Methods to Improve Water Infiltration on Fragile Soils[1]

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An important physical property of a soil is its infiltration rate. Infiltration rate of a soil, according to SSSA (Lutz and others, 1956), is the maximum rate at which a soil, in a given condition at a given time, can absorb rain. According to Parr and Bertrand (1960), some scientists believe that infiltration rate is governed solely by the soil mass and is largely independent of surface conditions. In contrast, Horton (1940) stated that infiltration rate is governed mainly by conditions at or near the soil surface. Duley and Russell (1939) noted that leaving crop residues on the soil surface greatly increased infiltration and reduced runoff, evaporation, and wind and water erosion.

Infiltration rate (I) of many soils is highly dependent on saturated hydraulic conductivity (Ks) of the soil surface. Research by Allison (1947), Christiansen (1944), and Poulovassilis (1972) established that Ks of soils undergoes changes with time. Gerard (1974, 1986) reported that Ks of fragile soils was a function of antecedent moisture and residue management. Time-dependent differences in Ks and I of many soils may be largely an expression of antecedent moisture and residue management and their indirect effects on soil properties and microbial activity.

Some of the conflicting ideas about factors that affect the I of soils are probably due to the failure to understand or appreciate the dynamic changes in some soils during and following rainfall. These changes and their subsequent effects on soil permeability are probably greatest on weakly structured or fragile soils. Fragile or weakly structured soils are low in organic matter, low or devoid of water-stable aggregates, and susceptible to surface sealing and crusting.

The purpose of this paper is to define the effects of antecedent moisture, residue and residue management, rainfall intensity, drying conditions, and their interactions on soil permeability and to suggest methods for improving the I of fragde soils. Studies were conducted on a fragile Miles soil. As shown in Table 1, this soil, like many in the Rolling Plains and southern U.S., is low in organic matter and devoid of 1-to 10-mm water stable aggregates considered essential for good structure (Tisdall and Oades, 1982). These conditions greatly reduce I and subject the soils to wind and water erosion.

Soils are less permeable to rainwater or water with a low level of salt than to water with significant quantities of salt. This fact was demonstrated using cores of a disturbed Miles soil that had an initial Ks of 4 to 4.5 cm h^{-1} when treated with either rainfall or water with an electrical conductivity of 0.8 dSm^{-1} and a sodium adsorption ratio of 1.5. After two wetting and drying cycles, Ks of soil to distilled water was only 2 percent of initial Ks, whereas the Ks of soil to water with an electrical conductivity of 0.8 dSm^{-1} was 20 percent of initial K_S.

Physical properties of a Miles fine sandy loam soil under different management systems described in Table 2 were measured in 1986. Data in Table 2 show measured runoff from natural precipitation and surface cover in July. As shown in Table 2, 36.8 percent of the natural rainfall ran off the bare soil compared to an average of 3.3 percent for the conservation-tilled treatments, which left half of the residue on the soil surface. Runoff averaged 11.7 percent from treatments that incorporated all the residue into the soil.

Runoff from bare soil and ryegrass treatments shows that runoff was a linear function of daily rainfall in centimeters. Calculations indicated runoff from the grass surface during a 25-mm rain amounted to about 5 mm, whereas runoff from bare surfaces amounted to almost 15 mm. The equations expressing runoff as a function of rainfall indicated that bare soil lost an average of 79 percent of the rainfall, but ryegrass lost only an average of 32.5 percent of the rainfall. Runoff on bare soil and ryegrass did not occur until 6 and 9.5 mm of rain fell on these surfaces, respectively. It should be noted that the experiment was conducted during the first year of growth for ryegrass.

Studies using collected rainfall with a rainfall simulator showed that I is high when Ks is high. The opposite is true of runoff. Ks and I from rainfall simulation are reported in Table 2. The effect of antecedent

TABLE 1. PROPERTIES OF THE TOP 150 MM OF A MILES FINE SANDY LOAM (FINE-LOAMY, MIXED, THERMIC UDIC PALEUSTALF) AND AN ABILENE SANDY LOAM SOIL (FINE, MIXED, THERMIC PACHIC ARGUISTOLL)

	Miles %	Abilene %
Sand	72.0	57.0
Silt	20.0	26.0
Clay	8.0	17.0
Organic matter	0.3	0.9
Moisture at 0.01 MPa	16.6	22.9
Moisture at 1.50 MPa	4.4	9.5
Aggregation >1 mm	0	—

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TABLE 2. RUNOFF LOSSES AND SURFACE COVER IN SPRING OF 1986 AND Ks AND INFILTRATION RATE (I) DETERMINED WITH RAINFALL SIMULATOR UNDER DIFFERENT TREATMENTS OF A MILES FINE SANDY LOAM SOIL

Treatment*	Runoff from natural rainfall***		Surface cover	—K_s****—		Ratio K_s	—I****—		Ratio I
				dry	wet	wet/dry	dry	wet	wet/dry
	cm	%	%	cm h^{-1}			cm h^{-1}		
Check	7.34	36.8	0	1.05	0.68	0.65	1.28	0.93	0.73
7.5 Mg ha^{-1} straw incorporated	1.12	5.6	4	1.26	0.72	0.57	1.78	1.16	0.65
15.0 Mg ha^{-1} straw incorporated	3.52	17.7	14	1.87	0.73	0.39	2.25	0.84	0.37
7.5 Mg ha^{-1} conservation-tilled**	0.86	4.3	56	2.96	1.44	0.49	3.25	1.69	0.52
15.0 Mg ha^{-1} conservation-tilled**	0.48	2.4	96	4.57	4.42	0.97	4.60	4.50	0.98
Ryegrass	2.43	12.2	88	4.55	3.24	0.71	4.74	3.41	0.72

*Each treatment was replicated twice. Plot size was 3.3×4.0 m.

