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Seasonal variation in soil nutrients under six rocky mountain vegetation types

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Seasonal Variation in Soil Nutrients Under Six Rocky Mountain Vegetation Types[1]

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ABSTRACT

Soils under vegetation types dominated by *Festuca idahoensis, Artemisia tridentata, Populus tremuloides, Pseudotsuga menziesii,* and *Abies lasiocarpa* were sampled at monthly intervals during 1974 and 1975 to determine the magnitude of seasonal variation in nutrient availability. Results may be summarized by expressing minimal values observed in 1974 as a percentage of maximum values: nitrate 27%, ammonium 30%, phosphorus 45%, potassium 65%, calcium 77%, magnesium 82%, sodium 60%, and organic matter 80%. Nutrients were most available in the early fall (September — October) and least available at midwinter (January — April). Rates of change in nutrient availability were smallest in winter and spring. Seasonal variation in *Abies* forests was notably less than in other vegetation types.

Additional Index Words: soil testing, phosphorus, nitrate, ammonium, potassium, sodium, pH, *Festuca idahoensis, Artemisia tridentata, Populus tremuloides, Pseudotsuga menziesii,* and *Abies lasiocarpa.*

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If soil tests are to be used in making management decisions, those qualities which vary with season must be recognized and sampled either periodically or at a standard time (Ball and Williams, 1968; Blakemore 1966; Garbouchev, 1966; Anderson and Tiedemann, 1970). The study presented below shows that nitrogen, phosphorus, potassium, sodium, and pH do vary significantly with season in stands representing major vegetation types of the northern Rocky Mountains described and classified by Daubenmire (1970), Daubenmire and Daubenmire (1968), Mueggler and Handl (1974), and Pfister et al. (1977).

METHODS

The study sites lay on a transect through vegetation typical of the Bridger Mountains, in southwest Montana, USA. They included, from lower to higher elevation, *Festuca idahoensis-Agropyron spicatum-Poa pratensis* site (at 1,715 m on a Typic Argiboroll developed in a nearly level foothills loess deposit), a wheatfield (*Triticum aestivum*) on the same substrate and adjacent to the first site, an *Artemisia tridentata-Festuca idahoensis-Agropyron spicatum-Poa pratensis* site (at 1,785 m on a Pachic Argiboroll developed on gneissic pediments sloping 20% toward the southwest), a *Populus tremuloides-Symphoricarpos albus-Poa pratensis* site (at 1,785 m on a Udic Haploboroll developed in nearly level draw sites in the sage and Douglas fir zones), a *Pseudotsuga menziesii-Symphoricarpos albus-Carex geyeri* site (at 1,850 m on a Typic Haploboroll occupying a north-facing 50% slope with a gneiss substrate), and an *Abies lasiocarpa-Pinus contorta-Carex geyeri-Vaccinium scoparium* site (at 1,997 m on a Mollic Cryoboralf developed on nearly level interbedded sandstone and shale). The wheatfield was fallow in 1974 and infested with *Conium maculatum* in 1975 since it was neither planted nor cultivated in 1975. Past grazing pressure has allowed *Poa pratensis* to invade the lowest three sites. The *Festuca* stand lay about 7 km north of Bozeman, Montana; the *Pseudotsuga* stand lay approximately 2.5 km east of it in Sypes Canyon; the *Artemisia* and *Populus* stands lay between these, and the *Abies* stand lay approximately 12 km to the northeast in the Bridger Canyon.

Plant names follow Hitchcock and Cronquist (1973). Common names of the plants discussed are *Abies lasiocarpa* = subalpine fir, *Artemisia tridentata* = big sagebrush, *Agropyron spicatum* = bluebrunch wheatgrass, *Carex geyeri* = elk sedge, *Conium maculatum* = poison hemlock, *Festuca idahoensis* = idaho fescue, *Pinus contorta* = lodgepole pine, *Poa pratensis* = kentucky bluegrass, *Populus tremuloides* = aspen, *Pseudotsuga menziesii* = Douglas fir, *Symphoricarpos albus* = snowberry, *Triticum aestivum* = wheat, and *Vaccinium scoparium* = grouse whortleberry.

Soil names follow Soil Survey Staff (1975). Solum depths ranged from 58 to 84 cm. Gravel contents were never greater than 10% and the soils were essentially stone-free except in one of the *Abies* stands where they occupied about 25% of the profile. Soil color hues were in the Munsell 10 year range; moist color values of the epipedons were in the 2 to 3 range except in the near-mollic soil of the *Abies* site where they were 3.5 moist and 6 dry; moist color values in the subsoil were 4 throughout.

