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EFFECTS OF CLEAR-CUTTING ON NUTRIENT LOSSES IN ASPEN FORESTS ON THREE SOIL TYPES IN MICHIGAN

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ABSTRACT

The effects of clear-cutting on NO_3^-, NH_4^+, PO_4^{3-}, K^+, Ca^{2+}, Na^+, Fe^{2+}, and Mg^{2+} losses were evaluated in three 60-year-old aspen stands in northern lower Michigan. Paired 0.5-ha sites (control and clear-cut) located on good, intermediate, and poor soils were compared for soil-nutrient leaching during the 1973 growing season. Preliminary analyses indicate that soil-nutrient leachate concentrations (NO_3^-, NH_4^+, PO_4^{3-}, K^+, Ca^{2+}, Na^+, Fe^{2+}, and Mg^{2+}) were not significantly higher ($P < 0.05$) on clear-cut plots than on paired control plots during the first growing season. Nitrate–nitrogen and ammonium–nitrogen leachate values were significantly less than seasonal precipitation input. Leachate concentrations reached maximum levels following spring thaw and then fluctuated through the growing season. Highest nutrient losses were generally found on the good soils, followed by the intermediate and then the poor soils. Groundwater accretion was estimated to be 12 cm per year higher on clear-cut plots. A preliminary nutrient budget was calculated from determinations of input (concentration x volume of precipitation) and output (leachate concentration x volume of groundwater flux). In the first-year data for carefully controlled clear-cuts, little evidence of increased nutrient losses was found for NO_3-N, NH_4-N, PO_4, Mg^{2+}, Na^+, K^+, and Fe^{2+} as a consequence of clear-cutting. Additional losses (leachate in excess of control losses) of Ca^{2+} and Mg^{2+} due to clear-cutting exceeded precipitation inputs only on the good soil. A definitive answer on nutrient losses cannot be determined until a complete nutrient and hydrologic budget is calculated over several seasons.

Trembling and bigtooth aspens (*Populus tremuloides* Michx. and *P. grandidentata* Michx., respectively) are among the dominant forest species in the Great Lake states of Michigan, Minnesota, and Wisconsin. Once considered a weed tree, aspen now contributes more than 45% (2 million cords) of the annual lake state pulpwood harvest (Leuschner, 1972). The aspen forests of the Great Lakes region today originated as sprout stands after the early logging and subsequent uncontrolled fires between 1870 and 1920 (Graham, Harrison, and Westel, 1963). Younger stands have been established over the past several decades by the practice of clear-cutting the older (50- to 80-year-old) aspen forests.

Increased clear-cutting of aspen because of pressures from the pulpwood industry and game management practices have made it essential to evaluate the consequences to soil and water regimes in the Great Lakes region in terms of both mineral cycling and productivity. This is especially true since the clear-cutting of forests has been brought under strong criticism (Connaughton, 1970; Davis, 1971). Economic and silvicultural motives are being reevaluated in consideration of possible aesthetic and environmental degradations resulting from the clear-cutting of forests. Much of the current criticism is a consequence of a study of vegetation removal in New Hampshire, in which it was found that soil-nutrient losses were alarmingly accelerated from a watershed denuded of a northern hardwood forest (Likens et al., 1970).

Significant increases in erosion, runoff, nitrification, decomposition rates, and stream concentrations of cation and nitrate–nitrogen were also reported by Bormann et al. (1968) and Likens et al. (1967). In the New Hampshire study, cation losses can probably be attributed to a series of events resulting from deforestation on steep slopes and vegetation suppression with herbicidal treatments. We should note that this is an unrealistic treatment combination to use in evaluating the effects of commercial clear-cutting.

Functionally, a natural forest recycles nitrogen. Nitrogen uptake ceases with vegetation removal, and ammonium becomes available for production of nitrates. This process releases a large amount of hydrogen ions that in turn accelerate cation exchange with soil colloids; thus both cations and nitrates can be leached from the ecosystem by percolating rainwaters.

