CHEMICAL AND PHYSICAL COMPONENTS OF CRUSTING IN SOUTHEASTERN SOILS

W. P. Miller,[1] D. E. Radcliffe[2] and J. Scifres[3]

AUTHORS: [1]Associate Professor, [2]Assistant Professor, [3]Graduate Research Assistant, Department of Agronomy, The University of Georgia, Athens, GA 30602.

REFERENCE: Proceedings of the 1989 Georgia Water Resources Conference, held May 16 and 17, 1989, at The University of Georgia. Kathryn J. Hatcher, Editor, Institute of Natural Resources, The University of Georgia, Athens, Georgia, 1989.

Cultivated soils of the Southeastern US have been acknowledged for some time as having low water infiltration rates due to formation of impermeable crusts or seals at the surface. Peele et al (1945) observed such sealing under simulated rainfall, and commented on its effects on runoff volumes, soil erosion rates, and water quality. The historically high rates of soil erosion and stream turbidity documented by Trimble (1974) and others were no doubt directly related to the tendency of Piedmont soils to seal and generate erosive runoff. Current erosion and sediment delivery to surface waters in the Southeast is exacerbated by crusting as well. Loss of potential plant-available water to rapid surface flows increases drought stress of plants, and also increases the likelihood of flooding.

The potential of Georgia soils to form impermeable surface crusts is illustrated in Figure 1, which shows the frequency of observed final infiltration rates of 26 topsoils subjected to simulated rainfall of 50-100 mm/h for a total of 50-75 mm of rain in runoff pan studies. About one-third of the soils had final (equilibrium) rates of <5 mm/h, which are similar to those reported for other crusting soils (McIntyre, 1958). The distribution shows that few soils are able to maintain an infiltration rate of even 20 mm/h after crusting, leading to significant runoff volumes. The high-intensity summer rainstorms simulated in these experiments deliver tremendous energy in the form of raindrop impact at the soil surface, which appears to induce the formation of the seal.

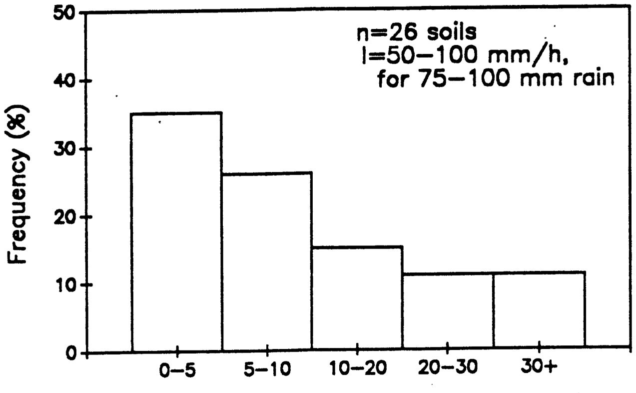

Figure 1. Final infiltration rates of 26 Georgia soils.

MECHANISMS OF CRUSTING

Crust formation has typically been equated with compression or compaction of the soil surface by raindrop impact, with consequent reduction of porosity and water conductivity. Pioneering work on soil crusting by McIntyre (1958) suggested that fine soil particles may move into the surface of soil to form a "washed-in" layer of low porosity in some soils. Recent studies in Israel have demonstrated that mobilization of clay is a major factor in soil sealing in that region, and is directly linked to colloidal dispersion of clay particles at the soil surface (Agassi et al., 1982; 1985).

Raindrop impact is the major factor involved in soil crusting, as demonstrated in Morgan's (1974) classic experiment showing order-of-magnitude reductions in runoff and soil loss on mesh-covered compared to bare plots exposed to rainfall. Aggregate breakdown and subsequent pore size reduction are logical explanations. Dispersion is a particular case of aggregate disruption occurring at the colloidal (micron) scale, in which clay particles repel each other due to electrostatic forces conditioned by the chemical environment. Dispersion is enhanced by low ionic strength, high Na content, and high pH of the soil solution, alone or in combination (van Olphen, 1977). Many soils are dispersive due to high Na content, but in the Southeastern US, dispersion is due largely to low ionic strength caused by intense leaching of these soils over time.

The importance of dispersion in regulating water movement through soils has been demonstrated in permeameter experiments which showed a clear inverse relationship between saturated conductivity of soil cores and turbidity of the percolate solutions (Chiang et al., 1987). In small pan experiments under simulated rainfall, both soil loss and runoff rate were significantly related to a measure of soil dispersion, that being the percent of total soil clay remaining dispersed in deionized water (Miller and Baharuddin, 1986).

