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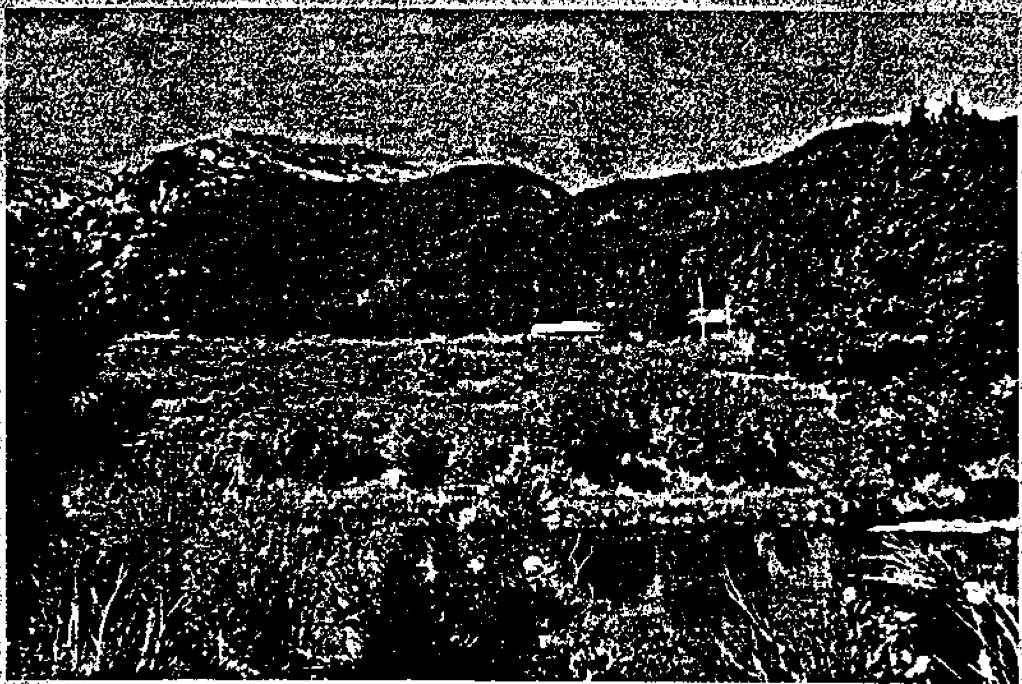

FACTORS AFFECTING FURROW EROSION

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FACTORS AFFECTING SHEAR FORCE

Erosion occurs when the shear force exerted by water on a soil unit exceeds the forces binding that unit to underlying soil. The primary factor affecting shear force exerted by water on the soil is velocity of the water. Velocity is determined by amount of water flowing per unit time and by slope of the furrow. Relative effects of slope and furrow flow rate on average water velocity can be deduced from equation 1, which is Manning's equation for flow in open channels, where Q is flow rate (M^3/s), A is cross sectional area of flow (M^2), S is slope (M/M), P is wetted perimeter (M), and n is the coefficient of roughness.

$$Q = A^{5/3} S^{1/2}/(n P^{2/3}) \qquad (1)$$

For many furrow shapes (that is, V-shaped), when water supply rate or slope varies, the breadth (B) of the water-filled cross section retains essentially the same ratio to its depth (D), that is B/D= K. When this ratio remains constant, B= KD, A= K' D^2 and P= K"$A^{1/2}$. Substituting the latter relation in eqation 1, and solving explicitly for A gives

$$A = (Qn/K'''S^{1/2})^{3/4}. \qquad (2)$$

Substituting this value of A into the definition, v=Q/A of the average stream velocity, and recognizing that bed shear stress, T, is proportional to v^2 gives

$$T = (K_o/n^{3/2}) \; S^{3/4} \; Q^{1/2}. \qquad (3)$$

Calculation of shear force on the bottom of an infinitely wide channel gives equal exponents for Q and S. Less sensitivity of T to Q than to S in furrows where B/D is constant (equation 3) is due to wetted perimeter increasing when Q increases, which spreads the restraining force over a larger area.