It is theorized that nutrient uptake will not be reduced significantly under clear-cut aspen because of rapid revegetation by aspen root sprouts. The mature root systems of harvested aspen trees remain alive and fully occupy the soil after clear-cutting. Within one year the site may support an aspen sprout stand that numbers 10,000 stems per acre and in two years up to nearly 28,000 stems per acre (Garrett and Zahner, 1964). This rapid development of shoots should permit absorption and recycling of nutrients from the soil solution and prevent their loss from the site. There are no scientific data to substantiate this, however, and there are no published studies of nutrient cycling in aspen-forest ecosystems. The purpose of this paper is to evaluate the first-year effects of clear-cutting on soil leaching in aspen forests on three soil types.

RESEARCH SITE AND METHODS

The effects of clear-cutting of aspen were studied at three sites on the forest land of the University of Michigan Biological Station near Pellston, Mich. (latitude 45°34′N). The three well-drained upland sandy soil sites chosen were considered representative of the moraine and glacial outwash typical of millions

of acres of aspen forests in the northern Great Lakes region. The soils of the research site were labeled good, intermediate, and poor on the basis of aspen production and are typical of areas where mature aspen stands (50 to 80 years old) have developed after logging and repeated fires. Two homogeneous study areas of approximately 1 ha each were located on each of the three soils. Homogeneity in terms of forest-species composition was determined by sampling all trees 5.00 cm (2.0 in.) and greater in diameter at breast height (dbh). Understory and ground cover were analyzed in 20 randomly placed 9- and 0.25-m^2 plots, respectively. Slopes on all sites range from 0 to 6%.

In the fall of 1972, paired 0.5-ha subplots established inside each 1-ha study area were utilized for treatment comparisons. One of the plots on each site was commercially clear-cut, and the slash material was left. The other site remained undisturbed as a control. A 25-m buffer strip separated the control from the clear-cut areas. The nutrient inputs and outputs of the control and clear-cut subplots were monitored in terms of bulk precipitation and soil leachate.

Precipitation (ppt) was measured with a network of six gages. Samples were collected immediately after rainfall and returned to the laboratory for chemical analysis. All analyses follow standard procedures (Environmental Protection Agency, 1971; Perkin–Elmer Corp., 1973).

Soil leachate from each of the sites was recovered with a series of pressure-vacuum lysimeters. The samplers consist of a one-bar entry value, porous, ceramic cup with a 1-μ size pore. The design and development of the lysimeter is described by Wagner (1962) and Parizck and Lane (1970). The control and clear-cut plots contain 20 and 30 lysimeters, respectively. Samplers were placed in pairs along five equidistant grid lines to uniformly divide the plots. Each lysimeter was placed in the upper portion of the C horizon (~90 cm deep). The lysimeters were installed at a 60° angle so that the porous ceramic tip would be positioned under an undisturbed profile.

Leachate was collected as soon as winter snow melt allowed. Samples were taken at monthly intervals or when sufficient leachate was available. All samples were frozen within 2 hr after collection, stored, and analyzed within 2 months. Cation analyses (Ca^{2+}, Mg^{2+}, K^+, and Na^+) were completed following standard procedures for atomic absorption spectrophotometry (Perkin–Elmer Corp., 1973). A Technicon Auto-Analyzer was used to analyze for NO_3, NH_3, PO_4, and Fe. Nitrate was analyzed for by the Greis–Ilsovay reaction and is reported as NO_3–N (Environmental Protection Agency, 1971). The Berphelot reaction was used to analyze for NH_4–N (Environmental Protection Agency, 1971). After manual digestion phosphorous was analyzed by the molybdate reaction and iron by the persulfate oxidation technique (Environmental Protection Agency, 1971).

A three-way layout was used to analyze the effects of time, site, and treatment on nutrient concentrations of soil leachate. All leachate values given are means of at least 15 replicates per treatment plot. Statistical analyses follow Sokal and Rohlf (1969).

RESULTS AND DISCUSSION

These results must be considered preliminary for two reasons. First, data from a single growing season are suggestive but not conclusive. Second, complete analysis of the effects of clear-cutting on the aspen ecosystem must await completion of total input–output nutrient and hydrological budgets for the system.

