FACTORS AFFECTING TEMPORAL AND SPATIAL SOIL MOISTURE VARIATION IN AND ADJACENT TO GROUP SELECTION OPENINGS

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Abstract: Soil moisture content was intensively sampled in three, 1-acre blocks containing an opening and surrounding mature upland hardwoods. Openings covering 0.19-0.26 ac were created by group-selection cutting, and they were occupied by 1-year-old trees and shrubs. During 1989, soil water content at each site decreased rapidly during the summer and did not increase until evapotranspiration declined near the end of the growing season. During wet periods, when weekly precipitation exceeded potential evapotranspiration, soil moisture was about the same in openings as under the trees. In dry periods, soil moisture was greater (1) in the openings than in the adjacent stand and (2) on concave-shaped than on convex-shaped areas. In openings, soil water increased with distance from the edge during dry periods but not during wet periods. Prediction equations based on these site variables and an expression of point-to-point variation in soil water-holding capacity explained over 60 percent of the spatial variation in soil water content during dry periods. Soil water-holding capacity was the most important variable in all prediction equations during both wet and dry periods, accounting for about 23% and 39%, respectively, of the variation in soil moisture. These results suggest that spatial variability in soil moisture in group selection openings is associated with relatively few stand and site variables.

INTRODUCTION

Regeneration by group selection creates small (<1 acre) openings in the forest canopy within which environmental conditions can vary widely (Smith 1962). Compared with our knowledge of environmental conditions in large openings, such as those made by clear cutting, we know little about conditions in small openings. Information gathered in large openings cannot be applied to small openings because of differences in the ratio of area to edge and because of gradients in light and soil moisture caused by the stand boundary. While both light and water influence the response of regeneration in openings (Godman and Krefting 1960, Geiger 1965, Minckler et al. 1973), the soil water regime has received less attention than light. Additional information on variation of soil moisture in openings during the growing season and within sites is needed to better understand the growth response of regeneration. In the present study, I measured temporal and spatial variation in soil water in and around openings of 1/5 to 1/4 acre in a mature hardwood stand during the growing

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season. My purpose was to determine the relative importance of soil, tree stand, and topographic factors on spatial variations in soil moisture.

METHODS

Study Area

This study was conducted in the Bent Creek Experimental Forest, a 6000-acre research facility maintained by the USDA Forest Service in western North Carolina, about 10 miles southwest of Asheville. The Forest is in the Blue Ridge Physiographic Province, whose geology is dominated by granites, gneisses, and schists. Winters are short and mild, and summers are long and warm. Annual precipitation, which averages about 46 inches, is evenly distributed during the year with little occurring as snow. Precipitation generally increases with elevation due to local orographic effects.

The study was installed in the Boyd Branch drainage, at the lower end of a large, east-facing cove at an elevation of about 2500 feet. The cove contains a variety of sites ranging from shallow concave drains to low convex ridges. It is dominated by mesophytic species, including yellow-poplar (*Liriodendron tulipifera* L.), northern red oak (*Quercus rubra* L.), and red maple (*Acer rubrum* L.) trees and an understory of flowering dogwood (*Cornus florida* L.) and sourwood (*Oxydendrum arboreum* (L.) DC). Scattered sweet birch (*Betula lenta* L.) and white oak (*Q. alba* L.) are also present. Steeper side slopes of the cove are dominated by chestnut oak (*Q. prinus* L.) and an understory of mountain laurel (*Kalmia latifolia* L.). This 40-acre cove stand is being regenerated by the group selection method.

During late 1987 and 1988, trees were harvested to create 14 small openings ranging from 0.1 to 0.4 acre in area. Improvement cutting and thinning were done in the timber stand between the group selection openings. Logs were skidded with a small farm tractor equipped with a winch. Logging was restricted during wet weather to reduce soil compaction and erosion. Site preparation in the openings consisted of felling all vegetation over 4.5 feet tall. When the study was initiated in June 1989, each opening was fully stocked with 1- to 2-year-old herbaceous vegetation, shrubs, tree seedlings, sprouts, and advance regeneration that had responded to removal of the overstory.

Soils in the stand are mapped as a complex of Tusquitee, Tate, and Brevard. Tate and Brevard are fine-loamy, mixed, mesic, Typic Hapludults. Tusquitee is a coarse-loamy, mixed, mesic, Typic Dystrochrept. All three soils are mixtures of alluvium and colluvium, and all have surface horizons over 6 inches thick and solums over 40 inches deep.

