Use of Infiltration Equation Coefficients as an Aid in Defining Hydrologic Impacts of Range Management Schemes

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Highlight: Based on infiltrometer data from 13 pinyon-juniper sites in Utah, the relationship of selected rangeland vegetation characteristics and soil physical properties to the various infiltration coefficients contained in three well-known algebraic infiltration equations was determined. Coefficients in Kostiakov's equation were related more to vegetation factors than to soil factors while coefficients in Philip's equation were more related to soil factors than to vegetation factors. The single coefficient in Horton's equation was somewhat intermediate, representing both vegetation and soil influences. It is conceivable that changes in rangeland use activities or intensity of use may be detected through changes encountered in infiltration coefficients, with emphasis on either vegetation or soil factors or both, depending on the equation or model used.

The relationship of infiltration in native and "disturbed" rangeland plant communities to soil and vegetation parameters has been of interest to hydrologists for many years. Many devices have been designed to measure infiltration rates, and these range from ring-type infiltrometers to sprinkling-type devices that attempt to duplicate certain characteristics of natural rainfall.

Based on actual measurements, various researchers have found that the results of infiltrometer trials may be expressed in terms of specific models or equations. Examples include Kostiakov's equation (1932), Horton's equation (1940), and Philip's equation (1957). Each of these equations contains various coefficients, most of which are speculatively related in some (perhaps unidentified) way to factors that may be controlling the infiltration process. The objective of this study was to determine, to the extent possible, the relationship of selected rangeland vegetation characteristics and soil physical properties to the various infiltration coefficients contained in the three well known algebraic infiltration equations mentioned above. This objective is especially pertinent in terms of possible interpretations of long- or short-term temporal changes in infiltration rates as a function of specific management plans, and especially in those circumstances where supplemental soil and vegetation data are minimal or completely lacking.

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Available Infiltrometer Data

All infiltrometer data were collected using the Rocky Mountain infiltrometer (Dortignac 1951). Plots (0.23 m^2) were run with soils at field capacity to start (prewet and allowed to drain). Samples were collected at selected time intervals during each infiltrometer run, and infiltration was assumed to be the difference between rainfall applied and runoff. Rainfall application rates generally exceeded 7 cm/hour and represented relatively low probability short-term high intensity convectional thunderstorms of approximately 30-min duration.

Infiltrometer data from approximately 500 infiltrometer plots covering 13 pinyon-juniper (*Pinus* spp.-*Juniperus* spp.) plant communities (250 mm to 325 mm annual precipitation) scattered throughout Utah were utilized for this study. For 12 of these sites, the following vegetation and soil information was available for each infiltrometer plot: bare soil (%); total vegetal crown cover (%); soil <2 mmd (%); silt plus clay (0–7.5 cm depth %); total porosity (0–7.5 cm depth %); noncapillary porosity (0–7.5 cm depth %); and bulk density (gms/cc 0–7.5 cm depth) (Williams et al. 1972). For site 13, vegetation cover and yield data were available plus soils data from both undisturbed 7.5-cm diameter soil cores and disturbed samples from both the 0–2.5 cm depth and the 0–7.5 cm depth. These data were as follows: total yield of vegetation on plot (kg/ha); bare ground (%); water-stable sand-sized aggregates (%); sand + sand-sized aggregates (%); silt (%); clay (%); saturated hydraulic conductivity (cm/hour); total porosity (%); capillary porosity (%); and bulk density (gms/cc) (Busby 1977).

Analysis Procedure

The three infiltration equations included in this analysis were as follows:

$$f = cnt^{n-1} \qquad \text{(Kostiakov 1932)} \qquad (1)$$

$$f = f_c + (f_o - f_c)e^{-kt} \qquad \text{(Horton 1940)} \qquad (2)$$

$$f = \frac{30S}{\sqrt{t}} + A \qquad \text{(Philip 1957)} \qquad (3)$$

where:

f = infiltration rate, in length/hour;
t = time (min) elapsed since simulated rainfall began;
c, n, k, s, and A = coefficients;
f_c = the constant rate approached by f asymptotically as time continues, in length/unit time;
f_o = initial infiltration capacity, when $t_o = 0$.

Equations (1) and (2) are strictly empirical while the Philip equation was derived based on the physics of flow through unsaturated porous media. In this latter instance, the first term of equation (3) describes the uptake of water by porous media via capillary forces and dominates infiltration when time is small, while the second term, A, describes the ability of the soil to transmit water due to gravity forces and becomes increasingly important with time.

Each of the three equations was fit to infiltration data from each plot on a given pinyon-juniper site and, based on the least squares fit, values were determined for each of the five coefficients. A stepwise multiple-regression analysis was then used to determine the relationship of the various vegetation and soil parameters to the five infiltration coefficients.