Site Description

Populus grandidentata Michx. is the dominant tree species on the treatment sites, with a percent basal-area coverage ranging from a high of 88.8% on the good clear-cut site to a low of 51.6% on the poor control site (Table 1). The biotic homogeneity (species composition, basal area, number of stems per hectare, etc.) between each control and clear-cut site shows little variation (Table 1). The index of similarity (Phillips, 1959) between the control and clear-cut plots on the good, intermediate, and poor soils is 83, 80, and 93%, respectively.

The large differences in site quality indicated by Table 1 are further defined by a comparison of the physical characteristics of the soil at each site (Table 2). The good (Menominee) and intermediate (Emmet) site soils are distinguished by a thin clay lens in the upper portion of the C horizon. This substantially increases the water-holding capacity of the good and intermediate soils as compared with that of the poor soil. The poor soil (Rubicon sand) is a minimal podzol of relatively poor productivity (Table 1) and low water-holding capacity.

Chemical analyses also reveal significant differences in soil fertility between sites. Total nitrogen in the A horizon ranges from a high of 890 ppm in the good soil to a low of 230 ppm in the poor soil. Soil pH in the A horizon is 5.6, 5.4, and 5.2 on the good, intermediate, and poor soils, respectively.

Precipitation and Chemistry

Precipitation during the 1973 growing season (March to September) was 51.7 cm. The seasonal rainfall total of 82.9 cm was 3.5 cm greater than the 27-year average. Chemical analysis of rainfall includes dryfall contributions. The mean annual concentrations of cations were 0.97, 0.25, 0.14, and 0.44 ppm for Ca^{2+}, K^+, Mg^{2+}, and Na^+, respectively. Concentrations of NH_4–N ranged from 0.03 to 1.5 ppm, with a mean value of 0.49 ppm. The concentration of NO_3–N in precipitation ranged from 0.002 and 0.7 ppm, with most values being between 0.2 and 0.5 ppm. Phosphorous (PO_4–P) values averaged 0.02 ppm. Nutrient values for all chemicals appear to be near average nutrient concentrations reported in the literature (Likens et al., 1967; Pearson and Fisher, 1971; Pecor et al., 1973). Preliminary analyses indicate that precipitation chemistry is quite variable from month to month, however, and several years of values will be required to determine temporal trends.

TABLE 1

STAND COMPOSITION AND STRUCTURE* OF THREE 60-YEAR-OLD ASPEN STANDS ON GOOD, INTERMEDIATE, AND POOR SOILS AT THE UNIVERSITY OF MICHIGAN, BIOLOGICAL STATION, PELLSTON, MICH.

Treatment and species	Basal area, m^2/ha	Basal area, %	Stems per hectare	Stem number, %	Average height of aspen clones, m	S.D.
Good Soil						
Control						
Populus grandidentata	26.83	79.8	634	48.7	25.98	±2.2
Fagus grandifolia	3.78	11.2	460	35.4		
Acer rubrum	2.37	7.0	140	10.8		
Acer pensylvanicum	0.46	1.4	40	3.1		
Acer saccharum	0.15	0.5	20	1.5		
Prunus serotina	0.02	0.1	7	0.5		
Total	33.61	100.0	1301	100.0		
Clear-cut						
Populus grandidentata	28.49	88.8	720	62.1	25.91	±2.3
Acer saccharum	1.51	4.7	120	10.4		
Acer rubrum	1.12	3.5	107	9.2		
Acer pensylvanicum	0.82	2.6	173	14.9		
Fagus grandifolia	0.09	0.3	27	2.3		
Amelanchier sp.	0.04	0.1	13	1.1		
Total	32.07	100.0	1160	100.0		
Intermediate Soil						
Control						
Populus grandidentata	24.93	77.8	1207	67.3	20.65	±1.7
Acer rubrum	5.89	18.4	514	28.6		
Betula papyrifera	1.02	3.2	47	2.6		
Populus tremuloides	0.16	0.5	20	1.1		
Acer saccharum	0.01	0.1	7	0.4		
Total	32.01	100.0	1795	100.0		
Clear-cut						
Populus grandidentata	23.89	84.8	894	66.7	20.80	±2.5
Acer rubrum	2.56	9.1	233	17.4		
Populus tremuloides	1.68	5.9	193	14.4		
Betula papyrifera	0.04	0.1	13	1.0		
Quercus rubra	0.02	0.1	7	0.5		
Total	28.19	100.0	1340	100.0		
Poor Soil						
Control						
Populus grandidentata	10.99	51.6	660	45.0	15.01	±0.6
Quercus rubra	7.02	33.0	334	22.7		
Acer rubrum	1.96	9.2	314	21.4		