Plot Establishment and Measurements

Three openings, spaced from 500 feet to 900 feet apart and ranging in size from 0.18 to 0.26 acre, were selected for study. Each opening represents a distinct landform: a small cove branching off the main cove, a low ridge, and a midslope that is linear rather than convex or concave. A square, 1-acre block was defined around each opening. A grid of 25 sample points (spaced at 50x50 feet) was located in each block for soil moisture determination. Total volumetric (in^3water/in^3soil) moisture content was determined by time-domain reflectrometry (TDR) (Topp and Davis 1985) using a Tektronix Model 1502 portable cable tester. Moisture content in the top 6 inches of soil was estimated using a pair of permanently placed 0.125-inch-diameter stainless steel welding rods spaced 2 inches apart and set flush with the soil surface. TDR methods are nondestructive, accurate, and allow repeated measures of soil moisture over time. Perhaps the most important advantage of TDR over conventional gravimetric methods of soil water estimation is that repeated sampling over time is free of errors normally associated with variations among sample location. An empirical, universal calibration curve was used to convert TDR readings to volumetric water content (Topp et al. 1980). The universal calibration curve was verified by measuring soil water content in the 0-6 inch layer at 10 randomly selected, coincident points by TDR and gravimetric methods. Means (and standard deviations) in soil water estimates by the two methods were nearly identical:

TDR	0.321 (0.030) in^3/in^3
Gravimetric	0.309 (0.031) in^3/in^3

Soil moisture was intermittently sampled eight times, from June to mid-October, on a schedule that allowed as much drying as possible before the next anticipated rainfall.

Seven soil, stand, and topographic variables were measured at each of the 25 points in each 1-acre block:

- Soil variable
    1. Soil compaction (lb/in^2)
- Stand variables
    2. Inside or outside of the opening
    3. Distance from edge of opening (feet)
    4. Basal area (10-factor prism)
- Topographic variables
    5. Aspect (degrees)
    6. Slope gradient (percent)
    7. Land surface shape

Four measures of soil compaction were taken in a square pattern around each sampling point using a Soiltest Model PR-025 Proving Ring Penetrometer (30-degree cone with 1.0 in^2 base area) and averaged. Compaction was determined when soil moisture was near field capacity. Several sample points were shifted slightly to avoid logging access roads. All stand and topographic variables were determined by standard methods and are self-explanatory except for land surface shape. Microsites (0.04 acre area that surrounded each soil sample point) varied in surface shape, ranging from slightly convex to concave. Land surface shape of each microsite was quantified by measuring the terrain shape index (McNab 1989). Means and ranges of the continuous variables measured on the three sites are presented in Table 1.

Table 1.--Mean and range of soil, stand, and topographic variables in the three sites studied.

Variable	Midslope	Cove	Ridge
	Mean (min./max.)		
Compaction (lb/in^2)	145 (74/236)	124 (54/238)	95 (51/184)
Basal area (ft^2/ac)	44 (0/100)	65 (10/120)	66 (0/120)
Distance from edge of plot (feet)	51 (5/105)	34 (30/40)	32 (5/85)
Aspect (degrees)	68 (9/159)	35 (333/87)	138 (63/193)
Slope gradient (%)	16 (5/26)	31 (16/51)	35 (16/22)
Terrain shape index	.01 (-.05/.19)	.00 (-.09/.12)	.02 (-.09/.24)

Soil moisture can also vary in response to other factors including bulk density, organic matter, and proportions of sand, silt, and clay. An indicator variable, soil water capacity, was determined at each sample point to account for these undetermined properties. This approach is similar to that of Helvey et al. (1972), who determined a factor to "remove the relatively unaccountable variation in moisture content resulting from the soils' ability to retain water against drainage and evapotranspiration." This variable, which I call "soil water capacity", is the amount of moisture in the soil when it is wetted to near field capacity. Values were determined somewhat arbitrarily in early June, 2 days after a 2-day rain. Water capacity values were determined for each of the 25 soil sample points on each 1-acre block (Table 2). Variation in the water capacity factors within 1-acre blocks was relatively wide, with no indication of a consistent gradient. Presence within an opening appeared to have little effect on the values. For example, water capacity values on the ridge ranged from 0.259 to 0.337 over a distance of 50 feet. Average water capacity varied somewhat among sites, as indicated by the means and standard deviations:

Cove	0.269 (0.035)
Midslope	0.286 (0.043)
Ridge	0.307 (0.046)

At near field capacity, soils had slightly greater water-holding capacity on the ridge than in the cove.

