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SOIL CHANGES AFTER HAY MEADOW ABANDONMENT in SOUTHWESTERN WISCONSIN

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Overland flow originating on ridgetop agricultural soils has caused extensive gullying of steep forested slopes in the Driftless Area of southwestern Wisconsin, southeastern Minnesota, and northeastern Iowa (Sartz 1961, 1970). Additional damage occurs where the gullies break out of the woods onto cleared land at the foot of the slope and deposit alluvium containing rocks and boulders. Research in the region has shown that simply abandoning these upland fields does much to reduce the runoff and erosion problem in a short time (Sartz 1970). This improved hydrologic condition is undoubtedly the result of many complex and interrelated biotic and abiotic processes (Parr and Bertrand 1960). Activities of small burrowing animals and freeze-thaw action are perhaps the most obvious of these.

A study was begun in 1969 on the Coulee Experimental Forest near LaCrosse, Wisconsin, to determine the rate that soil properties change after the land has been abandoned and to determine if winter or summer phenomena are most important. It was thought that summer effects would be dominated by biological processes (i.e., earthworm action) and winter effects by physical processes (i.e., freeze-thaw action).

EXPERIMENTAL PROCEDURE

The Coulee Experimental Forest is representative of much of 4.8 million ha (12 million acres) identified by Hays *et al.* (1949) as a "problem area" with regard to runoff and erosion. The topography is a dissected plateau with broad cultivated ridges, steep forested slopes, and narrow cultivated valleys. The ridge soils are primarily loessial Fayette and Dubuque silt loams (Typic Hapludalfs) overlying dolomitic bedrock. Weathering of the bedrock has produced a cherty-clay residuum that has been incorporated into the plow layer where the loess was originally shallow or has been eroded.

The study area was a hay meadow located on a broad ridge. The hay was originally established by underseeding oats with alfalfa *(Medicago sativa* L.). The alfalfa varied in density depending on time since seeding (4 to more than 10 years). The oldest areas were dominated by Kentucky bluegrass *(Poa pratensis* L.), goldenrod *(Solidago* spp. L.), and Queen Anne's lace *(Daucus carota* L.), with only small amounts of alfalfa.

Ten 0.1 to 0.2 ha (0.25 to 0.5 acres) areas all within 1 km (0.6 mi) of each other, were withdrawn from active haying operations in the fall of 1969. Two blocks in each area were permanently marked and divided into seven 1.5 m^2 (5 ft^2) plots. A grid was used to identify nine sampling points evenly spaced at 0.5 m (1.6 ft) within each plot. Seven of the nine points were randomly assigned fall and spring sampling dates beginning with the fall of 1969 and ending in the fall of 1972. On each sampling date (in early May and October, 2 days each) 140 soil samples were collected (7 from each block).

The first season's soil samples were taken with a corer that sampled to a depth of 7.1 cm (2.8 in). During this sampling it became apparent that small burrowing animals were abundant and that changes in bulk density might be concentrated in the large pore fraction due to the burrowing activity of these organisms. Therefore, subsequent pore volume data were collected separately for large and small pore fractions. These samples were taken with a corer that sampled to a depth of 4.3 cm (1.7 in) to accommodate an air pycnometer. It was felt that the possible confounding effect of the change would be minimal because sampling was in an Ap horizon and when viewed in context with the data from the balance of the sampling dates its effects could be evaluated.

The following variables were determined for each soil sample:

1. Bulk density — gravimetric method
2. Organic carbon — dichromate oxidation (Mebius 1960)
3. Moisture content by weight — oven drying at 105 C
4. Air-filled pores — air pycnometer
5. Water-filled pores — empirically derived from moisture content by weight
6. Total pore space — air-filled pores plus water-filled pores

Percent sand, silt, and clay for each block was determined by the hydrometer method.

As defined, the proportion of air-filled to water-filled pores would be expected to vary from one sampling period to the next simply because of differences in soil moisture content, thereby obscuring changes in proportions related to abandonment. To reduce variation from this source, all soil samples for a given sampling date were collected in 2 consecutive days beginning 48 h after a rainfall sufficient to wet the soil below 8 cm (3 in). Even with these precautions, soil moisture variation between dates was still expected to obscure changes in pore size distribution; therefore, it was necessary to adjust air-filled pore volume for differences related to varying moisture content. The adjusted value was defined as large pore volume and was compared between seasons.