TABLE 1 (continued)

Treatment and species	Basal area, m^2/ha	Basal area, %	Stems per hectare	Stem number, %	Average height of aspen clones, m	S.D.
Betula papyrifera	0.80	3.8	100	6.8		
Pinus Strobus	0.48	2.2	47	3.2		
Pinus resinosa	0.03	0.1	7	0.5		
Fagus grandifolia	0.02	0.1	6	0.4		
Total	21.30	100.0	1468	100.0		
Clear-cut						
Populus grandidentata	10.88	57.5	747	57.2	14.17	±2.5
Quercus rubra	5.98	31.6	247	18.9		
Acer rubrum	1.42	7.5	220	16.8		
Betula papyrifera	0.47	2.5	53	4.1		
Pinus Strobus	0.08	0.4	7	0.5		
Pinus resinosa	0.04	0.2	13	1.0		
Fagus grandifolia	0.04	0.2	13	1.0		
Populus tremuloides	0.02	0.1	7	0.5		
Total	18.93	100.0	1307	100.0		

*Only trees 5.0 cm dbh and greater are included here.

TABLE 2

PHYSICAL SOIL ANALYSES OF GOOD, INTERMEDIATE, AND POOR ASPEN SITES IN NORTHERN LOWER MICHIGAN

Horizon	Sand, %	Silt and clay, %	Depth, cm	Bulk density	Soil and series type	Physiography
			Good Soil			
A1	99.1	1.1	0–7	0.88	Menominee loamy sand	Well-drained moraine
A2	95.8	4.1	7–20	1.37		
B	98.0	2.0	20–78	1.34		
C	85.0	15.0	78+	1.77		
			Intermediate Soil			
A1	96.9	3.1	0–5	0.62	Emmet loamy sand	Well-drained outwash over till
A2	94.8	5.2	5–20	1.47		
B	98.4	1.6	20–88	1.44		
C	84.0	16.0	88+	1.83		
			Poor Soil			
A1	98.4	1.6	0–3	0.80	Rubicon sand	Well-drained outwash
A2	98.2	1.8	3–10	1.51		
B	99.7	0.3	10–80	1.58		
C	99.8	0.2	80+	1.71		

Soil-Leachate Analysis

The mean concentrations of Ca^{2+}, Mg^{2+}, K^{+}, and Fe^{2+} in soil leachate for each site (control and clear-cut) during the 1973 growing season are given in Table 3. Considerable variation in leachate values among both treatment and control samplers at each site was found. A minimum of 15 and 20 individual replicate samplers were used per site during each month on the control and clear-cut plots, respectively. An analysis of variance showed no significant difference ($P < 0.05$) between the control and clear-cut plots for all nutrient-leachate values. A statistically significant ($P < 0.05$) difference for month and site was found for all cations except sodium.

On the average, for the good and intermediate soils, the concentration of calcium leachate was 3 and 1.5 times as great, respectively, as that for the poor soil (Table 3). Iron leachate concentration was approximately 30% higher in the good soil than in the intermediate and poor soils (Table 3). The poor and intermediate soil leachate concentrations were only 25% of the Mg^{2+} leachate from the good soil (Table 3). Clear-cutting had no significant effect on phosphate leaching, but significant ($P < 0.05$) seasonal trends were found for PO_4–P (Fig. 1a).

Seasonal trends for leachate vary with each nutrient. Two general peaks in leachate concentration were noted in the April and July-to-August sampling periods. The first reflected spring thaw, and the second may be accounted for by the above average rainfall in July [Fig. 1 (a, b, and d) and Table 3].