Soil samples were taken at monthly intervals at two subsites representative of each site. The subsites were separated by > 30 m and < 400 m. The sample taken at each subsite consisted of 10 Oakfield sampler cores (2 cm diameter) each taken within 1 m of a permanently staked point. A second (replicate) set of samples was taken in 1974. The 0- to 10-cm and 10- to 30-cm horizons were separated and composited across cores; the organic horizon (Ao) was discarded wherever it was present. The 0- to 10-cm horizon came from the A1 horizon in all cases. The 10- to 30-cm horizon reached into the B horizon in the fescue-wheat stand (2 cm), the *Populus* stand (6 cm), the *Pseudotsuga* stand (2 cm), and the *Abies* stand (14 cm). The samples were promptly dried at 60°C, ground with a mallet and rolling pin, passed through a 2-mm sieve, and grouped for analysis.

Samples taken in 1974 were analyzed in the month they were collected; since the qualities of a control sample submitted with each set of samples were invariant we attribute the variation described below to seasonal changes in soil quality. To reassure ourselves on this point we processed all samples taken in 1975 at one time; the nine monthly samples from a subsite-horizon were ground and analyzed as a unit to avoid confounding possible variation in lab procedure with seasonal changes in soil nutrient availability. Again the qualities of a control sample submitted repeatedly did not vary. The control sample was a carefully homogenized sample of Amsterdam silt loam submitted as a lab standard with each run.

All soil analyses were made by the MSU soil testing laboratory. Potassium, calcium, magnesium, and sodium were extracted with 1*M* ammonium acetate (pH 7) and determined by atomic absorption. Phosphorus was determined by a modified Bray method (Smith et al., 1957 and Olsen and Dean 1965). Nitrate was determined by the phenoldisulfonic acid method (Snell and Snell, 1936). Ammonium was determined by micro-Kjeldahl distillation (Bremner, 1965). Organic matter was measured colorimetrically after dichromate oxidation (Sims and Haby, 1970). The pH was measured on a 1:2 soil water paste.

RESULTS AND DISCUSSION

Variation in Nutrient Availability with Season

Figures 1 and 2 illustrate the seasonal variation in soil nutrient availability in six Rocky Mountain vege-

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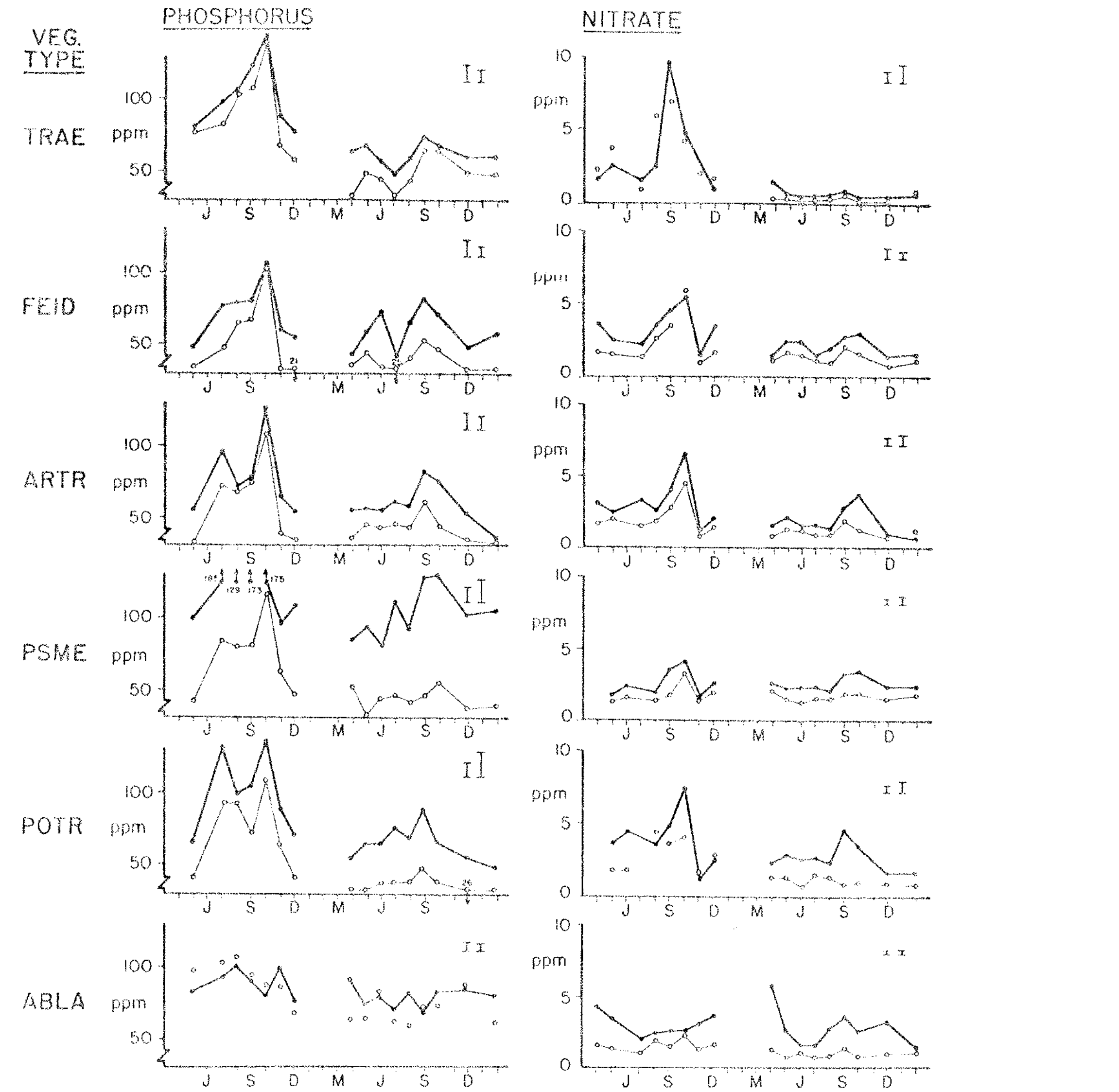