It appears that the physical effect of raindrop impact in compacting the soil surface, and the chemical effect of dispersed clay migrating into the surface to clog water transmission pores, operate synergystically in many soils. That is, raindrop impact catalyzes the dispersion process, so that pore clogging and runoff are much greater than if only dispersion or raindrop impact forces were acting separately (Agassi et al., 1985). In the absence of dispersion, crusts take longer to form and do not show the "washed-in" layer of clay just below the soil surface (Gal et al., 1984).

The implications of such a view of soil crusting are that runoff and sediment production might be controlled either by elimination of the dispersive tendencies of soils, or by protection of the soil surface from the impact of raindrops. These two approaches will be discussed in some detail in the remainder of this paper.

DISPERSION PROCESSES IN CRUSTING

Chemical treatments have been applied to soils in a variety of forms in order to improve physical properties and rainfall acceptance. Organic polymers and emulsions act to stabilize macro-aggregates in soils, but do not directly affect dispersion. Moderately soluble salts such as gypsum ($CaSO_4$ $2H_2O$) have been used for many years to improve high-Na soils, but have only recently been used in Israel and Australia on low-Na soils as anti-dispersive treatments to improve infiltration (Loveday, 1974; Agassi et al., 1982). By adding soluble salts to the soil surface, these treatments promote coagulation of clays and decrease runoff and sediment loss on cultivated fields.

This coagulating effect on soil clay is also evident in the effect of gypsum on soils of the southeastern U.S. In a rainfall simulator study of the Greenville soil (sandy clay loam topsoil) sampled near Plains, GA, 120 mm of rainfall was applied at 50 mm/h to untreated soil, to soil with 5 mt/ha gypsum applied to the surface, and to soil treated with $NaNO_3$ at 100 kg/ha. The infiltration curves (Figure 2) show that the control soil reached an equilibrium infiltration rate of 10 mm/h after roughly 60 mm of rainfall. When treated with only a small amount of Na, the soil crusted severely after only 20 mm of rain, with infiltration rates of less than 2 mm/h. The gypsum, applied as a fine-grained by-product material derived from phosphate fertilizer processing, maintained infiltration above 25 mm/h for the entire 120 mm rainfall event. Total soil loss for the untreated control was 1100 kg/ha, compared to 230 kg/ha for the gypsum-treated soil and over 5000 kg/ha for the Na treatment. Analysis of the sediment produced showed very high levels of primary clay particles in the Na-treated sediment (55% of the total sediment), moderate clay in the control (18%), and essential no dispersed clay in the gypsum treatment. The susceptibility of this soil to crusting is thus highly dependent upon the chemical environment at the surface; amounts of runoff and sediment, and sediment particle size and ease of delivery to surface waters are highly variable depending upon the prevailing state of dispersion.

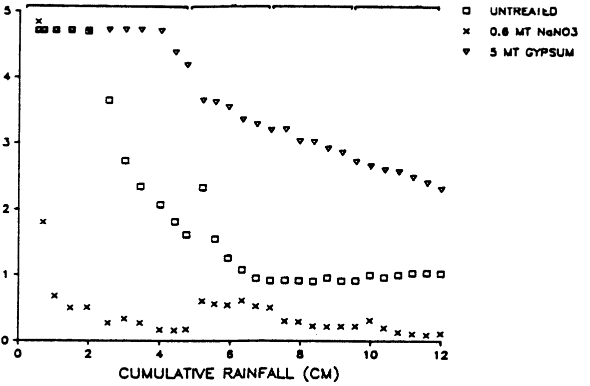

Figure 2. Infiltration rates of Na- and gypsum-treated Greenville soil under simulated rainfall (Miller and Scifres, 1988).

Other studies of southeastern soils have shown similar effects of gypsum on in laboratory settings (Miller, 1987). Recent field studies have substantiated this phenomenon under natural rainfall on m^2 plots of Appling soil near Watkinsville, GA, where four rates of gypsum (0, 2, 4, and 6 mt/ha) were applied in November to wheat, and runoff and erosion measured until the next June. A consistent effect of the gypsum treatments in reducing runoff volumes was observed (Figure 3). Runoff was reduced by roughly 50% with the highest gypsum treatment, and by intermediate amounts with the other gypsum additions. Soil loss on these plots was reduced to similar degrees by the chemical treatment, and particle size of sediments was increased to larger sizes.