In general, leachate concentrations did not closely follow precipitation patterns. This may be because lysimeters were not sampled after each rainfall; thus the leachate is a composite of several precipitation periods. It has also been reported that variation due to individual sampler intake rates, time between sampling periods, and microbial activity can modify leachate values considerably (Urie, 1974). To reduce variation in future seasons, we will sample a minimum of 20 lysimeters as soon as possible after each major rainfall.

Average monthly concentration values for NO_3–N, NH_4–N, and Na in control and clear-cut leachate on the good, intermediate, and poor soils is given in Fig. 1 (b, c, and d, respectively). Significant differences ($P < 0.05$) between sites were found for NO_3–N and K, Mg, Ca, and Fe. Seasonal differences were significant ($P < 0.05$) for all soil leachate ions except NO_3–N (Fig. 1 and Table 3).

Likens, Bormann, and Johnson (1969) have reported that nitrifier populations increase after clear-cutting. Our preliminary analysis of microbial populations in the litter indicate an increase from the poor to the good soil but show little difference between clear-cuts and controls. Further analysis on all sites will be required to substantiate the findings of Likens, Bormann, and Johnson.

Ammonium–nitrogen concentrations do not vary significantly among sites [Fig. 1(c)], but significant concentration differences ($P < 0.05$) are found among months [Fig. 1(c)]. During a few months on the good and intermediate

TABLE 3

MEAN* MONTHLY CONCENTRATIONS OF FOUR CATIONS IN SOIL LEACHATE FROM CONTROL AND CLEAR-CUT ASPEN PLOTS ON GOOD, INTERMEDIATE, AND POOR SOILS IN NORTHERN LOWER MICHIGAN

Site and treatment	March X̄	March S.E.†	April X̄	April S.E.†	May X̄	May S.E.†	June X̄	June S.E.†	July–August X̄	July–August S.E.†
Calcium, ppm										
Good										
Control	6.62	0.50	10.42	9.23	9.17	1.76	9.93	1.97	13.56	2.72
Clear-cut	13.70	2.58	13.02	1.75	12.49	2.35	13.63	2.37	13.41	2.34
Intermediate										
Control	6.35	0.44	10.69	1.44	6.21	1.13	6.67	1.06	9.19	0.77
Clear-cut	5.99	0.53	9.27	0.77	6.37	1.13	5.62	0.97	6.94	0.80
Poor										
Control	6.06	0.59	6.65	0.53	3.45	0.41	3.35	0.47	5.21	0.50
Clear-cut	5.86	0.30	6.17	0.39	3.39	0.36	2.04	0.32	3.45	0.34
Magnesium, ppm										
Good										
Control	2.26	0.25	3.54	0.70	3.25	0.76	4.66	1.24	7.84	2.98
Clear-cut	5.65	1.64	3.83	0.58	4.72	1.11	4.23	1.03	7.44	2.21
Intermediate										
Control	1.31	0.09	2.43	0.41	1.58	0.31	2.03	0.26	2.09	0.30
Clear-cut	1.10	0.13	1.80	0.11	1.16	0.16	1.36	0.14	1.09	0.16
Poor										
Control	1.15	0.07	1.38	0.08	0.89	0.08	0.95	0.08	1.01	0.09
Clear-cut	1.14	0.07	1.42	0.06	0.85	0.06	1.05	0.06	0.61	0.07
Potassium, ppm										
Good										
Control	1.32	0.18	1.44	0.24	1.24	0.16	1.48	0.19	1.74	0.26
Clear-cut	1.78	0.21	3.83	0.45	1.57	0.19	1.85	0.31	2.09	0.28
Intermediate										
Control	1.57	0.11	2.44	0.28	1.72	0.20	1.91	0.17	2.23	0.14
Clear-cut	1.79	0.22	2.89	0.14	2.00	0.24	2.24	0.24	2.26	0.23
Poor										
Control	1.67	0.26	1.67	0.15	1.35	0.11	1.19	0.09	1.35	0.11
Clear-cut	1.40	0.10	2.00	0.10	1.20	0.13	1.09	0.10	0.94	0.08
Iron, ppb										
Good										
Control	59.68	4.70	63.41	6.12	96.84	15.23	47.09	9.86	69.76	8.61
Clear-cut	63.73	7.20	63.32	8.33	83.17	10.37	59.73	5.05	63.38	4.97
Intermediate										
Control	60.14	9.18	56.63	4.97	86.14	17.19	27.48	2.80	41.80	4.33
Clear-cut	56.41	5.10	57.73	6.44	67.62	9.49	37.48	2.91	51.96	5.70
Poor										
Control	53.69	8.52	50.38	4.54	93.89	8.78	29.38	3.45	39.09	2.78
Clear-cut	55.07	4.60	47.15	3.83	64.94	6.21	26.30	3.14	44.47	3.32