The procedure required developing a regression equation for predicting large pore volume from measured bulk density. Large pore volume was then subtracted from total pore volume to obtain small pore volume. The procedure depended on collecting data under reasonably uniform moisture conditions. It was felt that this criterion could be met within one or more of the sampling dates. The following criteria were used to select the best date: (1) smallest coefficient of variation for measured air-filled pore volume, (2) moisture content at or above filled capacity, and (3) a spring date to minimize evapotranspiration differences between sites. Regression coefficients were then determined using air-filled pore space versus bulk density. Under these conditions, comparable large pore volumes were estimated for each season using the resulting coefficients and measured bulk density.

This procedure was based on the following assumptions: (1) the spatial differences in soil moisture content when at or above field capacity are a function of large pore volume (larger pores drain first), and (2) the relation between bulk density and large pore volume is the same whether measured through space or through time when soils and vegetation are similar. Previous work supports these assumptions (Byrnes and Kardos 1963, Mason *et al.* 1957, Nelson and Baver 1940). Total pore volume was also predicted from bulk density to smooth the curve by accounting for measurement error, and to provide an estimate of total pore volume for the initial sampling date.

For analysis, the two blocks within each area were considered independent because they were positioned on opposite sides, or at different elevations on the ridge. Data analysis followed standard methods for a randomized complete block design and multiple range tests. Simple linear regression and correlation techniques were used to examine relations between soil properties.

During the final summer each abandoned block was paired with an adjacent active hay meadow and infiltration rates were measured. Three single-ring infiltrometers were installed on each half of each pair 4 weeks before measurement. The distance between the paired infiltrometers was less than 20 m (67 ft) to minimize differences in soil depth and texture. The rings were driven approximately 12 cm (4.7 in) into the soil leaving 6 cm (2.3 in) exposed. During measurement the rings were equipped with floats that maintained a constant 5 cm (2.0 in) head. All paired measurements were made simultaneously. Two-hour infiltration rate curves were developed using the mean for the three infiltrometers on each active and abandoned area.

After plotting the data it was apparent that steady-state conditions were reached within 60 min. Therefore, the 60-min infiltration rates were examined for significant differences using paired comparisons.

RESULTS AND DISCUSSION

Soil changes progressed more quickly after abandonment than had been expected (table 1). Average bulk density decreased significantly ($\alpha = 0.01$) from 1.28 in the fall of 1969, to 1.16 in fall of 1970, and to 1.10 in spring of 1971, where it remained essentially constant during the following 1-½ yr. Total pore space increased exactly as would be expected (significant at $\alpha = 0.01$) considering the change in bulk density. Organic carbon content also increased significantly ($\alpha = 0.01$) during the 3 yr.

Soil texture differed between blocks as follows: clay 14 to 30 percent, silt 59 to 73 percent, and sand 10 to 16 percent. Clay content was significantly ($\alpha = 0.01$) correlated with bulk density within sampling dates (fig. 1), and on the average explained 36 percent of the between-sample variation. Organic carbon content was also significantly ($\alpha = 0.01$) correlated with bulk density and together with clay content explained 82 percent of the between-sample variation for a given sampling date. The relation of organic carbon to bulk density was examined by Curtis and Post (1964) with similar results. No correlation existed between organic carbon and clay content. As expected, measured total pore space agreed closely with changes in bulk density (fig. 2).