Results and Discussion

The amount of variance associated with each infiltration coefficient as explained by the seven vegetation and soil parameters (% crown cover and % bare soil were included as a quadratic function) on 12 of the pinyon-juniper sites is shown in Figure 1. R^2 values for c range from 0.35 to 0.98 ($\bar{x} = 0.85$); for n from 0.25 to 0.96 ($\bar{x} = 0.61$); for k from 0.30 to 0.79 ($\bar{x} = 0.54$); for S from 0.37 to 0.92 ($\bar{x} = -0.75$); and for A from 0.23 to 0.83 ($\bar{x} = 0.64$). Two examples of the ability of the seven parameters to explain variance associated with the five infiltration coefficients are shown in Figures 2 and 3 for different pinyon-juniper sites.

Significant soil and vegetation parameters for each infiltration coefficient, as defined in a pooled analysis (the 12 pinyon-juniper sites combined) were as follows:

Infiltration coefficient	Significant soil or vegetation parameter (.05 level)	Variance explained (%)
c	(% crown cover)^2	70
	total porosity (%)	12
	% soil <2 mmd	8
n	(% bare soil)^2	34
	(% crown cover)^2	33
	% soil <2 mmd	9
k	bulk density	32
	(% crown cover)^2	24
	% noncapillary porosity	9
S	% soil <2 mmd	55
	bulk density	25
	(% crown cover)^2	7
A	% soil <2 mmd	55
	% silt + clay	6
	bulk density	5

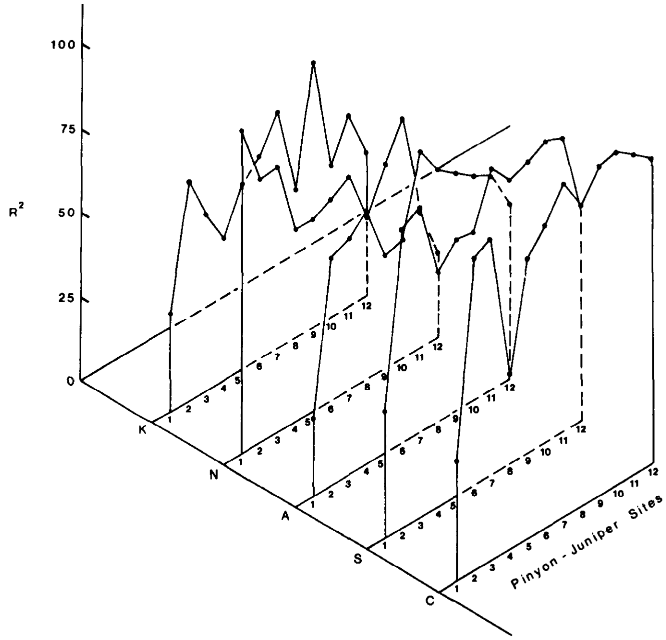

Fig. 1. *Amount of variance (R^2, %) associated with each infiltration coefficient as explained by seven vegetal and soil parameters on 12 pinyon-juniper sites in Utah.*

Analysis of data from pinyon-juniper site 13, a site on very uniform sandy loam soils in southeastern Utah, was somewhat disappointing. As previously mentioned, besides vegetation data, detailed soil data were available for each plot from undisturbed soil cores and disturbed samples collected from both the 0–2.5 cm and the 0–7.5 cm soil depths. However, R^2 values representing both sets of data indicates inadequate fit of the multiple regression model to any of the infiltration coefficients (maximum R^2 = .08; Fig. 4).

Discussion

The five infiltration coefficients studied were not related in a totally consistent way to any of the soil and vegetation parameters measured on infiltrometer plots. R^2 values for the various coefficients (as defined by multiple regression analyses) ranged

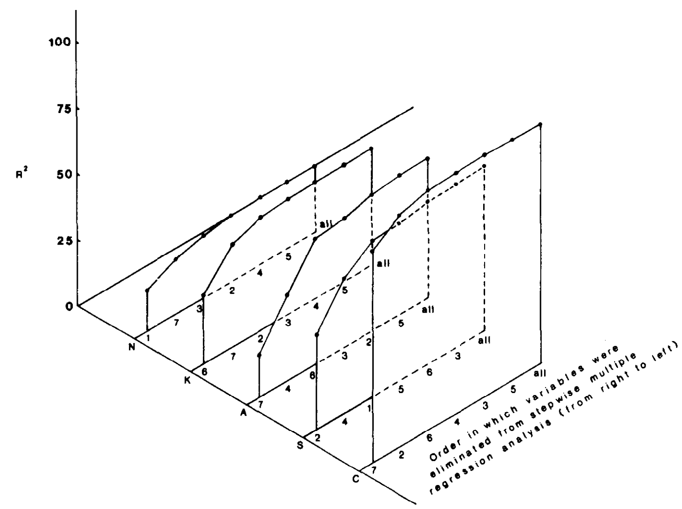

Fig. 2. *Amount of variance (R^2, %) at pinyon-juniper site 11 associated with each infiltration coefficient as explained by the following factors: X_1 = total porosity; X_2 = bulk density; X_3 = non-capillary porosity; X_4 = silt + clay; X_5 = soil <2 mmd; X_6 = (bare soil)^2; and X_7 = (crown cover)^2.*

