saved soil from one storm event is deposited in the sod strip and can be transported further downslope during subsequent storms. With terracing, the deposition is in the terrace channel which offers positive sediment retention, unless overtopping occurs.

Although effective for erosion control, conventional broad-based terrace systems are not compatible with efficient tillage operations or modern farm equipment. In addition, herbicides are making it increasingly difficult to maintain grassed waterways. To overcome these problems, a system of bench terraces with permanently vegetated backslopes is gaining popularity (Jacobson, 1966). In this system, all runoff is collected in low spots in the terrace channel and if necessary removed through underground tile outlets, thus grassed waterways. Parallel terraces materially straighten field alignment and eliminate objectionable point rows. In time sediment deposited in the channel reduces the slope in the terrace intervals.

Studies on instrumented watersheds in western Iowa on deep loess soil indicate that although terracing did not affect total water yield from a watershed, the surface flow component of water yield was significantly reduced. Only 14% of water yield from terraced watersheds was surface flow, while on unterraced but contour-farmed watersheds, surface flow accounted for 64% of water yield (Saxton and Spomer, 1968). These differences in surface flow were associated to sediment yield from these watersheds as shown in Table 3.5 (Piest and Spomer, 1968).

OUTLOOK

Slope modification measures combined with soil-conserving tillage practices can be effective in reducing soil erosion from cropped land. However, to become widely accepted, such practices must fit efficient farming operations and must be economically feasible. If presently available practices do not meet these requirements, new practices or systems that will control erosion and sediment production without loss of net income to the operator must be developed.

For example, consider a system where sheet erosion is controlled through till-plant tillage, and runoff is controlled by storage fills constructed across waterways (Jacobson, 1969). The fills, like bench terraces, would have favorable uphill slopes with a seeded backslope. Water would be removed from fills by tile outlets. It is anticipated

TABLE 3.5. Effect of land treatment on sediment yield of watersheds in western Iowa.

Watershed	Size	Crop	Land Treatment	Sediment Yield 1964	1965	1966
	(acres)				*(tons/a)*	
1	75	Cont. corn	Field contoured	30	60	8
2	83	Cont. corn	Field contoured	30	45	10
3	107	Grass	None	2	2	1
4	150	Cont. corn	Level terraced	2	2	1

Source: Adapted from Piest and Spomer (1968).

that such a system would almost eliminate soil loss from cropped fields on slopes up to 6%. Soil-moved sheet erosion is stored in the fills and eventually helps reduce slopes. Again, troublesome hillside waterways are eliminated. Straight row farming is possible, adding to farm adaptability. And the cost of such a system should be relatively low. Tillage costs will be lower, and building the system of storage fills often would be less costly than building waterways. On lands with slopes steeper than 6%, farming becomes progressively difficult. Unless the slope can be reduced to permit more efficient machinery operation, economics will force the retirement of much of these lands from row-cropping (Jacobson, 1969). Erosion control on such land will require bench terraces with tile outlets.

To reiterate, nearly all sediment is the result of man's removal or disturbance of natural soil cover of trees and grass. Since all land cannot be returned to its original cover, wise land use planning and careful use and treatment of land can reduce soil erosion, the source of sediment. Although the mechanics of the erosion process are not completely understood, guidelines have been developed, satisfactorily tested, and translated into erosion control practices, measures, and structures. Existing erosion control technology has not been universally accepted and used, primarily because of direct or indirect economic considerations (Swanson and MacCallum, 1969). The challenge to agriculturists, conservationists, engineers, and economists is to continue their efforts to develop an improved erosion control technology that will be compatible with modern requirements and economically feasible. Only when this challenge is met will there be a significant reduction in sediments redrived from agricultural lands.

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