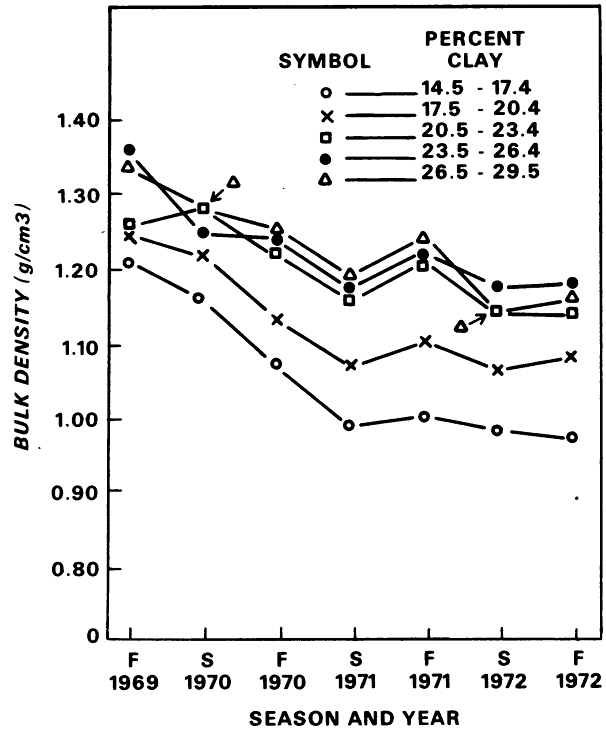

Figure 1. — *Bulk density as affected by clay content (significant at $\alpha = 0.01$) and time (significant at $\alpha = 0.01$). Each point is an average for plots having clay content in the ranges indicated. Measurements made in the spring (S) and fall (F) of each year.*

Table 1. — *Changes in soil properties following hay meadow abandonment*

Measured soil parameter	Season and year[1]						
	Fall 1969	Spring 1970	Fall 1970	Spring 1971	Fall 1971	Spring 1972	Fall 1972
Bulk Density							
Mean (gm/cc)	1.28	1.23	1.16a	1.10b	1.13ab	1.09b	1.09b
SEM[2]	0.018	0.018	0.023	0.025	0.027	0.022	0.021
Organic carbon							
Mean (%)	1.60	1.76	1.98a	2.00a	2.00a	2.20b	2.20b
SEM[2]	0.066	0.068	0.079	0.087	0.088	0.092	0.091
Measured total pore space							
Mean (%)	--	50.4	53.9a	55.4ab	54.0a	56.5b	54.9ab
SEM[2]		0.71	0.79	0.94	0.91	0.79	0.79

[1]Entries followed by the same letter are not significantly different ($\alpha = 0.05$).
[2]Standard error of the mean.

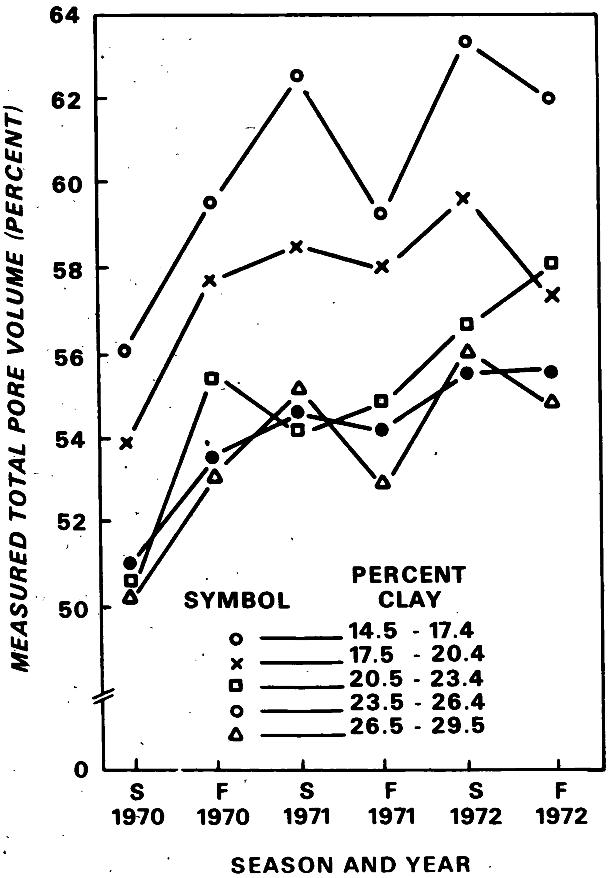

Figure 2. — *Measured total pore space as affected by clay content (significant at $\alpha = 0.01$) and time (significant at $\alpha = 0.01$). Each point is an average for plots having clay content in the ranges indicated. Measurements made in the spring (S) and fall (F) of each year.*