Amount of erosion will be determined by amount of particles or aggregates on the furrow perimeter which do not cohere strongly enough to the underlying soil to withstand shear stress. The specific nature of the relationship between erosion and the shear stress will be determined by the soil properties, but the exponent of the slope term (S) should be 1.5 times the exponent of the flow rate term (Q) if B/D remains constant as flow rates and slope vary and furrows erode. This constancy is difficult to predict or quantify. However, several data sets are available in which effects of slope and flow rate on erosion are related. The ratios of the slope and flow rate exponents found to fit the data sets best to equations of the type $E= kS^aQ^b$ are compared in table 1.

Table 1.--Comparison of the ratios of a/b in the equation, $E=Ks^aQ^b$ relating erosion (E) to slope (S) and flow rate (Q).

Investigators	a	b	a/b	Location
*Carter et al	2.7	1.8	1.5	ID Farms
Evans & Jensen (1952)	2.3	1.5	1.5	ND
Gardner & Lauritzen(1946)	1.5	1.0	1.6	Flume
Israelson et al(1946)	1.8	1.0	1.2	UT Farm
Israelson et al(1946)	1.6	1.2	1.2	UT Farm
Israelson et al(1946)	1.4	1.0	1.4	UT Flume
*Trout, Brown, & Rosenau	2.1	1.4	1.5	ID Farm

*Unpublished data

Only two of the a/b differed more than 0.1 from 1.5. Pictures in the Israelson et al. publication indicate that their furrows with a/b values of 1.2 and 1.3 had particularly broad flat bottoms. Many furrows in the studies where a/b was 1.5 ± 0.1 also developed relatively flat bottoms, but the assumption of B/D being constant was apparently close enough to reality for a/b to be practically 1.5. The consistency of the a/b= 1.5 relation is sufficiently good to suggest its use to decrease the data taking needed to adequately characterize erodibility of soils. The data sets generally indicate that the erosion, E, is a power function of the shear stress shown in equation 3, that is,

$$E=T^m=(K_o/n^{3/2})^m \; (S^{3/4} \; Q^{1/2})^m$$
$$=kS^aQ^b \qquad (4)$$

where m= 4a/3 or 2b. Data sets needed to estimate m and $(K_o/n^{3/2})$ are measures of runoff and sediment yield (1) on a known slope at two flow rates or (2) at a known flow rate on two slopes. Data collected by Carter et al. indicate that the pertinent slope is that which is immediately upstream from the sediment measuring station.

High slopes and flow rates often cause rapid erosion of cultivated soil which slows down or stops at cohesive plow pans or other layers in which cohesion withstands the shear. In analyses of the Trout et al. and Carter et al. data, measurements were not used to help determine the exponents if erosion had already proceeded down to an obviously more cohesive underlying soil.

While the ratios of a/b for the soils in table 1 are reasonably consistent, associated values of m and $K_o/n^{3/2}$ varied greatly even within soil series. Factors which account for substantial portions of these variations are discussed in the following sections.

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IRRIGATION HISTORY, ROOT FABRIC AND TIME SINCE TILLAGE

The bottom curve in figure 1 shows erosion from Portneuf silt loam as a function of rate of runoff during the second irrigation following initial cultivation and furrow forming. The field was cultivated again on July 26, 1983. During the following irrigation on August 1, 1983, erosion from these furrows increased substantially, particularly at the high rate of flow. The lesser increase at lower flow rates was probably due to increased roughness of the furrow, caused by the cultivation, which slowed the water and increased the wetted perimeter. At higher flow rates channels were quickly smoothed by more rapidly flowing water and more complete disintegration of quickly wetted clods. During successive irrigations the exponent associated with flow rate decreases because easily eroded soil has been removed. Part of the decreased erosion in the soil following winter wheat (fig. 2) appeared to be due to the furrow bottom encountering soil consolidated by root fabric. Curves in figure 2 are averages for four irrigations of a bean crop. Straw in furrows also decreases erosion (Aarstad and Miller 1980) substantially. However, little straw was left in these furrows following harvesting of the wheat for silage. Mech (1959) provides some of the most comprehensive data and astute observations on factors affecting furrow erosion.