Fig. 1—Seasonal variation in available (Bray) P and nitrate under six Rocky Mountain vegetation types. The *heavy line* shows nutrient availability in the 0 to 10-cm layer, and the *light line* shows nutrient availability in the 10 to 30-cm layer. See text for further explanation.

tation types. The vegetation types and their abbreviations are *Triticum aestivum* (TRAE), *Festuca idahoensis* (FEID), *Artemisia tridentata* (ARTA), *Pseudotsuga menziesii* (PSME), *Populus tremuloides* (POTR) and *Abies lasiocarpa* (ABLA). Average standard errors associated with the points presented are indicated by a pair of vertical bars at the top of each graph in Fig. 1 and 2: the left bars indicate the average 0-10 cm standard error and the right bar indicates the average 10-30 cm standard error.

Phosphorus, nitrate and ammonium vary together with season (Fig. 1, 2). In both 1974 and 1975 peaks in the availability of phosphate, nitrate and ammonium appear in early fall (Sept.-Oct.) in stands of wheat, *Artemisia, Pseudotsuga,* and *Populus.* A lesser peak appears in the spring of 1974; it is best illustrated by the July phosphorus data from the *Festuca* grassland, the *Artemisia* shrubland, and the *Pseudotsuga* and *Populus* forests. A spring peak is also suggested by 1974 nitrate data from the wheat field, *Pseudotsuga* forest, and *Populus* forest. The spring peak did not appear in 1975—perhaps because air temperatures were 2°C below normal in February, April, and May of 1975 while there were 2°C above normal in April, June, and July of 1974.

The pH dropped in October 1974 at the same time that phosphorus, nitrate and ammonium were rising.

Potassium availability peaked 1 month earlier (Sept. 1974) in stands of wheat, *Festuca, Artemisia,* and *Pseudotsuga.* Sodium availability peaked 2 months earlier (August 1974) in all vegetation types studied.

Available calcium, magnesium, and organic matter varied little and showed no seasonal trends either within or between vegetation types. Coefficients of variation (standard deviation/mean) across seven months of 1974 average 9± 5% for calcium, 9± 6% for magnesium, and 11± 5% for organic matter.