*A minimum of 15 replicates were used in each calculation.
†One standard error of the mean.

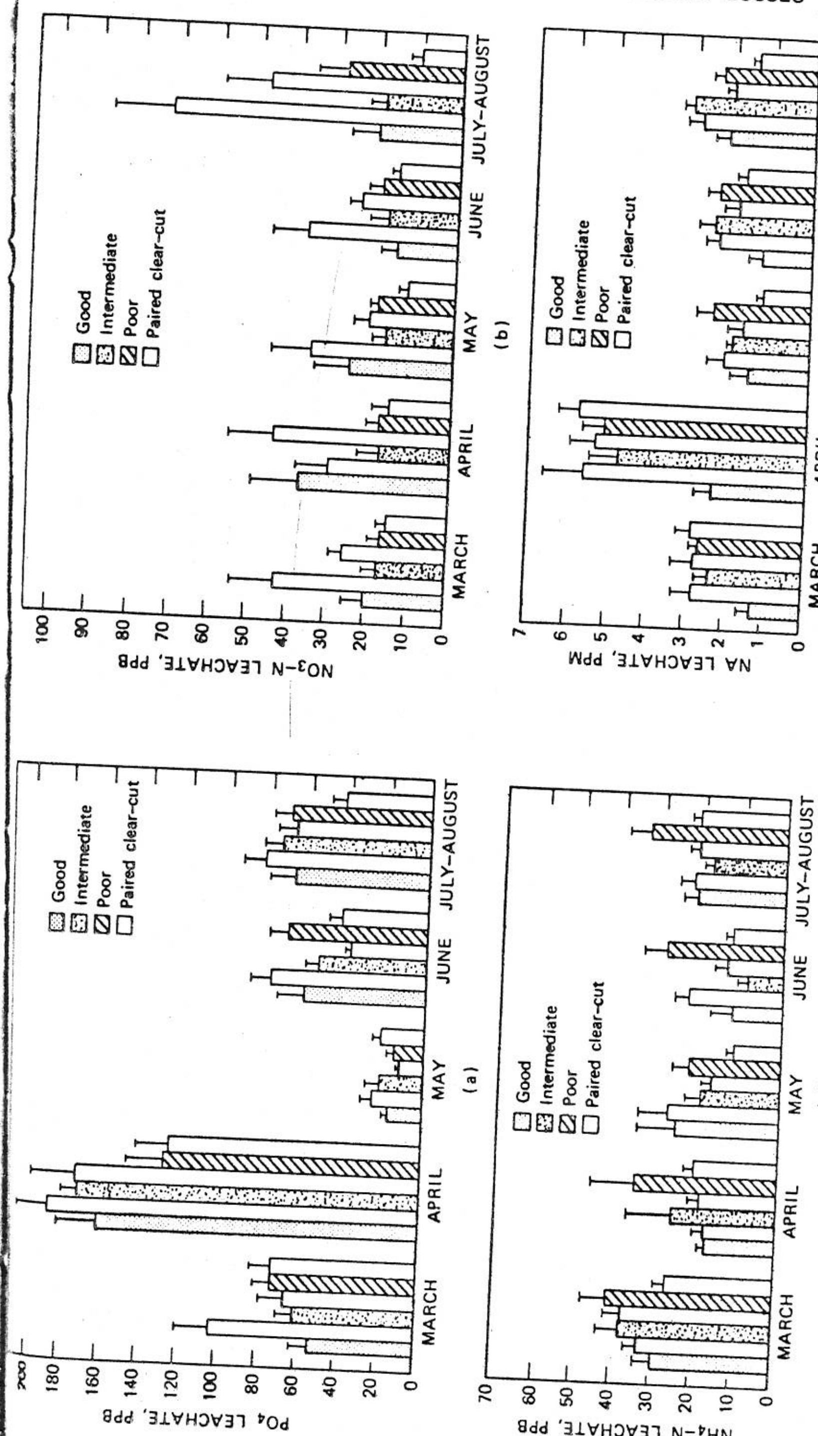

Fig. 1 Average monthly soil leachate concentrations for (a) PO_4, (b) NO_3–N, (c) NH_4–N, and (d) Na^+ in aspen plots on good, intermediate, and poor soils in northern Lower Michigan. The error bars indicate one standard error of the mean.

soils and in all months on the poor soil, the control plots released a more concentrated NH_4–N leachate than the clear-cut plots. Biological activity and the amount of organic matter present play important roles here. The amounts of carbon in the A horizon of the poor control and poor clear-cut plots are 0.41 and 0.24%, respectively. Nitrogen (Kjeldahl) values average 230 ppm on both sites. The lower carbon-to-nitrogen ratio for the poor clear-cut area may be indicative of reduced ammonification and the resulting decrease in NH_4–N leachate concentration.

Preliminary Water and Nutrient Budget

Although few clear-cutting effects have been shown in terms of nutrient concentration losses, it is possible to fully estimate nutrient-enrichment effects or net losses in the ecosystem only when some indication of accompanying water fluxes are given.

Annual potential evapotranspiration was calculated to be 55.5 cm (Thornthwaite and Mather, 1957). Hendrickson and Doonan (1972) estimated evapotranspiration for the area to be 45.7 cm by subtracting the average annual runoff from the average annual precipitation. Since aspen stands reach their best development on sandy soils with high infiltration capacity, it is doubtful if any nutrients are added directly to streams via surface runoff.

