NORTH CENTRAL FOREST EXPERIMENT STATION
Research Note NC-233
1992 FOLWELL AVE. ST. PAUL, MN 55108 FOREST SERVICE-U.S.D.A.
1978

ESTIMATING INFILTRATION RATES FOR A LOESSAL SILT LOAM USING SOIL PROPERTIES

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ABSTRACT. — Soil properties were related to infiltration rates as measured by single-ring steady-head infiltrometers. The properties showing strong simple correlations were identified. Regression models were developed to estimate infiltration rate from several soil properties. The best model gave fair agreement to measured rates at another location.

OXFORD: 114.123. KEY WORDS: Bulk density, organic carbon, ground cover, pore volume, modeling.

Land-use practices affect soil properties that, in turn, are related to infiltration rates and overland flow (Sartz 1970). A knowledge of these relations is particularly important if land-use is changing and overland flow and erosion are serious problems. These conditions exist in the Driftless Area of southwestern Wisconsin, northeastern Iowa, and southeastern Minnesota (Hays *et al.* 1949). Inferences about hydrology are often drawn from measured soil properties because direct hydrologic measurements are difficult, expensive, and time-consuming to obtain. The present study was undertaken to improve our ability to make inferences concerning small agricultural watershed response to infiltration in the Driftless Area when only soil properties are measured. Infiltration rates on different soils were measured to find which soil properties most affect infiltration on abandoned hay meadows. A model was then developed to relate soil properties to infiltration rate.

Steady-head infiltration using single-ring infiltrometers may be expected to closely parallel conditions in settling basins where Swartzendruber and Huberty (1958) successfully modeled infiltration rates so I used their model as a basis for the present study.

It is:

$$F = AT^{B} \qquad (1)$$

where F is cumulative infiltration in mm, A and B are constants, and T is time elapsed in minutes. The instantaneous infiltration per unit time interval (f) may be written:

$$f = ABT^{B-1} \qquad (2)$$

where A is numerically equal to the mean rate for the first unit time interval and B is an expression of curvature. The magnitude of B indicates how well the infiltration rate holds up under continuing infiltration. A and B reflect different aspects of the infiltration process and, therefore, may be affected by different soil properties. Soil properties related to A and B were identified and prediction models were developed for each constant.

METHODS

Infiltration rates were measured with single-ring steady-head infiltrometers on abandoned hay meadows on the Coulee Experimental Forest in southwestern Wisconsin. Twenty sites were selected (Knighton 1977). The soils were Fayette and Dubuque silt loams (*Typic hapludolf*) of loessal origin and were positioned on broad ridges overlying a fractured dolomitic cap rock. Hay had not been harvested from the sites for 3 years and the predominant vegetation was alfalfa (*Medicago sativa* L.). Cumulative infiltration was measured at each site with three infiltrometer rings. Two-hour infiltration runs were made simultaneously for all three rings while maintaining a steady-head of 4 cm (1.6 in.) (Harris 1972). One sample of the surface 4.3 cm (1.7 in.) of soil was taken adjacent to each ring to determine bulk density, organic carbon content, air-filled pore space, water content, and texture. Infiltration and soil property data were averaged for each site. Ground cover was sampled at each site using 10 settings of a 10-point frame (Goodall 1952) on a line transect. Point strikes were classed as follows: (1) bare, (2) litter, (3) alfalfa, (4) forb, or (5) grass.

The infiltration constants in equations (1) and (2) were determined for each site using the measured cumulative mean curves. Points along the mean curve were then used in a least squares analysis of the log transformation of equation (1):

$$\log F = \log A + B \log T. \quad (3)$$

The resulting constants for each site were examined by multiple linear regression analysis using the constant as the dependent variable and soil and cover factors as independent variables. Significant correlations were noted and the regression models that best predicted A and B were determined (Draper and Smith 1966).

To test the regression model selected, actual and predicted infiltration curves were compared from data taken at a site 6 km (10 miles) away on a field with a Fayette silt loam soil that had been abandoned for 6 years (Harris 1972). Infiltration rates at this site were measured with single-ring steady-head infiltrometers identical to those used in the present study.

RESULTS

The infiltration constant A was negatively correlated ($\alpha = 0.01$) with soil bulk density and positively correlated ($\alpha = 0.05$) with air-filled pore volume (table 1). These properties reflect how quickly water enters the soil. Bulk density has long been used to indicate the hydrologic condition of soils (Parr and Bertrand 1960) and it is evidently important for the soils considered in the present study. Air-filled pore volume is related to bulk density (Knighton 1977) and reflects a similar hydrologic condition.

The infiltration constant B was significantly correlated ($\alpha = 0.05$) with several properties that reflect the capability of the soil to maintain high infiltration rates (table 1). Organic carbon content, for example, is related to the structural stability of the soil and it increased with B. The density of alfalfa cover and litter cover were also significantly correlated ($\alpha = 0.01$ and $\alpha = 0.05$, respectively) with B. However, the relation decreased with alfalfa and increased with litter cover which suggests that the invading herbaceous vegetation (primarily grass) encourages higher infiltration rates. The constant B was significantly ($\alpha = 0.01$) related to soil moisture content and the relation was positive. This is consistent with the definition of B in that the wetter a soil is at the onset of infiltration the less change there will be in infiltration rate as wetting continues. The opposite is reflected in the negative correlation with air-filled pore space.