Significant changes in nutrient availability with season have been shown in other vegetation types. In British fields nitrate, phosphorus, and potassium all become more available in the fall (Russell, 1961; Blakemore, 1965; Garbouchev, 1965). British *Deschampsia* grasslands show spring peaks in ammonium and phosphorus and a fall peak in nitrate (Davey and

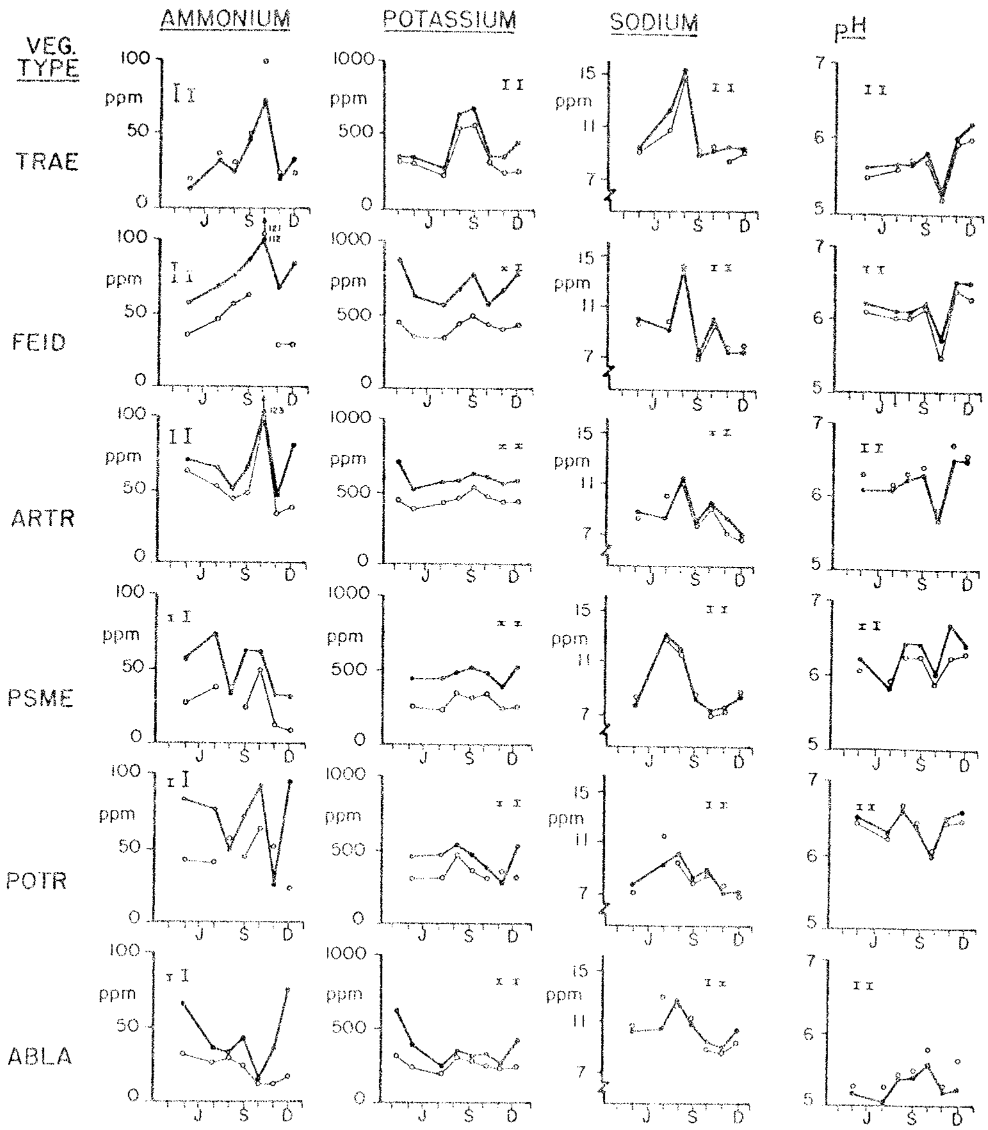

Fig. 2—Seasonal variation in ammonium, K, Na, and pH under six Rocky Mountain vegetation types. The *heavy line* shows nutrient availability in the 0 to 10-cm layer and the *light line* shows nutrient availability in the 10 to 30-cm layer. See text for further explanation.

Taylor, 1974; Gupta and Rorison, 1975). Stream water from deciduous forests of the eastern US carry large amounts of ammonium, nitrate, phosphate, potassium, calcium, magnesium, and sodium in the fall and spring (Likens et al., 1977); this is due in part to the seasonal pattern of water discharge, but it may also be due to seasonal variation in the availability of nutrients to leaching.