Thus estimates of groundwater accretion range from a low of 27.5 to a high of 37.2 cm per year on the control plots. The higher accretion value (37.2 cm) was used in this study to calculate maximum potential losses of nutrients via groundwater leaching on control plots (ppt – evapotranspiration = groundwater accretion: 82.9 – 45.7 = 37.2 cm).

Evapotranspiration in aspen stands is estimated to be reduced 27% by the effects of clear-cutting (Johnston, 1970). Thus clear-cutting is estimated to result in an annual increase in groundwater yield of 12.3 cm. This estimate is close to the 10-cm values reported by Urie (1971) in a study estimating groundwater yield after strip cutting of pine on sandy soils in northern lower Michigan. The clear-cut plots are, thus, estimated to yield a maximum of 49.5 cm of water to groundwater during the first year after clear-cutting.

Table 4 summarizes available data on inputs, outputs, and treatment effects on the three aspen stands. The calculated losses on the clear-cut plots are generally considered to overestimate nutrient losses since increases in evapotranspiration due to aspen sucker regrowth was not included in this budget. Net losses from the system would also decrease if some estimate of nutrient addition via geologic weathering were included.

Nitrogen inputs in precipitation greatly exceed leachate losses on all sites. This, coupled with the extremely low but similar levels of NO_3–N and NH_4–N leachate on both the control and clear-cut sites, indicates little or no effect of clear-cutting on nitrogen losses. This finding is in contrast to the high nitrogen losses reported by both Bormann et al. (1968) in their study of clear-cut and

TABLE 4

PRELIMINARY NUTRIENT BUDGET COMPARING THE CONTROL AND CLEAR-CUT ASPEN PLOTS ON GOOD, INTERMEDIATE, AND POOR SOILS IN NORTHERN LOWER MICHIGAN*