Precipitation and air temperature were determined and recorded by an automatic weather station located in the midslope opening. Weekly potential evapotranspiration was determined by the method of Thornthwaite and Mather (1957) using a computer program (Stone 1988).

Table 2.--Soil water capacities in the top 6 inches of soil at 25 sample points on each of three sites. Sample points were arranged in a grid with each row and column spaced 50 feet apart. Underlined sample points are in an opening.

	Column				
Row	1	2	3	4	5
			Cove		
1	.209	.267	.283	.275	.209
2	.283	.291	.322	.267	.314
3	.274	.299	.209	.275	.275
4	.267	.267	.322	.209	.283
5	.275	.226	.283	.307	.226
			Midslope		
1	.322	.299	.218	.307	.314
2	.267	.314	.259	.307	.242
3	.299	.322	.330	.307	.337
4	.283	.259	.226	.226	.314
5	.251	.209	.242	.345	.359
			Ridge		
1	.322	.291	.352	.291	.330
2	.307	.330	.267	.299	.322
3	.426	.259	.330	.259	.337
4	.366	.185	.291	.306	.259
5	.337	.322	.251	.306	.322

That method of estimating plant water use and evaporation has been criticized as too simplistic, but it is useful in this case for broadly characterizing environmental conditions. Because precipitation is a major cause of temporal variation in soil water content, sampling dates were stratified into two periods, dry or wet. Dry periods were arbitrarily defined as weeks in which potential evapotranspiration exceeded precipitation. In wet periods, weekly precipitation exceeded evapotranspiration.

Data were analyzed in two phases. Effect of the discrete factor (in or out of opening) on soil water was examined by analysis of covariance. Correlation and multiple regression analysis were used to determine the relationship of the continuous site variables to soil moisture content on each measurement date. Since sites were unreplicated, statistical comparisons among sites could not be made. Regression coefficients were tested for significance at the

0.05 level. Those results are omitted from this presentation because of its limited scope. A dynamic local model of soil moisture as a function of time and amount of precipitation was not developed, but such a model has been developed for a nearby region of greater precipitation in the southern Appalachians (Helvey et al. 1972).

RESULTS AND DISCUSSION

Temporal Variation

In 1989, losses of soil water to evapotranspiration generally exceeded inputs from precipitation at Bent Creek from early July through early September (Figure 1). The pattern of precipitation was typical, except for September, when heavy rain associated with a hurricane fell for 2 days. July through early September precipitation in 1989 was about 50 percent above the 44-year normal at Bent Creek Experimental Forest. Soil moisture was sampled during three wet periods and five dry periods:

Wet periods: June 22, 29, October 13
Dry periods: July 10, 18, 28; August 18, September 5

Soil moisture content decreased rapidly during July, as precipitation decreased and evapotranspiration increased, and then leveled off during August (Figure 2). Total soil water content during June was slightly higher in the cove than at midslope or on the ridge site. By mid-July, water contents were almost identical on all blocks. Soil moisture contents in mid-September were about 40 percent below those of early June. Soil moisture began to increase by October, as potential evapotranspiration decreased. A similar trend in seasonal soil moisture content was reported for Coweeta Hydrologic Laboratory by Helvey and Hewlett (1962).

Spatial Variation

During wet periods, there was little spatial variation in soil water content. During dry periods, a typical drying pattern emerged, which was dependent upon several factors. For analysis of spatial soil water data, June 22 was selected as a typical wet period and September 5 as a typical dry period.

Soil Water Capacity. Water capacity values were highly correlated with soil water content during both wet and dry periods, as indicated by the following correlation coefficients:

Wet $r=0.48$
Dry $r=0.63$

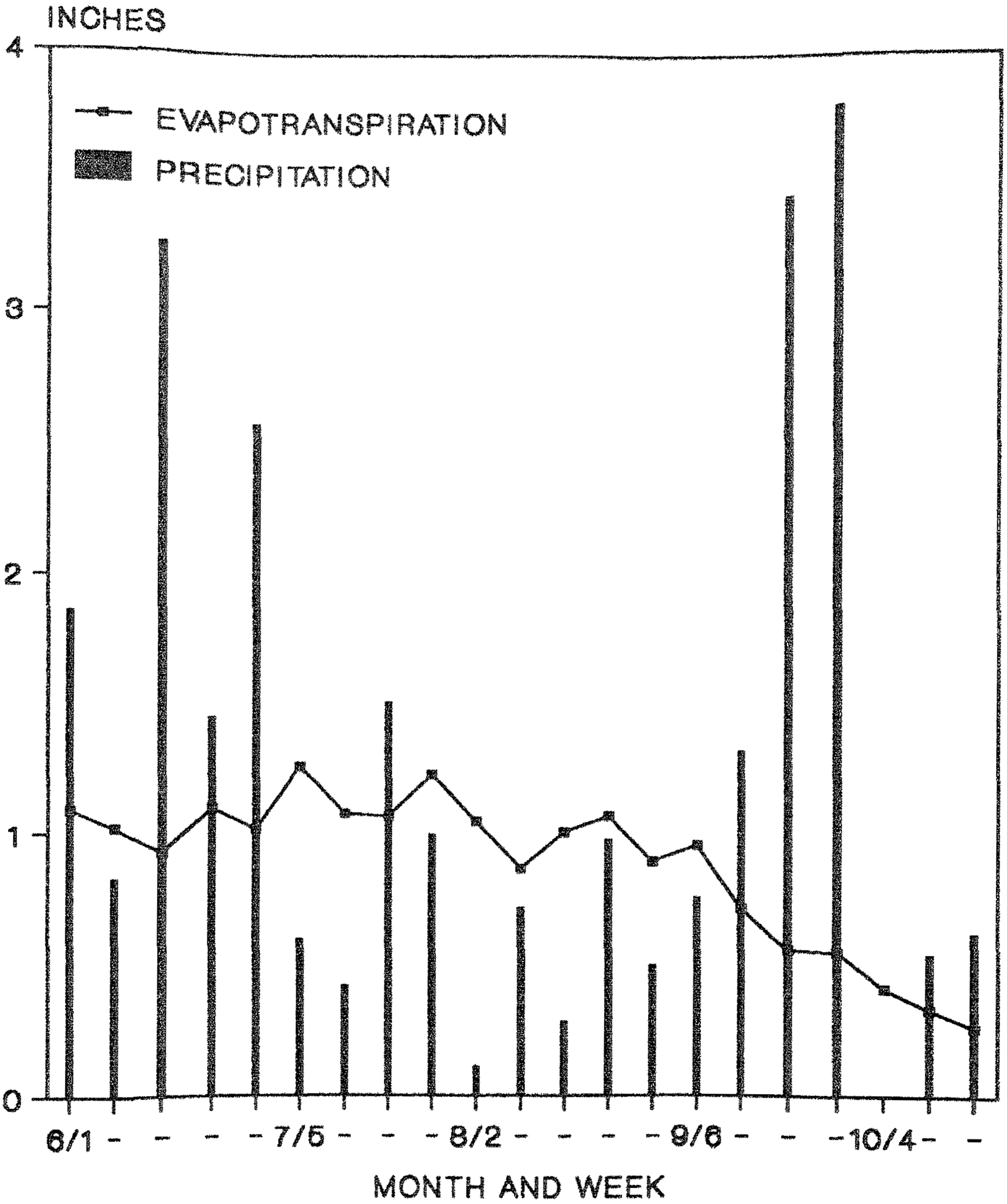

Figure 1. Weekly precipitation and potential evapotranspiration at the midslope site from June 1 to October 4, 1989.

Helvey et al. (1972) reported that a similar variable, which accounted for variation in moisture-holding ability of the soil, was the single most important variable affecting soil water in a study at Coweeta Hydrologic Laboratory.