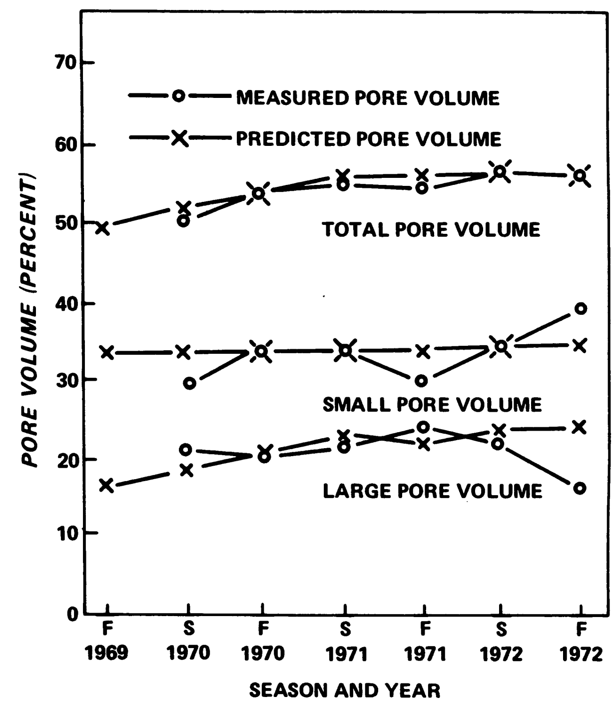

Figure 3. — *Relative change in large and small pore volume following hay meadow abandonment. The predicted pore volumes eliminate the confounding effects of different moisture levels between seasons. Measurements were made in the spring (S) and fall (F) of each year. Regression equations are: Large pore volume (percent) = 50.63 − 26.13 (bulk density), r = 0.88; Total pore volume (percent) = 94.25 − 35.29 (bulk density), r = 0.96. Predicted small pore volume represents the differences between predicted total pore volume and predicted large-pore volume.*

Those plots having soils with high clay content had significantly ($\alpha = 0.05$) higher mean bulk densities (fig. 1). The soils high in clay were located on steep slopes and were the result of either originally shallow loess, extensive sheet erosion, or both. In either case, the clay residuum had become part of the plow layer, increasing clay content at the soil surface. High bulk density associated with high clay content appears to be a long-lasting if not permanent effect. Regardless of clay content, bulk density changes nearly ceased in less than 2 yr. That some processes were still active is evident from the increase in organic carbon.

Total pore volume apparently increased from 49 to 56 percent in 3 yr, based on values predicted from bulk density. As expected, predicted values agree closely with measured values (fig. 3). The regression equation used to predict total pore volume was derived from pooled data using all sampling dates except the first because no measured values were available for that date. The regression means were linear ($\alpha = 0.05$) for all dates and the slope of the regression lines for each date were not significantly different ($\alpha = 0.05$). Therefore, pooling was justified.

Predicted large-pore volume (essentially noncapillary pores) increased from 17 to 22 percent in 3 yr and predicted small pore volume (essentially capillary pores) remained more stable at 32 to 34 percent (fig. 3). As expected, measured air-filled pore volume was erratic between sampling dates and was not significantly ($\alpha = 0.05$) affected by abandonment. However, after varying moisture content was compensated for, increased pore volume appears to have been concentrated in the large-pore fraction. Analysis of the relation between measured air-filled pore volume and bulk density indicated that the data could not be pooled for all sampling dates because the regression means were not linear, or, in other words, moisture content varied between sampling dates. However, the slope of the regression lines for each sampling date were not significantly ($\alpha = 0.05$) different. This suggests that, regardless of the mean soil moisture content at the time of sampling, the change in air-filled pore volume as a function of bulk density was always the same. The regression equation selected for predicting large-pore volume was based on data from the spring of 1972 because it best met the criteria mentioned previously.