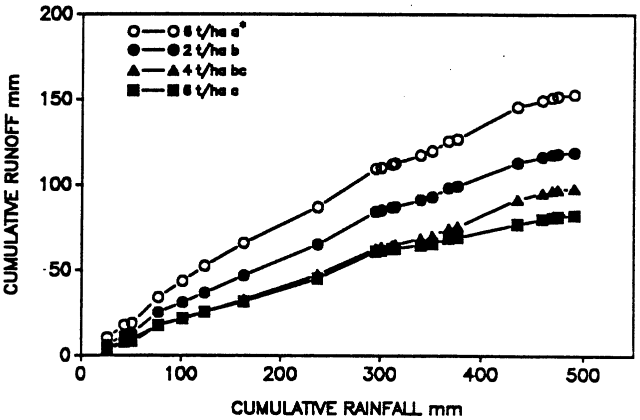

Figure 3. Runoff from gypsum-treated field plots under natural rainfall at Watkinsville over winter 1987-88.

The degree to which soluble salt additions increase infiltration is an indicator of dispersive tendencies of soils, and a possible ameliorative treatment for dispersive behavior. The reductions in runoff volumes, sediment load, and sediment particle size show promise in improving water quality and reducing peak flows.

EFFECTS OF CROP RESIDUES

Crusting can be reduced by physically protecting the soil surface from raindrop impact. This is done in con-

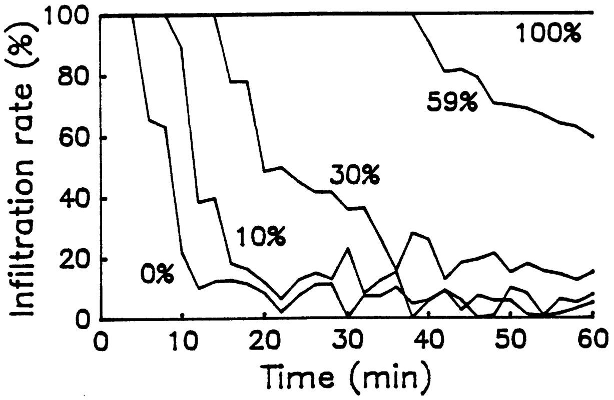

Figure 4. Effect of % straw cover on infiltration rate of Cecil sandy clay loam.

servation tillage systems where the residue of the previous crop is left on the soil surface in planting the succeeding crop. Residues intercept raindrops and reduce physical aggregate breakdown and subsequent dispersion of soil clay. The effect of increasing percentage of straw cover on infiltration rate in a Cecil sandy clay loam soil can be seen in Figure 4. With the bare soil, infiltration rate decreased sharply as a crust formed within the first ten minutes. Covering 10% of the surface with straw had little effect, but 30% cover significantly improved infiltration. At 100% cover, there was no runoff using a simulated rainfall rate of 80 mm/h. Conservation tillage systems are defined as any management system that reduces water runoff and/or erosion below that of conventional practices, and in terms of residue cover, this is attained with roughly 30% cover or greater at the soil surface.

The % cover at planting can be increased by using a winter cover crop. Grasses such as rye (*Secale cereale* L.) or wheat (*Triticum aestivum* L.) and legumes such as crimson clover (*Trifolium incarnatum* L.) and hairy vetch (*Vicia villosa* Roth.) are common winter cover crops in the Southern Piedmont. These crops protect the soil from erosion during the winter, and in the case of legumes, provide nitrogen to the summer crop as they decompose. If the summer crop is planted using conservation tillage, then the winter crops also provide greater cover that can improve infiltration during the summer growing season. The effect of a leguminous and non-leguminous cover crop on infiltration at the end of the summer on a Greenville sandy clay loam can be seen in Figure 5. Hairy vetch, a legume, was more effective than wheat in improving infiltration compared to no cover crop (fallow). Percent cover at the time infiltration was measured was approximately 100% in both wheat and vetch and 10-20% in the fallow. The greater infiltration with hairy vetch compared to wheat may have been due to the production of more stable aggregates at the surface. Polysaccharides are produced as microbes decompose residue, and these become the nuclei of soil aggregates that have enough strength to withstand raindrop impact. The percentage of soil in the 0-2.5 cm depth that consisted of stable aggregates larger than 250 μm tended to be greater in hairy vetch compared to wheat (Table 1). This may have due to the greater dry matter produced by hairy vetch and the lower carbon-to-nitrogen ratio of the legume dry matter, which favored microbial decomposition.