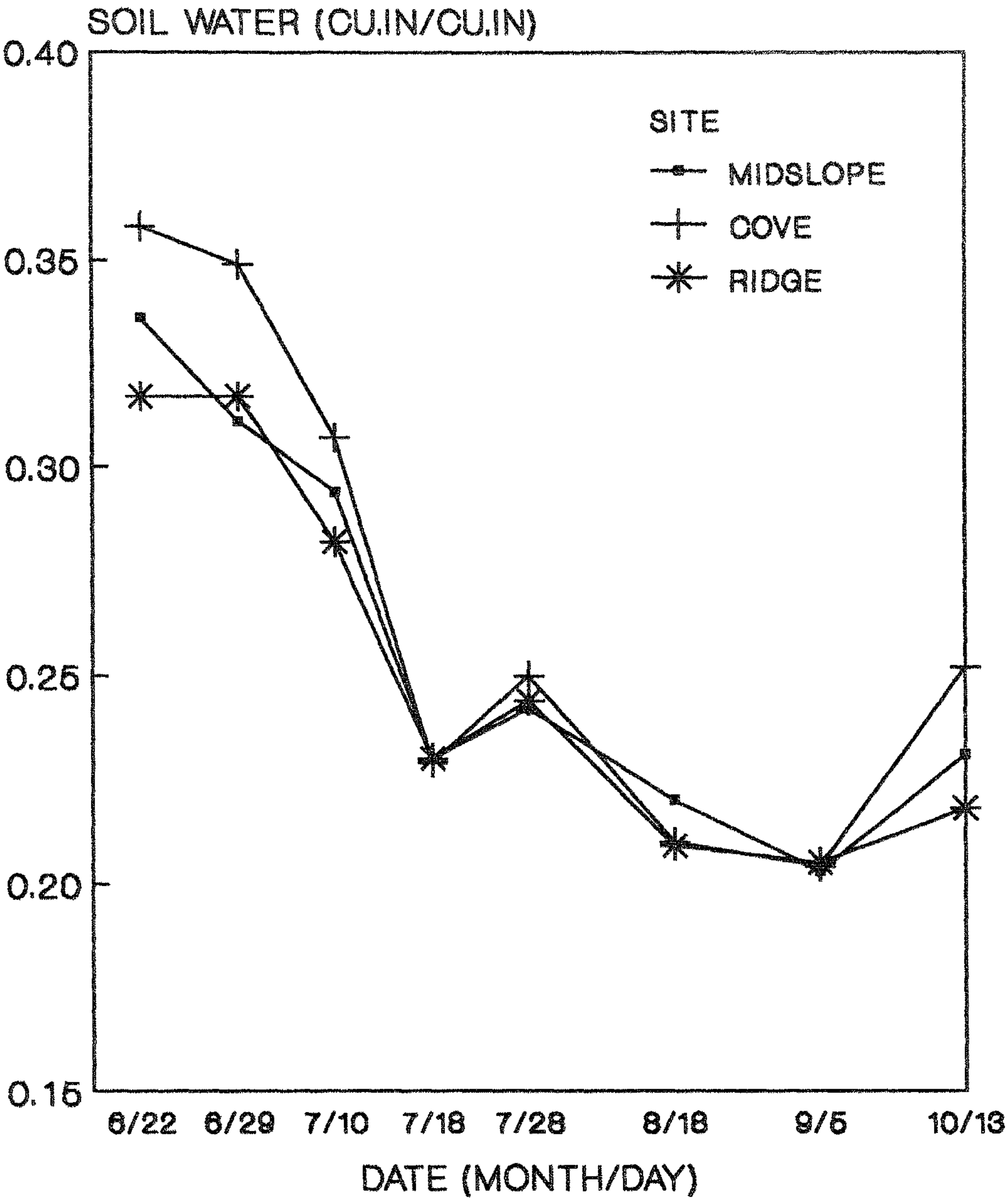

Figure 2. Temporal variation in moisture content of soil on three sites, 1989.

Group Selection Openings. During wet periods soil water content was about the same inside and outside the openings. In dry periods, however, soil moisture was significantly greater inside the openings. The cove site had somewhat greater soil water contents inside openings during dry periods than did the ridge site, with the midslope intermediate between the two (Table 3).

Table 3.--Means and standard deviations () for soil moisture contents in openings and adjacent stands by rainfall period and site.

Site	Inside opening	Adjacent stand	Mean
		WET PERIOD	
Cove	0.351 (.085)	0.349 (.025)	0.349 (.038)
Midslope	0.327 (.028)	0.297 (.042)	0.311 (.038)
Ridge	0.311 (.053)	0.322 (.057)	0.317 (.054)
Mean	0.324 (.052)	0.327 (.044)	0.326 (.047)
		DRY PERIOD	
Cove	0.282 (.059)	0.189 (.041)	0.204 (.055)
Midslope	0.246 (.061)	0.163 (.061)	0.203 (.073)
Ridge	0.214 (.054)	0.197 (.084)	0.205 (.070)
Mean	0.251 (.049)	0.182 (.061)	0.204 (.065)

Soil water content in openings was affected by rainfall period and distance from the edge. During wet periods, no differences in soil water content were evident at sample points in the stand or the opening. In dry periods, however, water content at the edge of the opening was about equal to that in the adjacent stand. Soil water content increased rapidly with distance into the opening (Figure 3) and tended to level off about 30 feet into the opening. These results suggest that trees along the opening boundary influence soil water content mainly through water use by roots. Casual observations revealed that crowns typically extended about 15 to 30 feet into the openings. Minckler et al. (1973) also reported increased soil moisture with distance into the openings.