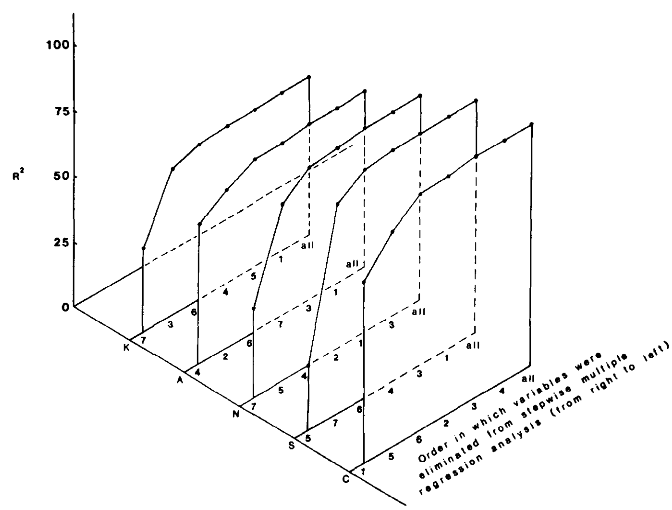

Fig. 3. *Amount of variance (R^2, %) at pinyon-juniper site 1 associated with each infiltration coefficient as explained by the following factors: X_1 = total porosity; X_2 = bulk density; X_3 = non-capillary porosity; X_4 = silt + clay; X_5 = soil <2 mmd; X_6 = (bare soil)^2; and X_7 = (crown cover)^2.*

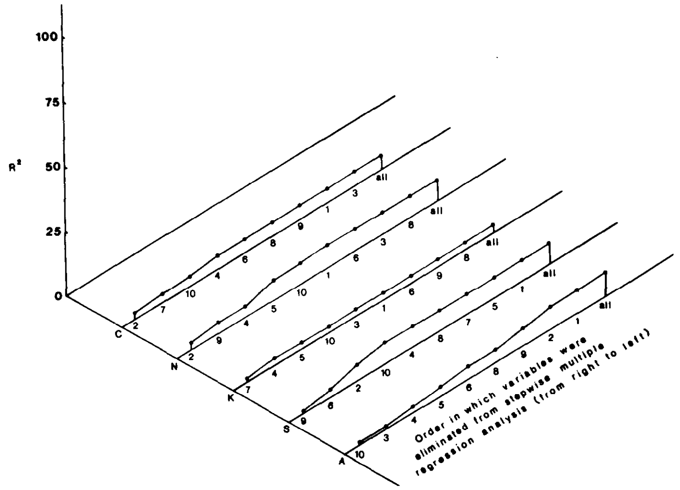

Fig. 4. *Amount of variance (R^2,%) for data from the 0-7.5 cm soil depth at pinyon-juniper site 13 associated with each infiltration coefficient as explained by the following factors: X_1 = kg/ha vegetation on plot; X_2 = bare ground; X_3 = water stable sand-sized aggregates; X_4 = sand + sand size aggregates; X_5 = silt; X_6 = clay; X_7 = hydraulic conductivity; X_8 = capillary porosity; X_9 = total porosity; and X_{10} = bulk density. Data from the 0–2.5 cm depth looked nearly identical.*

from 0.02 to 0.98 over 13 pinyon-juniper sites scattered throughout Utah. Based on an analysis of data pooled over 12 sites it appeared that coefficients in Kostiakov's equation were related more to vegetation factors than to soil factors, while coefficients in Philip's equation were more related to soil factors than to vegetation factors. The single coefficient in Horton's equation was somewhat intermediate, representing both vegetation and soil influences.

It is recognized that both soil and cover factors interact in a complex and highly variable way to determine the rate at which the infiltration process takes place on a given site (other things being equal). Assuming that the Rocky Mountain infiltrometer provides a valid measure of infiltration rates, then it is obvious that on most sites other unmeasured soil and vegetation properties were also acting to control the behavior of the various coefficients. Because vegetative cover is often relatively sparse on semiarid rangeland sites, it was anticipated that soil physical properties would be extremely important in all attempts at modeling the infiltration process. However, based on this study, it appears that some models may be more sensitive to vegetation or soil protective cover and resultant impact on the infiltration process than to the input of soil parameters. It is therefore conceivable that changes in rangeland use activities or intensity of use may be detected through changes encountered in infiltration coefficients, with emphasis on either vegetation or soil factors or both, depending on the equation or model used. Obviously, as was reflected in the R^2 values, changes in infiltration coefficients may at times not reflect changes in any of the soil or vegetation parameters included in this study.

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