Changes in bulk density and pore volume improved at equal rates during winter and summer. Although organic carbon increases were not consistent for each sampling period, there was not sufficient evidence to conclude that changes were greater during one season or the other. The sampling periods selected did not separate physical from biological process. Numerous fresh earthworm casts observed during spring sampling showed that earthworms had obviously been active after the previous fall sampling. This masked the role of freezing and thawing, precluding a positive evaluation of this effect on soil properties. The fresh earthworm casts on the soil surface and scattered throughout the matted plant material from the previous growing season were the main evidence of biological activity. Because of the casts' position in the material, they obviously had been deposited after the winter snows had matted the vegetation. The most likely period of activity, ranging from 2 to 4 weeks, was between the time of final snowmelt and sampling. However, some of the activity may have occurred earlier under the snowpack where earthworms were reasonably well insulated from extremely cold weather. Most earthworm casts would be expected in the spring when fresh litter is readily available and soil moisture is high. Telfair *et al.* (1957) noted that the most striking effect of earthworms was a rapid increase in aggregate stability in soil cores containing alfalfa meal. They concluded that alfalfa served as an excellent food for earthworms, encouraging their activity and growth. Similarly, the presence of unharvested alfalfa on abandoned hay meadows may promote rapid soil changes. The importance of an uninterrupted supply of organic material for earthworms was reported by Vimmerstedt and Finney (1973).

The earthworm activity left numerous channels in the surface mineral soil horizon. These channels probably account for the rapid change in bulk density that occurred during the first 18 mo of the study. After that, earthworm activity, although remaining high, apparently tended to close old channels as new ones were being opened, and equilibrium was approached. This explanation is supported by the apparent increase in noncapillary pore space.

Earthworms were probably active in these soils before abandonment; however, continual compaction by heavy farm equipment may have been offsetting their effect. Two to three crops of hay were being harvested annually and it is unlikely that any significant portion of these meadows escaped compaction each year.

As expected, the infiltration rate increased significantly ($\alpha = 0.01$) after abandonment. The mean increase throughout the infiltration curve was approximately 100 percent. Mean 60-min infiltration rates with 95 percent confidence intervals on active and abandoned hay meadows were 9.6 ± 3.3 cm/h (3.8 ± 1.3 in/h) and 20.2 ± 7.0 cm/h (8.0 ± 2.8 in/h) respectively, and are consistent with those measured by Harris (1972) on similar soils.

The change in infiltration rate following abandonment can be related to total storm flow and peak flow for a major storm in southwestern Wisconsin as follows:

	Active (hay meadow)		Abandoned (old field)		Difference
	(cm/h)	(in/h)	(cm/h)	(in/h)	(Percent)
Infiltration rate (this study)	9.6	3.8	20.2	8.0	+110
Peak Flow (Sartz 1969)	6.1	2.4	3.4	1.3	−43
	(cm)	(in)	(cm)	(in)	
Total Flow (Sartz 1969)	2.0	0.8	1.3	0.5	−35

The measured increase in infiltration rate was directly related to several properties associated with abandonment. However, it is important to keep in mind that the soils studied here had reasonably good structure at the time of abandonment. Also, they were reasonably fertile, had favorable texture, and had an established and productive vegetative cover. These initial conditions strongly influenced the rate of change that followed abandonment. Apparently, infiltration increased because of the increased number and length of large channels, a relation discussed by Ehlers (1975). Increased soil stability through existence of a continuous standing crop, development of a litter layer, and increased microbial activity all contributed to the increased infiltration rate.

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OXFORD: 181.3(775). KEY WORDS: bulk density, porosity, organic carbon, earthworms, infiltration.

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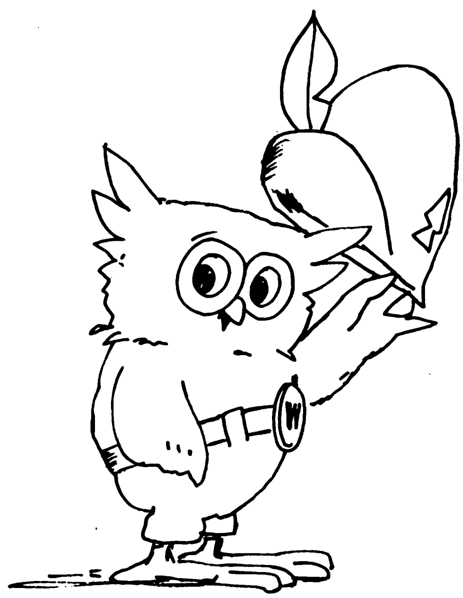

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