Although not measured in this study, tree regeneration toward the center of the openings appeared to be taller than that near the edges. Increased light is one reason for better growth, but greater soil moisture is also a likely contributing factor. An application of these findings is that the group selection openings should be large enough so that soil moisture in much of the area is not influenced by the adjacent stand and can be utilized by the regeneration for rapid height growth.

Soil, Stand and Topographic Variables. Soil water content was closely correlated with soil compaction, basal area, and terrain shape index, and somewhat less with slope gradient (Table 4). With the exception of terrain shape index, all correlations were negative. And, except for basal area, the significant variables were correlated with soil moisture in both wet and dry periods.

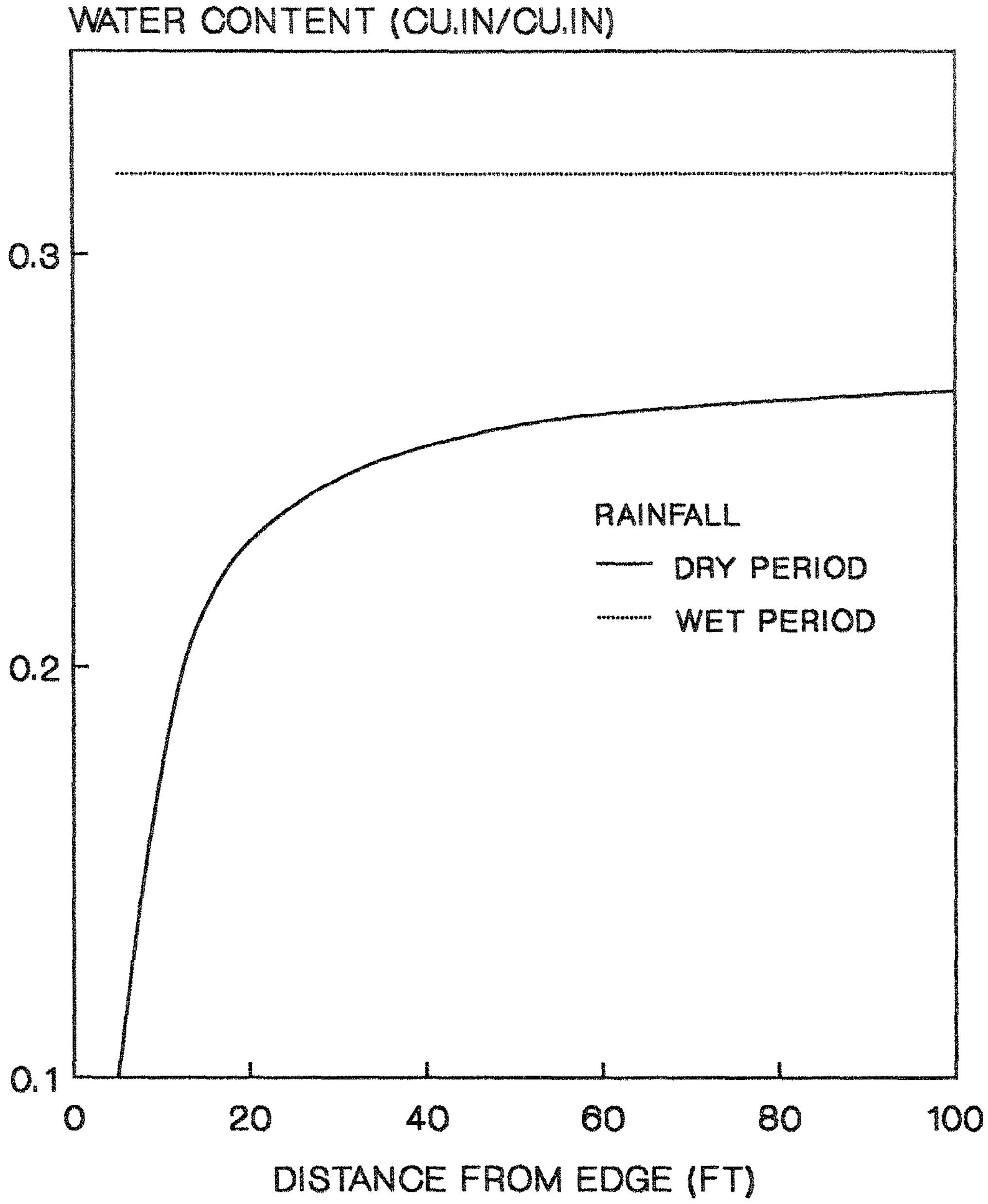

Figure 3. Predicted soil water content in an opening during a dry period as related to distance from edge of opening.