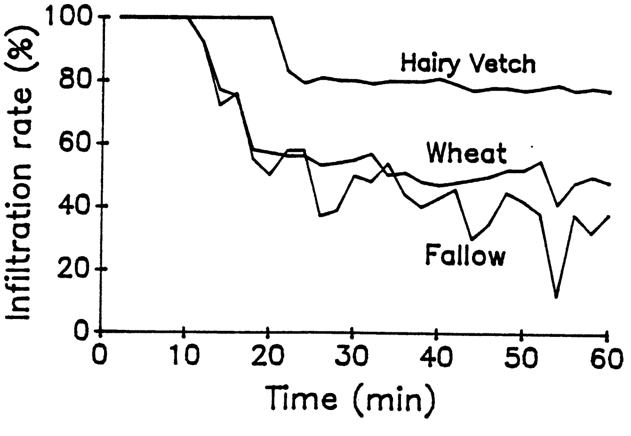

Figure 5. Effect of winter cover crop on infiltration rate of Greenville sandy clay loam.

Table 1. Aggregate stability, dry matter production, and carbon-to nitrogen ratio at Plains, GA., 1987.

Cover crop	Stable aggregates	Dry matter	C:N ratio
	%	kg/ha	g/g
Hairy vetch	37.7a*	4122a	7.8
Wheat	32.6ab	1531b	8.4
Fallow	28.9b	0c	8.5

*Values within columns with different letters are significantly different at p=0.05.

CONCLUSIONS

Research in both the Coastal Plain and Piedmont regions of Georgia has shown that rainfall-induced soil crusting on cultivated soils results in low infiltration rates, high soil erosion losses, and significant clay content of eroded sediments. High peak flows and degraded water quality are further evidence of this phenomenon. The formation of impermeable surface seals is both a physical and chemical process, by which aggregates are mechanically disintegrated and porosity reduced by raindrop impact, and clay is dispersed and migrates into the surface to form a washed-in layer of low porosity. Since dispersion is a chemically controlled process, applications of soluble Ca salts such as gypsum have the potential to reduce crusting. Small pan and field studies have demonstrated the ameliorative effects of gypsum in slowing runoff and sediment production; by-product gypsum is available at low cost from industrial sources, and may be an economically viable option for runoff and erosion control in many situations.

Physical protection of the soil surface using crop residues is another valuable management strategy for controlling crust formation by shielding the soil surface from raindrop impact. The presence of at least 30% residue cover at the surface significantly reduces runoff volumes, increasing potentially plant-available water and helpint to mitigate drought stress. Use of these approaches to field water management has significant implications in improving stream flow conditions and the quality of surface waters.

LITERATURE CITED

Agassi, M., J. Morin, and I. Shainberg. 1982. Laboratory studies of infiltration and runoff control in semi-arid Israel. Geoderma 28: 345-356.

Agassi, M., J. Morin, and I. Shainberg. 1985. Effect of raindrop impact energy and water salinity on infiltration rates of sodic soils. Soil Sci. Soc. Am. J. 49:186-190.

Chiang, S. C., D. E. Radcliffe, W. P. Miller, and K. D. Newman. 1987. Hydraulic conductivity of three Southeastern soils as affected by sodium, electrolyte concentration, and pH. Soil Sci. Soc. Am. J. 51:1293-1299.

Gal, M., L. Arcan, I. Shainberg, and R. Keren. 1984. Effect of exchangeable sodium and phosphogypsum on crust structure--scanning electron microscope observations. Soil Sci. Soc. Am. J. 48:872-878.

Loveday, J. 1974. Recognition of gypsum-responsive soils. Aust. J. Soil. Res. 25:87-96.

McIntyre, D. S. 1958. Permeability measurements of soil crusts formed by raindrop impact. Soil Sci. 85:185-189.

Miller, W. P. 1987. Infiltration and soil loss of three gypsum-amended Ultisols under simulated rainfall. Soil Sci. Soc. Am. J. 51: 1314-1320.

Miller, W. P., and M. K. Baharuddin. 1986. Relationship of soil dispersibility to infiltration and erosion of southeastern soil. Soil Sci. 142:235-240.

Miller, W. P., and J. Scifres. 1988. Effect of sodium nitrate and gypsum on infiltration and erosion of a highly weathered soil. Soil Sci. 145:304-309.

Peele, T. C., E. E. Latham, and O. W. Beale. 1945. Relation of the physical properties of different soil types to erodibility. So. Car. Agric. Exp. Sta. Bull. 357.

Trimble, S. W. 1974. Man-induced soil erosion on the Southern Piedmont, 1700-1970. Soil Cons. Soc. Am., Ankeny, Iowa. 180 p.

van Olphen, H. 1977. An introduction to clay colloid chemistry. Second ed. John Wiley and Sons, New York.