Another factor causing decreased erosion in the non-tilled soil in figure 2 is the tendency of this soil to become more cohesive with time. Increases of wet sieve aggregate stability with time are shown for moist and air-dried Portneuf soil in the two left curves in figure 3. Bonds in this soil were broken by shear when moist. Some aggregates were then air dried and others kept moist for the indicated times. Some dried aggregates were then brought back to moisture levels of $\theta = 0.13$ and 0.31 by passing moist air from a vaporizer through them. Bonds reformed rapidly in aggregates with high water contents. In air-dried soil (about one molecular layer of water on mineral surfaces) formation of these bonds took 100 to 400 times as long. These differences in rates are of the same order as differences in diffusion rates measured (for example, VanSchaik and Kemper 1966) in soils at these water contents, indicating that diffusion of ions and molecules through the liquid phase to particle-to-particle contacts where they bond the particles together may be the rate controlling mechanism.

Since cultivation is effective in the disruption of such bonds, it is probable that cultivation and lack of time to regain cohesion plays a major role in higher erosion of tilled soils (that is, fig. 2).

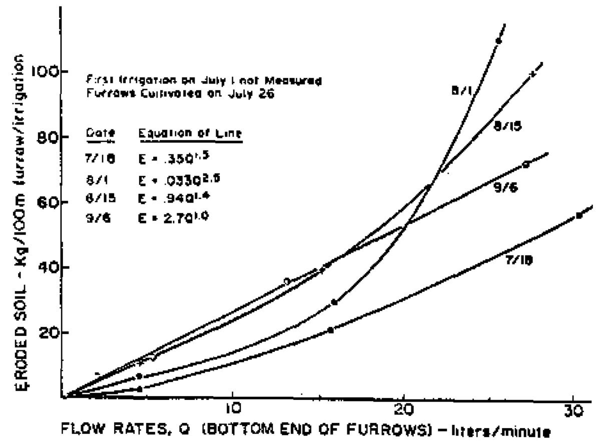

Figure 1. Effects of flow rate and sequence on erosion of Portneuf silt loam on 1 percent slope following fallow.

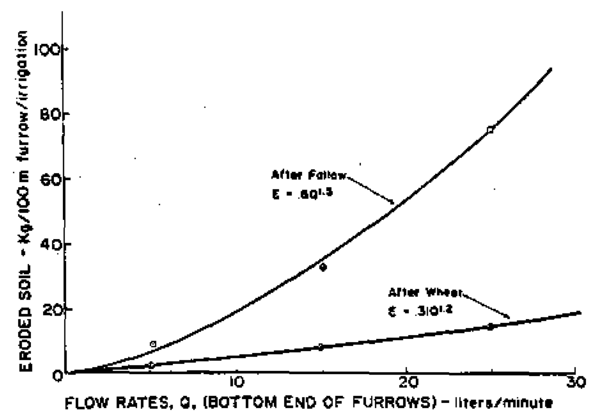

Figure 2. Effects of winter wheat and flow rate on furrow erosion during the following summer.

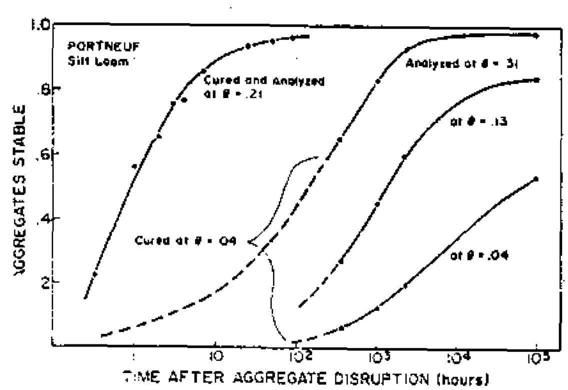

Figure 3. Increases in aggregate stability with time of moist and air dry soil.

INITIAL WATER CONTENTS AND WETTING RATES

During 1982, runoff and erosion were measured from furrows in a bean field on Portneuf silt loam during six successive irrigations. Sediment content of water during the third and fourth irrigations was much lower than in the other irrigations (fig. 4). The only apparent physical differences recorded were traces of precipitation prior to irrigation. These traces of precipitation, followed by clear nights and heavy dew, increase water content of the immediate soil surface from 1 or 2 percent up to 5 to 10 percent.

