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TABLE 1: PARTICLE SIZE DISTRIBUTION OF PARENT MATERIAL OF NINE REPRESENTATIVE SOILS OF THE GLACIAL LAKE BENSON AREA

Site No.	Soil Series	Depth In.	Sand %	Silt %	Clay %	Texture	Nature of Glacial Mat.
A	Barnes	30-54	35.7	39.5	24.8	loam	till
B	Buse	18-60	39.0	39.3	21.7	loam	
C	Bearden	27-60	1.3	62.7	36.0	silty clay loam	lacustrine
D	Colvin	28-60	5.0	73.2	21.8	silt loam	
E	Hegne	22-60	3.3	56.2	40.5	silty clay	
F	Hantho	30-60	10.0	75.0	15.0	silt loam	
G	Renshaw[4]	22-60	54.2	10.8	5.0	sand-gravel	outwash
H	Marysland	27-60	92.3	3.5	4.2	sand	
I	Hecla	36-60	93.6	1.9	4.5	sand	

Site locations are shown on Figure 2. Depth of sampling is generally below zone of soil development. Texture is defined and characterized according to the National Cooperative Soil Survey. There is 30 percent gravel in Renshaw soil.

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ABSTRACT — Soil water trends were monitored during the 1971 growing season on the Anoka Sand Plain in east-central Minnesota. Soils were sampled under four vegetation densities, ranging from old field through increasing amounts of oak overstory. There was no difference over the sampled period in total soil water content (to 100 cm) on the four sites. Differences were found in water content of individual soil horizons, and especially in the surface horizon (0 to 10 cm). A model of evapotranspiration was used to simulate the observed trends and the prediction and observations were closely correlated ($r^2 = 0.91$).

General agreement exists concerning the importance of meteorological factors in influencing water use by vegetation. Differences of opinion exist, however, on the relative importance of kind and density of species on such use. Some studies have found relatively little difference in water use by a variety of species, as long as soil and climatic conditions were similar (Cohen and Strickling, 1968; Herring, 1970). Other studies have found relatively large differences in water use associated with differences in vegetation (Johnston, 1970; Marston, 1962). Douglass (1966), in a review paper, concluded that differences do exist in water use between grass and forest, due mainly to differences in rooting depths. Douglass makes the qualification that under humid climatic conditions and a readily available water supply, evapotranspiration may not be measurably different under grass and forest. Although species differences do not seem to affect water use by well-stocked forest vegetation, density does appear to make a difference, especially following forest thinning (Barrett and Youngberg, 1965; Orr, 1968).

The objectives of this study were to determine whether measurable differences existed in soil water under different types of natural vegetation and to attempt to predict the measured soil water levels with an evapotranspiration model. Selected for study was the Anoka Sand Plain, a large glacial outwash in east-central Minnesota. The outwash material in the area is uniformly high in sand and low in silt and clay. Four sites within 0.8 km of one another were studied. These included the grass site, an old field dominated by smooth brome (approximately 60 percent cover) and lesser amounts of sand dropseed (15 percent), sandbur (10 percent), and other species. The grass cover was not continuous, and about 10 percent of the surface was bare. The other three sites had grassy understories and increasing densities of burr and red oak overstory. These latter three sites were designated grass and oak (4 m^2/ha of oak basal area), oak and grass (16 m^2/ha), and oak (22 m^2/ha). The soils underlying all sites have been tentatively classified as members of the Sartell soil series (mixed, frigid, Typic Udipsamments). These excessively-drained fine sands are found on undulating to rolling dune-shaped topography on outwash plains.

Eighteen sampling periods

Soil water was determined gravimetrically during the 1971 growing season. The three sites with oak were first sampled on 5 May, and the grass site on 19 June. Most of the statisti-

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cal analyses are based on soil water content determined at approximately weekly intervals from 19 June through 1 November (18 sample periods). Samples were collected with a bucket auger from three randomly located points at each site. The A1, B, and C horizons, corresponding to depths of 0 to 10 cm, 10 to 50 cm, and 50 to 100 cm respectively, were sampled at each point. In autumn 1971 the soil profiles were described and major horizons were sampled.

Particle size distribution of the soil samples was determined by the hydrometer method (Day, 1956); sand was determined by wet sieving and clay by hydrometer at eight hours. Porous-plate apparatus was used to determine the water-retention characteristics of the samples. All gravimetric soil-water data were converted to volumetric measures based on bulk densities determined by the core method. One-way analysis of variance was used to analyze variation in soil-water content at each sampling time, and two-way analysis, blocking on time, was used to analyze variation over the entire sampling period.