Table 1.— *Simple linear correlation coefficients for infiltration constants and soil properties (only those soil properties that significantly related to at least one infiltration constant are reported)*

Infiltration constant	Simple correlation coefficient					
	Bulk density	Organic carbon	Water filled pores	Air filled pores	Alfalfa cover	Litter cover
A	[1]-0.77	0.23	-0.18	[2]0.49	-0.28	-0.10
B	0.19	[2]0.53	[1]0.60	[2]-0.52	[1]-0.60	[2]0.47

[1]Significant at $\alpha = 0.01$.
[2]Significant at $\alpha = 0.05$.

THE MODEL

As expected the soil properties were correlated with each other, thereby limiting the number that provided significant information in each model. Also, some variables that were not significant in simple correlation with the constants A and B did provide important information in the multiple regression models. The best model for estimating A included bulk density, clay content, and moisture content (table 2); however, similar results were obtained by deleting either clay content or moisture content. The best model for estimating B included organic carbon content and moisture content (table 2). The standard error was reduced when clay content was used in place of organic carbon content.

The infiltration model, using estimated values for A and B, closely estimated the infiltration curve at the test site (fig. 1, table 3).

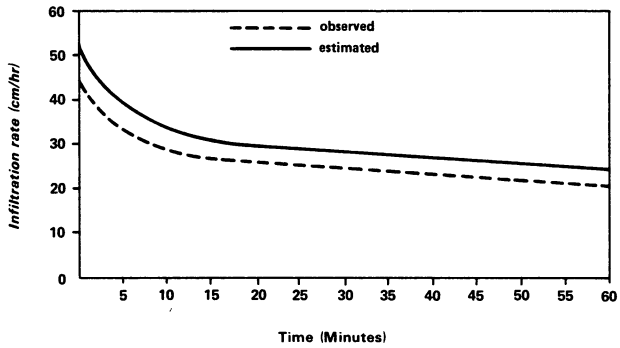

Figure 1. — *Observed and estimated infiltration rates for an abandoned field studied by Harris (1972).*

Table 2. — *Significant regression coefficients ($\alpha = 0.05$) and standard errors associated with the selected regression models for estimating the constants A and B in the infiltration model $f = ABT^{B-1}$*

Infiltration constant and model	Measured variables: Bulk density	Organic carbon	Clay	Moisture	Estimated constants and confidence intervals (95%)	Mean observed constants
	gm/cc	*Percent*				
A						
I	1.13	-	17	33.5	8.6 ± 1.6	10.7
II	1.13	-	17	-	8.3 ± 1.6	10.7
III	1.13	-	-	33.5	9.4 ± 1.4	10.7
B						
I	-	2.32	-	33.5	0.85 ± 0.04	0.81
II	-	-	17	33.5	.80 ± .05	.81

Table 3. — *Estimated value and confidence interval for the infiltration constants A and B given the independent variables measured on an abandoned field by Harris (1972) compared with associated mean observed constants*

Infiltration constant and model	Regression coefficients: Constant	Bulk density	Organic carbon	Clay	Moisture	r	Standard error of estimate
		gm/cc	*Percent*				
A							
I	33.185	-29.699	-	0.281	0.124	0.83	2.189
II	33.743	-25.758	-	.216	-	.80	2.267
III	32.590	-22.584	-	-	.0710	.78	2.386
B							
I	0.348	-	0.111	-	.00734	.74	0.0696
II	.387	-	-	.00802	.00841	.71	.0726

The range of soil properties used to construct the model were as follows:

Soil Property	*Range*
Bulk density	0.94 - 1.44 g/cc
Total pore space	43 - 61 percent
Vacant pore space	7 - 40 percent
Water-filled pore space	17 - 38 percent
Organic carbon	2 - 3 percent
Texture	
Clay	15 - 29 percent
Silt	60 - 71 percent
Sand	11 - 15 percent
Cover	
Alfalfa	8 - 50 percent
Forb	0 - 32 percent
Grass	4 - 60 percent
Litter	8 - 42 percent
Bare	0 - 46 percent

APPLICATION

The procedure for estimating infiltration rate is as follows:

1. Select the appropriate models for estimating the constants A and B from table 2 depending on what soil properties have been measured on the sites in question.
2. Estimate A and B using the regression coefficients from table 2. For example, using Model I, the equations would be:

   A = 33.185 - 29.699 (bulk density) + 0.281 (% clay) + 0.124 (% moisture)

   and

   B = 0.348 + 0.11 (% organic carbon) + 0.00734 (% moisture).
3. Substitute estimated A and B in equation (2) to calculate infiltration rate in mm/min.
4. Plot the results for several areas and compare.

This model is intended for use in estimating the effect of changes in soil properties on infiltration rate and should be used only if soil properties are within the range of those used in constructing the model. Infiltration rates will vary greatly within a watershed and the estimated value will only approximate the mean. These estimated rates are for infiltration by a steady-head single-ring infiltrometer. Final rates may be as much as 10 times those for a sprinkling infiltrometer on similar soils (Green *et al.* 1964). Similar differences could be expected when comparisons are made to precipitation infiltration rates.

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