Differences in wet sieve aggregate stability of 1- to 2-mm aggregates of Portneuf silt loam at different initial water contents are indicated by intersections of the curves in figure 5 with the ordinate. Aggregates with these initial water contents were also wetted to saturation at different rates by placing them on filter paper and applying water at different rates to the filter paper. For portions of the furrow wetted quickly by direct contact with flowing water, increasing initial water content from 2.7 to 9.0 percent would increase aggregate stability from about 16 percent up to 58 percent. For aggregates on portions of the furrow where wetting by capillary action took about 60 seconds, increase in stability would be from about 52 up to 73 percent. These data substantiate the possibility that the reductions in sediment load of the runoff during the third and fourth irrigations (fig. 4) resulted from increases in initial soil water content which increased stability of aggregates in the wetted perimeter of the furrow. When aggregates were wet slowly, taking 30 minutes or more to go from dry to wet (fig. 5), they were all highly stable.

To determine whether rapid wetting increases erosion, two pairs of furrows each 100 meters long, were irrigated with identical amounts of water. One of each pair had an initial supply rate of 38 L/min for 1 houe, which was then dropped to 80, 60, 40, and 20 percent of this rate in successive hours. The other furrow of each pair was provided with 20 percent of 38 L/min for the first hour and this rate was raised by 40, 60, 80, and 100 percent in successive hours. Erosion during these 5 hours of irrigation for these quick and slow wetted furrows is shown for the first irrigation following cultivation in figure 6. Faster wetting more than doubled erosion during the irrigation following cultivation. The faster wetting rate reduced water intake by 32, 17, and 19 percent on the first, second, and third irrigations following cultivation.

Analysis of the data indicate that the increased erosion was caused by both increased runoff and decreased cohesion.

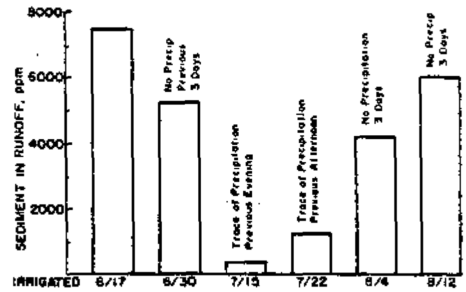

Figure 4. Differences in sediment concentration of furrow runoff.

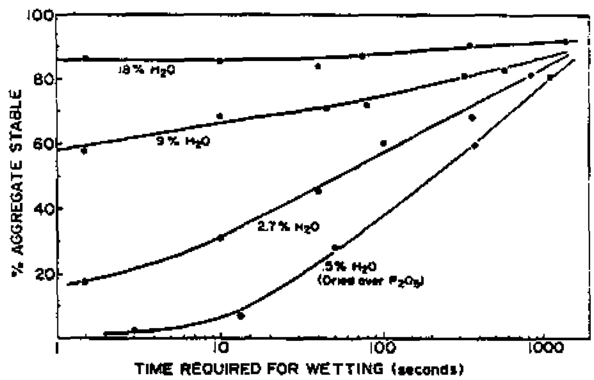

Figure 5. Aggregate stability as a function of initial water content and rate of wetting prior to immersion (Portneuf soil).

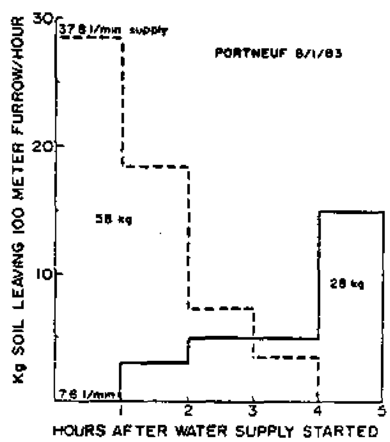

Figure 6. Effect of wetting rate on furrow erosion (Portneuf, August 1, 1983).

CONCLUSIONS

Furrow erosion is a function of the shear stress, which is an exponential function of furrow slope and flow rate. The exponent of slope is generally about 1.5 times the exponent of flow rate. Soil cohesion and fabric of roots and other organic residues in the soil provide resistance to erosion. Cohesion of soils is a function of type of, and time since, preceding tillage, water content prior to wetting, and rate of wetting at the inception of the irrigation. Faster wetting causes more erosion.

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