In addition to the measurement of soil-water with time, SOGGY, an evapotranspiration model (Grigal and Hubbard, 1971) was used to simulate soil-water trends. The model uses both meteorological data and soil parameters. Evapotranspiration is computed as a function both of potential evapotranspiration determined by the combination energy balance – aerodynamic approach (Penman, 1956) and of soil-water tension. Meteorological data for the simulation came from records of nearby U.S. Weather Service Stations. Dew point and wind data were obtained from the first-order stations of St. Cloud and Minneapolis (29 and 84 km away, respectively). Temperature data were from the Santiago station (5 km). Solar radiation data came from St. Cloud, the St. Paul campus of the University of Minnesota (77 km), and the Cedar Creek Natural History area of the University (48 km). We used precipitation data from Santiago and from three cooperators in a "backyard raingauge" study (at 11, 14, and 14 km). All meteorological data were weighted by the distance from the site to determine average site values.

Some uniformities on all sites

Particle size distribution of the soils on all sites showed the expected uniformity. Clay content over all sites ranged from two to three percent in the 0 to 10 cm horizon and two to four percent in the 10 to 50 cm horizon. The clay content of the 50 to 100 cm horizon was two percent at all sites.

Analysis of soil-water content over time showed differences in distribution of water with differences in vegetation, but only two of the 18 sampled dates showed significant (at the 95 percent level) differences in total soil-water content (to 100 cm) among the four sites. A two-way analysis of variance, blocking on time and testing differences among sites, showed no significant difference in total soil-water content among the four sites over the sampled period ($F\ (3, 51) = 1.53$). When the individual horizons were tested in the same way, highly significant differences (at the 99 percent level) were found at the surface and in the 50 to 100 cm horizon ($F\ (3, 51) = 57.36$; 0.22; 11.41 respectively for 0 to 10 cm, 10 to 50 cm, and 50 to 100 cm horizons).

Figure 1 shows the average volumetric water content of the four sites over the entire sampling period and also shows water content of the sites on the driest sampling date (12 August). Here again, analysis of variance showed no significant difference among sites in total soil-water to 100 cm. When the horizons were tested individually at this date, only the surface showed significant differences between sites. Duncan's multiple range test at the 95 percent level (Steel and Torrie, 1960) showed no significant difference in the surface soil-water between the grass and the grass and oak sites, and no significant differences between the grass and oak, oak and grass, and oak sites.

SOGGY was used to simulate soil-water content. SOGGY was originally developed for simulation of soil-water content in a silt loam soil under a deciduous forest in eastern Tennessee. Modifications of SOGGY for use in this study included the use of appropriate water release curves for the Minnesota soils:

$$\text{0 to 10 cm} \qquad \theta = 0.80\ \tau^{-0.2314} \qquad (1)$$

$$\text{10 to 100 cm} \qquad \theta = 6.43\ \tau^{-0.1489} \qquad (2)$$

where θ is the volumetric water content of the horizon in centimeters of water, and τ is the tension in bars at which that moisture is held. Soil-water suction at field capacity was

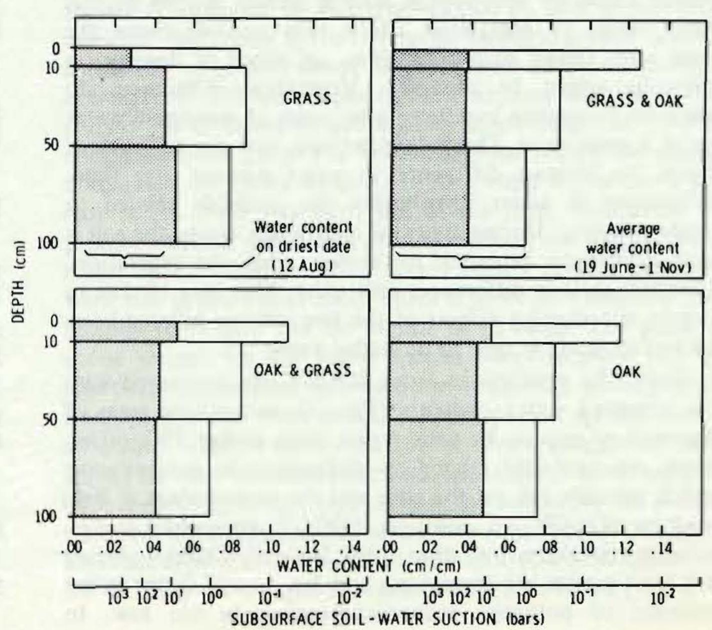

Figure 1.

