RESPONSE OF AN APPALACHIAN MOUNTAIN FOREST SOIL, SOIL WATER AND ASSOCIATED HERBACEOUS VEGETATION TO LIMING

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Abstract: Agricultural limestone was applied in varyious amounts to the surface of three 10-m square forested plots on Pea Vine Hill in Westmoreland County, Pennsylvania; a fourth plot served as a control. Measurements of soil exchangeable calcium and base saturation revealed positive responses to limestone addition on all treated plots. However, percolating soil water (leachate) was not significantly affected up to five months after treatment. Four years after treatment, A horizon exchangeable Ca and base saturation were reduced almost to pre-treatment levels. Response of E horizon soil to limestone treatment was manifested in a doubling of base saturation after two years with a return to pre-treatment values after four years. E horizon exchangeable Ca was also increased but by a lesser amount. Forest floor vegetation responses were highly variable; however, liming increased species diversity.

INTRODUCTION

Current interest in the potential impact of acid deposition on terrestrial ecosystems is in part centered around the long term supply of soil base cations as it relates to increased leaching caused by acid deposition, (Bondietti and Shortle 1990). Many investigators have been attempting to relate observed tree decline symptoms to nutrient depletion. Roberts et al. (1989) reviewed literature related to Type I Spruce Decline and concluded that acid deposition-induced soil magnesium (Mg) deficiencies are a chief cause of these symptoms. They cite several studies that reported reversal of decline symptoms following Mg fertilization. Ke and Skelly (1990) reported Mg deficiencies in a Norway spruce (*Picea abies* (L.) Karst) plantation near the site of this work. Joslin and Wolfe (1989) reported significant correlations between Ca concentrations in northern red oak (*Quercus rubra* L.) roots and leaves and various liming treatments.

Johnson and Todd (1990) and others have recently reviewed Ca depletion on forested sites in relation to leaching by acid deposition. Bondietti and Shortle (1990) and Federer et al. (1989) have concluded that acid deposition has resulted in increased Ca leaching. Based on an analysis of long term soils data at five sites in the eastern U.S., Federer et al. (1989) have estimated Ca leaching rates to be 4-16 kg/ha/yr.

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However, previous work on the fertilization of hardwoods in Pennsylvania is equivocal on this point. Auchmoody (1983) reported increased growth of black cherry (*Prunus serotina* Ehrh.) following N and P fertilization and he further contended (Auchmoody 1985) that Ca was not limiting growth for black cherry in the Allegheny National Forest. Ward and Bowersox (1970) showed increased growth in an oak stand that received both N and Ca applications. Sharpe et al. (in preparation) report increased growth of red oak seedlings after fertilization with bone meal ($CaPO_4$) in a greenhouse study. Fertilizer applications have been shown to be beneficial to the establishment of black cherry following harvesting activity (Auchmoody 1985). The effects of applications of N, K and lime on element fluxes were investigated by Matzner et al. (1983). They concluded that N and K fertilization increased leaching of Al and Mn while liming substantially increased the Ca/Al ratio in soil solution.

In 1983 an investigation of biogeochemical cycling of acid deposition was initiated on Pea Vine Hill in southwestern Pennsylvania. As a part of this effort, 10m x 10m plots were treated with agricultural limestone to determine the impact of calcium (Ca) addition on soil leachate quality. In this study we attempted to determine the impact of lime additions on soil leachate chemistry, soil exchangeable Ca, base saturation, and herbaceous and woody ground vegetation.

METHODS

A description of the study area is given by DeWalle et al. (1988). Instrumentation for the collection of soil leachate samples, leachate analysis and estimation of nutrient fluxes are given by DeWalle et al. (1988) and Swistock et al. (1990). The soil was a Hazelton/DeKalb loamy-skeletal, mixed mesic typic Dystrochrept located on Pea Vine Hill in southwestern Pennsylvania.

Adjacent 10m x 10m plots were established next to an excavated soil lysimeter pit. Suction lysimeters were installed on these plots and pan lysimeters were positioned beneath the plots. Soils in each pit were characterized (DeWalle et al. 1988). One plot (plot #2) was designated as the control and received no limestone. Plots #1, #4 and #5 received bagged agricultural limestone on November 1, 1984 at the rate of 5.9, 11.1, and 2.9 tonnes/ha, respectively in a one-time application. The limestone was applied to the surface of the litter layer by hand. These application rates were designed to produce a buffer pH of 5.5, 7.0 and 1/2 the 5.5 rate, respectively in the A soil horizon. The calculation of limestone application rates was based on the SMP buffer pH (Penn State Soil and Forage Testing Laboratory) of the O, A, and E horizons prior to treatment and the volume of stone free soils in each horizon. The soil in the A and E horizons was estimated to be 30 percent stone. The standard agricultural lime requirements to produce the buffer pH's mentioned, for an initial buffer pH of 5.8 for a soil depth of approximately 17 cm, were adjusted by reducing the lime requirement by 30 percent. The 1986 measurements of A horizon soil pH for the light, moderate and heavy application revealed estimated pH's of 4.0, 6.1, and 5.8, respectively. The control A horizon pH remained near pH 3.8. Consequently, the method used to estimate lime application is in need of further refinement for acid soils.

Two samples were obtained from each soil horizon on each plot. Soil samples were analyzed in the Soil and Forage Testing Laboratory at the Pennsylvania State University for CEC, pH, exchangeable Ca, Mg, P and K and base saturation.