Constituent (major form)	Input from precipitation	Output by good control plot	Output by good clear-cut plot	Δ,† kg/ha	Output by intermediate control plot	Output by intermediate clear-cut plot	Δ,† kg/ha	Output by poor control plot	Output by poor clear-cut plot	Δ,† kg/ha
NO_3–N	2.1	0.3	0.2	‡	0.1	0.2	0.1	0.1	0.1	0.0
NH_4–N	4.1	0.1	0.1	0.0	0.2	0.2	0.0	0.1	0.1	0.0
PO_4–P	0.2	0.3	0.5	0.2	0.3	0.4	0.1	0.3	0.3	0.0
Ca	8.3	38.8	65.2	26.4	28.6	36.2	7.6	19.4	19.8	0.4
Mg	1.7	17.7	26.6	8.9	7.0	6.6	‡	3.9	4.9	1.0
Na	3.3	6.7	15.3	8.6	10.6	14.2	3.6	11.2	12.0	0.8
K	2.5	7.6	9.6	2.0	7.4	11.2	3.8	5.3	7.6	2.3
Fe	§	0.3	0.4	‡	0.2	0.4	0.2	0.2	0.2	0.0

*The budget was calculated from determinations of input (nutrient concentrations x volume of precipitation) and output (nutrient concentrations x volume of groundwater accretion).

†Control losses minus clear-cut losses. Losses are based on a yearly maximum groundwater accretion of 37.2 and 49.5 cm for the control and clear-cut plots, respectively.

‡Clear-cut losses are less than control.

§Samples were not analyzed for this constituent.

herbicide treatment and Reinhart (1973) in his clear-cut study in New Hampshire.

The effects of clear-cutting on PO_4–P losses appear minimal since first-year leachate values are low and the additional losses (Δ = control losses – clear-cut losses, in kilograms per hectare) caused by clear-cutting did not exceed inputs (Table 4).

Significant losses as a result of clear-cutting were not found for potassium or iron. Only at the clear-cut site on good soil did additional (Δ = 8.6 kg/ha) sodium leachate losses greatly exceed ppt input (Table 4). This increase in leachate may be due to the higher levels of slash material left at this site. The importance of net losses of sodium from the site is reduced when the estimate of Johnson et al. (1967) for sodium inputs (4.6 ± 0.4 kg/ha) via chemical weathering for midlatitude glaciated regions is added to the ppt inputs for the system.

Calcium and magnesium losses on the control and clear-cut sites on good soil and calcium losses on control and clear-cut sites on intermediate soil exceed the range of losses reported by Cole and Gessel (1965), Likens et al. (1967), and Weetman and Webber (1972) for perturbated forest ecosystems. However, calcium losses from our system are within the range of values reported by Reinhart (1973). He calculated calcium losses to be 90 kg/ha (41 kg/ha for year 1 and 48 kg/ha for year 2) over a two-year period after the clear-cutting of a New Hampshire forest. The significance of calcium discharge from the New England clear-cut seems minimal since Reinhart (1973) estimated that calcium losses amounted to only 4% of the nutrient capital (organic matter and soil) available in the ecosystem.

The percent loss of nutrient capital of calcium and other cations from the aspen system may be very low also. A final evaluation of the importance of net cationic losses resulting from clear-cutting in the aspen forest will be possible only when a complete nutrient and hydrologic budget is completed through several seasons after sucker regrowth.

The implication of our first-year data is that, under carefully controlled clear-cuts on the three glacial soil types of our study areas, little evidence of increased nutrient loss was found for NO_3–N, NH_4–N, PO_4, K^+, Na^+, and Fe^{2+} as a consequence of clear-cutting. Additional leachate losses (above control values) of Ca^{2+} and Mg^{2+} due to clear-cutting exceeded ppt inputs only on the good soil. This seems to support the hypothesis of Marks and Bormann (1972) that dense stands of fast-growing successional species will regulate ecosystem function soon after perturbation.

Extrapolation from these data is valid only on the condition that aspen regrowth be allowed to develop naturally after clear-cutting. These data also do not address the practices of whole-tree harvesting, clear-cutting followed by burning, the optimum clear-cut size, or the rotation periods necessary to maintain a viable forest ecosystem on sandy soils in the Great Lake states. The

important issue of evaluating clear-cutting in the aspen forest obviously deserves more basic research.

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