The size of a nutrient pool must depend on inputs to and withdrawals from it (e.g., Cole et al., 1977; Reuss and Innis, 1977). One can speculate (i) that P and N availability rise in the spring because rapidly growing decomposer populations release nutrients more rapidly than they are absorbed by relatively inactive plants; (ii) that N and P availability fall in the summer because plants growing logarithmically absorb nutrients faster than decomposers release them; (iii) that the autumn rise in availability is due to high microbial activity after autumn rains, the contribution of new substrates by senescing plants, and with relatively low plant activity; and (iv) that the decline in availability of late autumn is due to lowered microbial activity coupled with continued slow uptake by plants. The pH drops in the fall when N and P become more available; this may be due to release of CO_2 by decomposers. The reason for earlier fall peaks in sodium (August) and K (September) is less clear; perhaps materials are leached from aging plants in that order (Tukey, 1971) or perhaps they are being released from microorganisms in the declining microbe populations (Blakemore, 1965).

Seasonal trends in nutrient availability under *Festuca, Artemisia, Pseudotsuga,* and *Populus* vegetation below 1,900 m were strikingly similar and notably different from those observed in an *Abies* stand near 2,000 m. There was less variation across season in the *Abies* stand; spring and fall peaks disappeared (except for sodium) and a weak midwinter peak in ammonium, nitrate, potassium, calcium, and magnesium appeared. One might attribute the differences to a greater stability of the soil environment in the *Abies* forest; (i) due to its constant winter snow cover, soil temperatures at 10-20 cm probably stay near 0°C from November through May (and rise to 5-10°C in August) while soils in lower stands with discontinuous snow cover are more thoroughly frozen; and (ii) periods of soil water stress are significantly shorter (or nonexistent) in the *Abies* stand than in lower *Festuca*, *Artemisia*, and *Pseudotsuga* stands (Weaver, 1977). The tendency of ammonium, nitrate, calcium, and magnesium to be most available at midwinter may be due to constant slow microbial activity coupled with little uptake by trees exposed to harsh above-snow conditions.

Inspection of Fig. 1 and 2 suggests that if one sampled natural vegetation in January-March he would measure minimum nutrient availabilities, if he sampled in May-July he would meaure normal growing season levels and if he sampled in September-October he would find maximum nutrient availabilities. As a standard sampling period the winter or spring may be better than the fall because availability is changing less rapidly. Since availability may vary little in stands with deep snow cover, the season of sampling is less important in such stands.

Variation in Nutrient Availability Between Years

Nitrate, phosphorus, and potassium were studied in both 1974 and 1975; all three were less available in the second year. The striking drop in the availability of these nutrients in the wheatfield was undoubtedly due to plant uptake: as noted above, the field was essentially plant-free in 1974 and was vegetated in 1975. Severe drops observed in other vegetation types may have been due to differences in weather noted above: the spring of 1974 was warm and dry while the spring of 1975 was cool and normally moist.

Average Nutrient Availability in Six Variously Vegetated Stands

Since the quantities of nutrients available in soils vary between vegetation types (Curtis, 1959; Daubenmire, 1968; and Weaver, 1979), quantities of nutrients available (average of seven measurements made between May and December of 1974) in the top 10-cm of the soils we studied are expected to vary between stands. Average nitrate-N under conifer forests ranged from 2.6 to 2.9 ppm while under other vegetation types it ranged from 3.0-3.9 ppm. Ammonium nitrogen was also less available under conifer forests (40-49 ppm) than under other natural vegetation (70-78 ppm). Bray phosphorus may be more available under forest than grass-shrubland types. Potassium availability declined up the water gradient from a *Festuca* grassland (674 ppm) to an *Abies* forest (337 ppm). Calcium availability declined similarly up the water gradient from a *Festuca* grassland (21 ppm) to an *Abies* forest (11 ppm) except in *Populus* groves (23 ppm). Magnesium availability was less under *Artemisia* shrubland and *Pseudotsuga* forest (2.6-2.9 meq/100 g) than under other vegetation types (3.4-4.8 meq/100 g). Sodium content is about 0.4 meq/100 g throughout the water gradient. The pH was 5.3 in the *Abies* forest and 6.2 and 6.4 under other vegetation types. Organic matter contents lay in the 5.6-6.7% range in all stands. Trends in nutrient availability between vegetation types shown in the 0- to 10-cm soil layer were repeated in the 10- to 30-cm horizon.

A comparison of the 0- to 10- and 10- to 30-cm horizons (Fig. 1) shows that organic matter is less concentrated in the lower layer, that pHs are similar or slightly lower in the lower horizon, that nutrient elements (N, P, K, Ca, and Mg) are less available in the lower horizon except for P and Mg in the *Abies* stand where they are similar, and that sodium concentrations do not differ between the horizons.