**Consemation-tilled consisted of incorporating one-half of the straw with the soil and leaving the other half of the straw on top of the soil

***Total recorded rainfall 19.91 cm

****K_s and infiltration rate (I) of treatments were determined with a rainfall simulator at a rainfall intensitv of about **5.4** cm h^{-1}

moisture on Ks (wet vs. dry) in combination with bare soil or residue is also given in Table 2. Antecedent moisture is the moisture content of the top 25 mm of soil before determining Ks or I. When the Miles soil was dry, Ks increased with increasing residue. The effect of residue on Ks was considerably less when the soil was wet before the rainfall, especially when residue was incorporated. For a dry surface, Ks of Miles soil is a positive linear function of surface cover. In contrast, for a wet surface of a Miles soil, Ks is a curvilinear function of soil cover. High antecedent moisture reduced the benefits of surface cover, especially for surface cover greater than 60 percent.

The I as affected by treatments determined with a rainfall simulator are reported in Table 2. The ratios of Ks-wet/Ks-dry and I-wet/I-dry are probably indicative of the surface sealing after rainfall. The lower the ratio, the greater the surface sealing and the greater the reduction in the Ks or I. High surface cover by ryegrass or 15.0 Mg ha^{-1} of residues in conservation-tilled treatments reduced surface sealing and maintained soil permeability.

Runoff studies with diked furrows on Miles and Abilene soils indicated that retarding water flow by diking, especially diking every furrow, was effective in substantially reducing runoff and increasing yields (Gerard et al., 1984). On fragile soils, even on gentle slopes, the only way to prevent or substantially reduce runoff is to retard flow of water down slope by diking or by grass or residue cover. Cultivation also can reduce runoff by increasing soil surface roughness and by breaking the surface crust.

The cumulative infiltration and runoff of a Miles soil was measured at rainfall intensities of 1.3 to about 6.7 cm h^{-1} after a surface crust or seal had formed. When the soil was dry, runoff occurred only at rainfall intensities greater than 1.3 cm h^{-1}. In contrast, when surface was wet and sealed over, runoff occurred at all intensities measured. Regardless of rainfall intensity, the Ks of a dry Miles soil was almost constant at 1.35 cm h^{-1} compared to 0.5 cm h^{-1} for a wet soil. Two points are noteworthy. First, bare Miles soil sealed over as much at low rainfall intensity as at high rainfall intensity. Secondly, antecedent moisture had a significant effect on K_s.

A conservation-tilled Miles soil treated with 7.5 Mg ha^{-1} of straw was considerably more permeable to rainfall than the bare soil. Rainfall intensities had a significant effect on runoff and soil permeability. When dry and just cultivated, the residue-treated Miles had runoff at rainfall intensities of 5.5 and 6.5 cm h^{-1}, but not at rainfall intensities of 3.65 cm h^{-1}. When wet, soil subjected to rainfall intensity of 3.65 cm h^{-1} had some runoff after the second wetting and drying cycle but not at rainfall intensities greater than 3.65 cm h^{-1}. These data also showed a high Ks immediately after cultivation and a much lower Ks after the first drying cycle. Maximum drying of the surface 25 mm occurred 4 to 6 days after wetting. Ks increased about 0.3 cm h^{-1} for each day of drying and reached a maximum in 4 to 6 days.

Tisdall and Oades (1982) recently discussed the role of organic matter and water-stable aggregates in soils. They stated that g o d structure for crop growth depends on the presence of water-stable aggregates of 1-10 mm in diameter. Many soils in the southern USA are low in organic matter, weakly structured, and almost devoid of 1- to 10-mm water-stable aggregates. The status of the fine particles in these soils need to be better defined because these particles often govern the permeability of fragile soils. Questions such as "Why do fragile soils seal over and exhibit low permeability characteristics?" and "What management schemes will enhance the I of fragile soils?" need to be answered. Very little research has been concerned with measuring the status of fine particles in soils. A method to measure micro-aggregate stability from USDA Handbook No. 60 (1954) is briefly described below. The method involves measuring the concentrations of two suspensions of the same soil, one of which is dispersed by standard dispersion procedures to give total silt and clay. The other suspension, prepared by mild (end-over-end) agitation of the sample in water, gives a measure of the unaggregated silt and clay. The difference in reading with a hydrometer after 40 seconds (Bouyoucos, 1927) measures the aggregated silt and clay and after 2 hours measures the aggregated clay.