Water content of four soils on the Anoka Sand Plain during 1971. Unshaded portion is the average water content during the period 19 June through 1 November. Shaded portion is water content on the driest sampled date, 12 August.

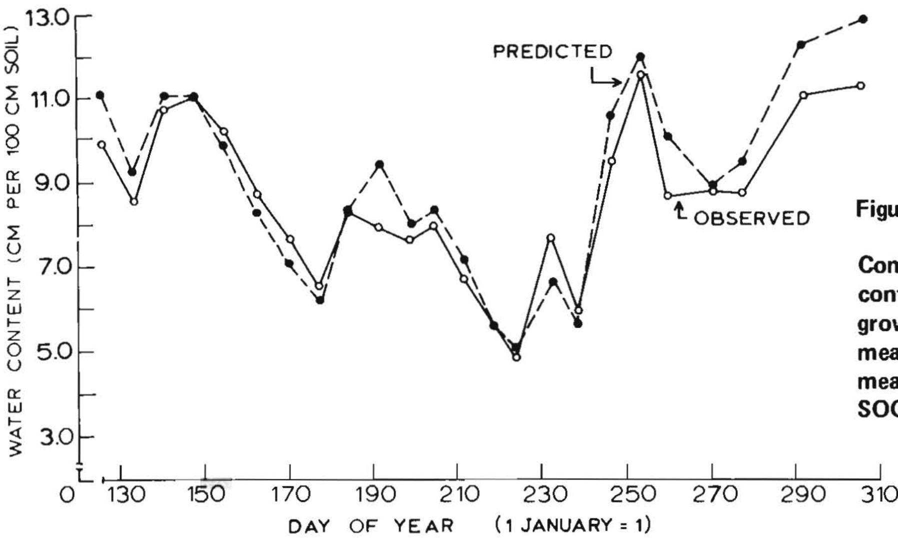

Figure 2.

Comparison of predicted and observed soil-water content on the Anoka Sand Plain during the 1971 growing season. Observations until day 170 are means based on three sites, and after that time are means based on four sites. Predictions are based on SOGGY, an evapotranspiration model.

assumed to be 0.06 bars (based on observed water content in the field following rainfall events). In addition, a modification was made for the reduced unsaturated conductivity of sand at low water contents as compared to the silt loam in the Tennessee study. Phenology is considered in the model, and the midpoints of the periods of leaf emergence (15 May) and of leaf-fall (5 October) were determined by observation.

Figure 2 shows the relationship between the measured mean water content of all sites and that predicted. The grass site is not included in the mean until 19 June (day 1970). The observation and prediction over 24 sample times are closely correlated ($r^2 = 0.91$). Two-way analysis of variance, blocking on time over 18 sample times, showed a significant difference at the 95 percent level ($F (4, 68) = 2.69$) among the total soil-water content to 100 cm measured at each of the four sites and that predicted by SOGGY.

Results here agree with Douglass's (1966) conclusions. Under humid conditions and only limited dry periods (Fig. 2), soil-water trends under grass or increasing density of forest vegetation did not differ greatly. The most dense forest in this study (22 m^2/ha), however, certainly cannot be considered dense by comparison with a closely spaced natural forest stand or plantation which may contain twice the basal area. Under such conditions, an effect of density on soil-water might be observed. Vegetation differences do manifest themselves in determining zones of maximum water use at a given time. These data indicate that the soil surface shows the greatest difference in water content over time. Differences in water distribution are probably related to rooting density. During times of high water stress, the soil is more uniformly depleted, no matter what the vegetation. However, surface differences still exist. This may be due in part to the shading effects of the tree canopy helping keep the surface moister than in unshaded areas.

When the predictions from SOGGY are compared with the observed water contents (Fig. 2), two major areas of discrepancy appear. In some cases, such as day 190, differences are probably related to differences in precipitation which actually fell on the sites and the meteorological data used in SOGGY. In addition, SOGGY apparently underestimates evapotranspiration after leaf-fall. Perhaps during this time grasses are transpiring and the "crop" factor in the estimate of potential evapotranspiration is too low. In general, however, SOGGY's predictions correspond very well to the measured soil-water contents.

This study was conducted on excessively-drained sites with no restricting soil horizons. In addition, due to the relatively low fertility and droughty nature of the Sartell soil, vegetation density was lower than on finer-textured sites in the same climatic area. The results of the study should be interpreted with those considerations in mind. Under other conditions differences in water use among vegetation types may occur. Based on these results, however, the rationale for a model of soil-water content based primarily on soil and climatic factors, and not heavily weighted by vegetation differences, becomes stronger.

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