Soil, stand, and topographic variables significantly correlated with soil water content, along with soil water capacity, were included in a multiple regression analysis for the typical sample date during wet and dry periods. The following linear model provided the best fit during dry periods:

$$\text{Soil water (in}^3/\text{in}^3) = b_0 + b_1(\text{soil water capacity}) + b_2(\text{basal area}) + b_3(\text{terrain shape index}) \qquad [1]$$

This model accounted for 62 percent of the variation in soil moisture at individual sample points. The soil water capacity was the single most important variable, accounting for 39 percent of the variation. Stand basal area and terrain shape index were about equally important. During wet periods, only the water capacity factors had a significant effect on soil moisture, accounting for 23 percent of the variation.

Table 4.--Pearson correlation coefficients of soil water content with soil, stand, and topographic variables.

Variable	Wet periods	Dry periods
	---------- r ----------	
Soil water capacity (in^3/in^3)	.46**	.57**
Compaction (lb/in^2)	-.29**	-.36**
Basal area ($ft^2/ac.$)	-.24	-.39**
Aspect (azimuth)	-.09	-.09
Slope gradient (%)	-.10*	-.12*
Terrain shape index	.20**	.37**

* Significant at the 0.05 level.
**Significant at the 0.01 level.

Several variables that were correlated with soil moisture content were not significant in the prediction model because of intercorrelations among variables. Soil compaction was not a significant variable in the model because it was strongly correlated with the soil water capacity (Figure 4). The effect of slope gradient on soil moisture was largely accounted for by terrain shape index. Similar interrelationships between topographic variables have been found in many soil-site studies.

Figure 5 illustrates the response surface of the model for soil water in the 0-6 inch layer on a typical sample date (September 5) during a dry period. Lowest predicted values of soil water content are found on a convex soil surface with high basal area. The model indicates that soil water content approximately doubles when: (1) basal area is reduced from 120 to 0 ft^2/acre with constant surface shape, or (2) soil surface shape changes from slightly convex to concave with constant overstory basal area. If basal area and surface shape change simultaneously, predicted soil water contents are about three times greater in a group selection opening with 0 basal area and a concave surface, compared to a sample point in the adjacent stand with high basal area and a convex shape.