The soil of the wheat field studied differed from that of the adjacent grassland in two ways. First, the difference between the 0- to 10- and 10- to 30-cm horizons is less in the field than in the grassland; this is probably due to mixing of the layers by plowing and/or erosion of the richest topsoil. Second, the ammonium (62-37 ppm), potassium (509-380 ppm), magnesium (4.7-3.9 meq/100 g), calcium (19.6-13.9 meq/100 g) and organic matter (6.3-5.0%) contents of the top 30 cm have all been reduced significantly (about 20%) by 75 years of farming. The pH is lower on the farmed (5.7) than on the unfarmed (6.1) land. Nitrate, phosphorus, and sodium are apparently more available on farmed than unfarmed land, perhaps due to fertilizer application. Similar changes have been observed in Ohio, Oklahoma, Iowa, Texas, and Colorado (Schollenberger, 1920; Garman, 1948; Thompson et al., 1954).

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Cation Release from Michigan Spodosols Leached with Aspen Leaf Extracts[1]

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ABSTRACT

Soil samples (<2 mm) from the A horizons of three sandy Michigan Spodosols of varying productivity were leached with water extracts of *Populus grandidentata* Michx. leaves. Laboratory leaching experiments were used to simulate natural weathering of soil minerals by hydrogen ions of organic acids and the complexing of cations by organic compounds in the extracts. All of the soil samples released significant amounts of Mg, K, Na, and Fe, and most released Ca. Using data for Fe released by the leachings and existing data for subsoil Fe accumulation and ground water losses in similar soils, an estimate was made of the number of years of field conditions simulated by the laboratory treatments. The annual elemental release through mineral weathering in the A horizon in each soil was then estimated. Although estimated Ca weathering rates were notably low, estimated rates of Na weathering were comparable to those observed for podzol soils in New England.

Additional Index Words: mineral weathering, soil genesis, *Populus grandidentata* Michx., iron solubilization, weathering rates.

Adams, P. W., and J. R. Boyle. 1979. Cation release from Michigan Spodosols leached with aspen leaf extracts. Soil Sci. Soc. Am. J. Am. J. 43:593–596.

Although mineral weathering and soil-forming processes have been studied extensively in the laboratory, the evaluation of, or extrapolation of laboratory data to weathering on the ecosystem scale has been less frequently attempted. Analyses of drainage water composition have been used to estimate areal weathering rates (11, 19), but this method is not applicable to many sites and requires careful experimental design to obtain reliable results (12, 17). Mineralogical and chemical analyses have also been used to evaluate soil mineral weathering when the profile of interest includes relatively unaltered parent material (2). This method can provide useful information on total profile changes due to weathering and soil development, but estimates of rates of mineral weathering obtained from this information are less reliable.

This paper outlines some laboratory experiments designed to simulate several years of field weathering in some Michigan forest soil samples in order to estimate current rates of cation release through weathering in these soils. Natural organic materials were employed as weathering agents since it is likely that such materials play a primary role in the genesis of Spodosols. The solubilization of mineral Fe by aqueous extracts of fresh and decomposing tree leaves has been demonstrated (3, 7, 16) and contrasted with low Fe solubilization by H_2O and CO_2-charged H_2O (23). Iron and other elements have been solubilized through laboratory mineral weathering with organic acids (4, 9, 23) and the significance of cation chelation in such reactions has been suggested (4, 23).

METHODS

Soil samples used for the weathering experiments were collected from three forested sites at the University of Michigan Biological Station near Pellston in northern lower Michigan. This area receives a yearly average of 79.4 cm of precipitation and the mean annual temperature is 5.5°C (8, 21). The sites are dominated by *Populus, Quercus* and *Acer* species and were classified earlier as good, intermediate and poor in relative aspen productivity (20).

The poor site is mapped (unpublished USDA-SCS map, 1976; Grayling, Michigan) as Rubicon sand, a sandy, mixed, frigid Entic Haplorthod developed in deep glacial outwash. The good and intermediate sites are each mapped as Montcalm loamy sand, a sandy, mixed, frigid Alfic Haplorthod. The upper horizons of this soil were formed in sandy outwash material with an underlying horizon sequum of similar or finer textures developed during an earlier pedologic period.

Samples from the A horizon were collected from five plots randomly located over a 0.5-ha area at each of the study sites. The bulk samples were composited, air dried, and soil material passing through a 2-mm sieve was used in the weathering experiments. Particle size distributions of the composites are

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