Adding residue to the Miles soil increased the stability of the silt and clay, and high antecedent moisture reduced silt and clay aggregation of the Miles soil. Clay aggregation of two Rolling Plains soils was about 100 percent for oven-dry soils but decreased with increasing antecedent moisture. At antecedent moisture suction of about 0.01 MPa, clay aggregation of Miles and Abilene soils decreased to about 0 percent and 55 percent, respectively. At high antecedent moisture, dispersed or unaggregated silt and clay particles can increase surface sealing, clog up large pores, and decrease I and Ks of fragile soils. Properties of the Miles and Abilene are compared in Table 1. These results were discussed in greater detail by Gerard (1986).

Silt and clay aggregation of oven-dried soils under crop and rangeland in the Rolling Plains ranged from 16 percent to 70 percent. Clay ranged from 9 percent to 36 percent and organic matter ranged from 0.3 percent to 1.76 percent. Stepwise regression analysis showed that aggregation of silt and clay was positively related to percent organic matter and clay but negatively related to percent sand. This is indicative of why sandy soils such as the Miles can be problem soils. Stengel et al. (1984) reported that soils high in sand and low in clay were problem soils in no-till and low-till systems.

Compaction refers to the close packing of particles. Compaction can be so severe that it stops root penetration and reduces permeability or I of soils. Traffic is the most commonly recognized cause of compaction, usually tractor or animal traffic. Soils are especially susceptible to compaction when tilled or cultivated wet. Natural compaction due to soil properties and drying conditions without mechanical forces being imposed has rarely been understood or recognized. Conservation tillage has often been referred to as tillage systems that tend to maximize residue retention on the soil surface. However, conservation tillage has contributed to soil compaction, according to Dickey et al. (1983), Hamblin et al. (1982), Whiteley and Dexter (1982), and Gerard (1986). Gerard (1986) and Taylor et al. (1966) reported that slow drying and drying, respectively, were important factors in excessive soil strength and compaction.

Many soils in Texas and the world contain high percentages of sand and low percentages of clay. Natural and induced compaction are serious problems associated with sandy soils. Natural compaction of the Miles and Abilene soils treated with residue was measured in the laboratory after three to four wetting and drying cycles at different drying conditions. Residue was mixed with the soil in cores or placed on the soil surface (mulch) of like cores. Soil cores were dried at 25°C and 35°C. Differences in bulk density were considered an estimate of natural compaction for both soils. The results of this experiment showed the following: (1) residue mixed with soils decreased bulk density, (2) slow drying (25°C) increased bulk density compared to fast drying (35°C), and (3) mulching increased bulk density. The effects of slow drying and mulching were more dramatic on the coarse-textured Miles soil than on the medium-textured Abilene soil. The Miles fine sandy loam is more of a problem soil because it is very low in organic matter and clay.

Conservation and low-till practices have created problems and yield reductions on some soils, especially soils low in organic matter and clay (Hamblin et al., 1982; Stengel et al., 1984; Whiteley and Dexter, 1982). Observations in the Rolling Plains in spring 1986 showed that wheat under conservation tillage on sandy soils had poor growth and was yellow. Strength of these soils under conservation tillage was high at the 200- to 250-mm depth. This caused some wheat to produce insufficient growth for grazing. In fact, because of poor growth some growers plowed up wheat under conservation tillage in spring 1986. This would suggest a need for scientists and growers to evaluate the strength profiles of soils when wet before adopting conservation tillage practices. Strength values of 1.5 to 2.0 MPa when wet in the upper 400- to 600-mm soil depth would suggest the need for chiseling before adopting conservation tillage systems on these soils.

Studies comparing conventional (tilled) and deep-plowed Abilene soils showed that deep plowing increased sorghum yields an average of 12 percent from 1981-1985. It is interesting to note that deep plowing increased yields an average of 22 percent on the lower part of the slope. Since water is the dominant factor for yields in the Rolling Plains, these data showed that some runoff water from the upper and middle parts of the field was captured in the lower part of the deep-plowed soil. Surface sealing probably reduced the yield increase from deep plowing on the upper and middle parts of the field to only 4 percent to 5 percent.

In conclusion, surface cover from residue in conservation tillage or grass was highly effective in increasing Ks, reducing surface sealing, and increasing the I of fragile soils. High antecedent moisture decreased the stability of fine particles. Dispersed silt and clay particles increase surface sealing and clogging of soil pores and reduce soil permeability. Slow drying or mulching can increase natural compaction. However, the adverse effects of antecedent moisture and slow drying due to conservation tillage are not as great as the beneficial effects cited above.

Compaction can be reduced by chiseling with little or no disturbance to the soil surface. Tillage sometimes can be used to increase surface roughness, break up restrictive crusts, and increase the I of soils. Practices such as furrow diking, sometimes in conjunction with straw mulching, can retard the flow of water downslope, reduce runoff, and increase water storage for crop production. Finally, the anticipated benefits from conservation or low-till systems on fragile soils may not be apparent for several years.

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