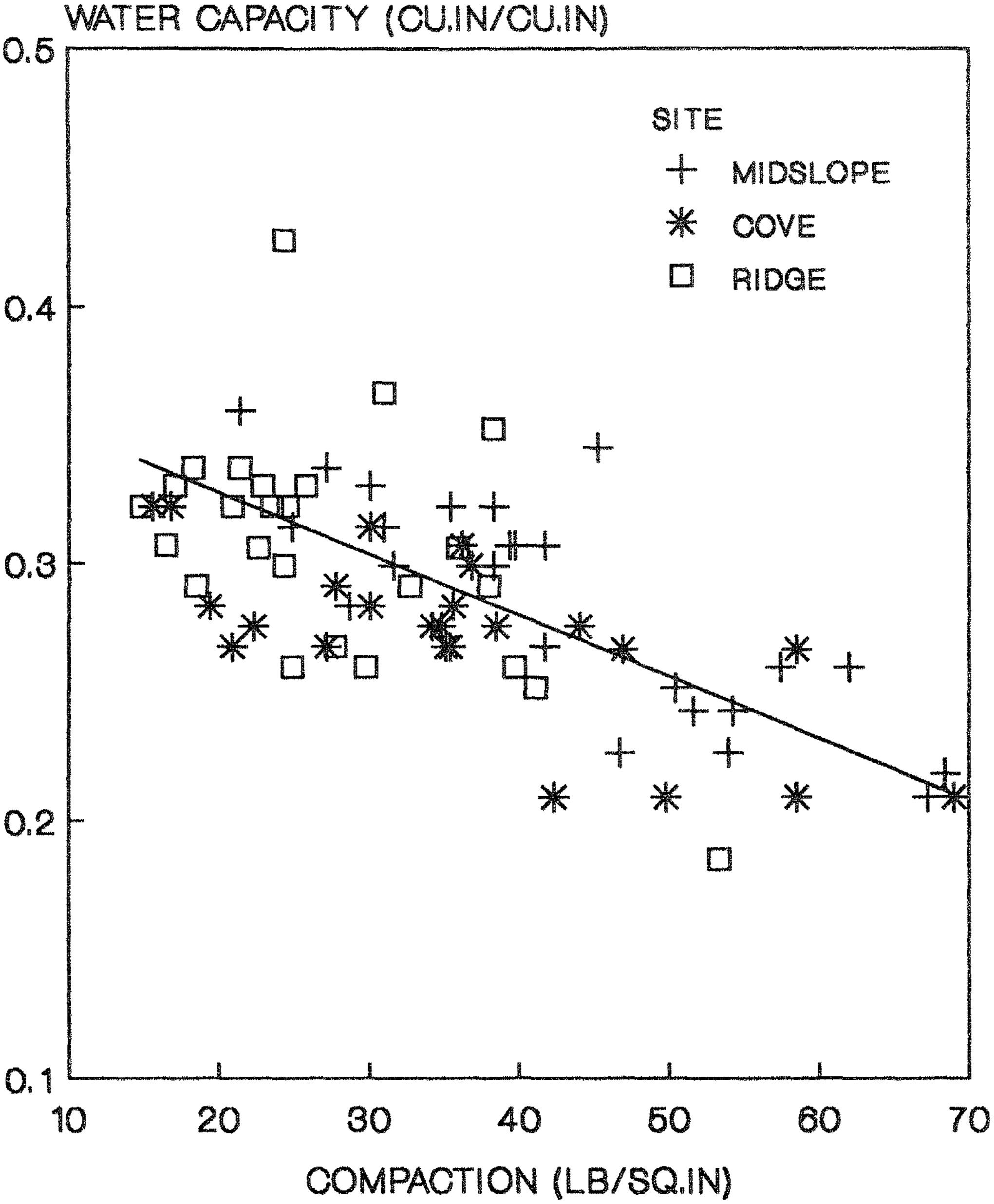

Figure 4. Relationship of soil water capacity to soil compaction, by site and sampling point.

The relationship between soil compaction and soil water capacity may be useful for field application of these results. Field determination of water capacity is time consuming and requires specialized equipment. However, by using a relationship similar to that of Figure 4, the soil water capacity might be estimated from the more easily measured variable, soil

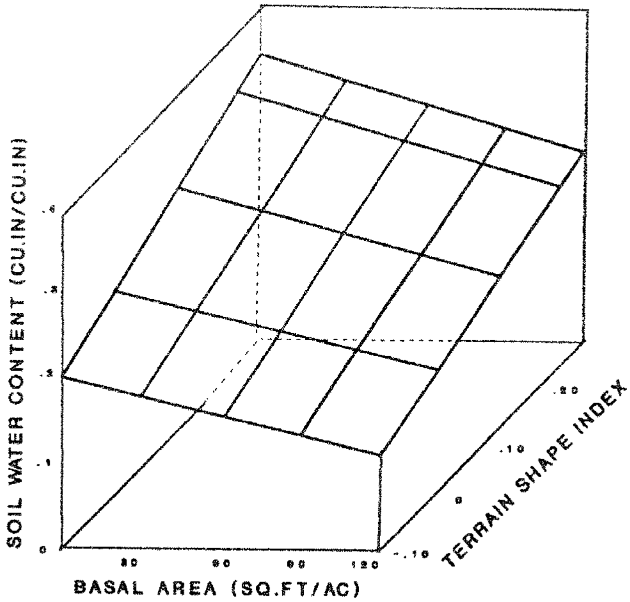

Figure 5. Predicted soil water content as a function of stand basal area and terrain shape index for the 0-6 inch layer on September 5, 1989.

compaction. Another approach would be to reformulate the prediction equation in terms of soil compaction. In any event, water holding capacity of the soil can be estimated with little need for soil sample collection and laboratory analysis.

The effects of temporal and spatial variations in soil moisture on the growth of mesophytic species like yellow-poplar may be quite large. In my own work, I have found an increase in yellow-poplar site index of over 20 feet at age 50 associated with a change in terrain shape from convex to concave. Results of the present study indicate that the effect of terrain shape is probably through additional soil moisture during dry periods. In addition, Beck (1984) reported that a very large proportion of the annual variation in radial growth of individual yellow-poplar trees in the southern Appalachians can be explained by annual variations in rainfall in June and July. He postulated that soils were typically fully charged with moisture early in the growing season, but that supplies sufficient for rapid growth were exhausted by the end of June in dry years. Similar sorts of relationships between soil moisture and growth may also hold for other mesophytic species on well-drained sites.

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