Soil leachate was collected bi-weekly utilizing both zero tension pan and ceramic-cup suction lysimeters. Swistock et al.(1990) contains the details of lysimeter installation, data collection, and laboratory methods. Only E horizon zero-tension data are reported in this paper.

Surveys of forest floor vegetation employed ten randomly selected permanent $1m^2$ plots on each 10m x 10m treatment area. All woody and herbaceous stems were counted once prior to treatment and four times after treatment. Surveys were conducted in September of 1984, 85, 86 and 89 and June of 1990.

RESULTS

Soil Chemistry

Limestone applications resulted in increased levels of exchangeable Ca and base saturation in the A and E soil horizons. The greatest increases were in the A horizon soil (Tables 1 and 2). Within two years after surface application of ground limestone, levels of both exchangeable Ca and base saturation increased dramatically; however, within five years of treatment significant declines approaching pre-treatment levels were apparent. Despite these declines, more Ca was present on the treated plots than prior to treatment.

Table 1.--Changes in exchangeable Ca in A and E horizons with time for all plots.

	Plots							
	Control		Low Lime		Med. Lime		High Lime	
Year	A	E	A	E	A	E	A	E
	Ca (meq/100g)							
1983	0.85	0.70	0.75	0.35	0.70	0.60	0.60	0.35
1986	1.45	0.40	3.65	0.62	16.4	0.58	21.0	0.62
1988	0.35	0.30	1.40	0.30	0.98	0.40	1.72	0.30

The precise fate of much of the applied Ca is not known. A portion was most probably taken up by plants growing on the site and is being cycled through the system, with temporary storage in the forest floor and humus. It is also quite likely that Ca has been leached from the root zone by percolating soil water.

Table 2.--Changes in A and E horizon base saturation with time for all plots.

	Plots							
	Control		Low Lime		Med. Lime		High Lime	
Year	A	E	A	E	A	E	A	E
	Base Saturation %							
1983	5.1	7.50	4.75	5.60	5.45	6.55	3.04	5.20
1986	11.47	7.22	21.78	10.82	81.68	10.27	79.32	11.10
1988	2.52	4.00	10.38	5.31	8.55	5.18	9.68	4.88

Soil Water

Soil water was collected beneath the E and B horizons on all plots with zero-tension pan lysimeters for one year prior to lime application and five months afterward. Because of seasonal differences in soil water quality, statistical comparisons of before and after leachate data are for the same five month period (November-May). Table 3 contains a summary of E horizon leachate chemistry before and after lime application. There were no significant differences in Ca concentrations as estimated by the E horizon lysimeters before and after limestone applications or among plots. Al concentrations were not significantly different for any comparisons except the before and after periods on the control plot. In general, there were no consistent differences in these data. Unfortunately, monitoring of soil water chemistry could not be continued beyond the five month period. Because ground limestone dissolves relatively slowly, five months was probably not sufficient to detect an increase in Ca concentration in the E horizon soil water. Marschner et al. (1989) reported that increased Ca was not monitored in leachate at 50 cm depth until six months after liming a sandy soil. However, the fact that E horizon soil exchangeable Ca and base saturation increased is evidence for leaching of Ca from the litter, humus and A horizons.

Forest Floor Vegetation

Changes occurred in herbaceous and woody vegetation growing on the test plots. For some species these changes appeared to be consistent and statistically significant. For others, however, it was difficult to ascertain either trends over time or significant differences among treatments. We have selected some species of greatest interest to management foresters for discussion. These include grass (unspecified), hay-scented fern (*Dennstaedtia punctilobula* Michx.), blueberry (*Vaccinium* spp.), deer tongue grass (*Panicum clandestinum* L.), blackberry (*Rubus* spp.), red maple (*Acer rubrum* L.), black cherry, red oak and chestnut oak (*Quercus prinus* L.).

Table 3.--Mean soil water chemistry at the E horizon depth for all plots before and after liming.

Parameter	Plots: Control Before	After	Low Lime Before	After	Med. Lime Before	After	High Lime Before	After
pH	4.37ab[1]	4.75a*[2]	4.64a	4.43a	4.34b	4.39a	4.41ab	4.46a
				(mg/L)				
Ca	2.1a	1.3a	2.0a	1.7a	1.4a	1.7a	1.2a	0.9a
Mg	0.4a	0.3a*	0.6a	0.4b	0.4a	0.4ab	0.4a	0.3ab
K	2.1a	2.6a	0.8b	0.8b	0.9b	1.1ab	0.2c	0.3b
Na	2.4ab	4.4a	3.9a	2.8ab	0.4b	0.6b	0.7b	0.4b
Al	4.5a	2.0a*	2.5a	3.3a	3.2a	3.0a	2.8a	2.5a

[1] Values in the same row followed by different letters are significantly different between plots at α=0.05 for the same period.

[2] An asterisk (*) denotes a significant difference (α=0.05) for the before and after periods on the same plot.

Some care in the interpretation of the vegetation data is appropriate. For example, although 1985 was the first year following liming, much of the lime remained visible on the forest floor indicating that it was not yet available for plant use. Consequently, 1985 should be viewed as a transition year where the full affect of the treatment was not evident. From 1985 to the present there is an increase in the amount of grass (unspecified) on the limed plots. However, except for 1985, the amount of grass on any limed plot was not significantly different from that on the control. Deer tongue grass (Figure 1) increased from 1986 through 1990 on the plot which received the least lime. On the medium lime plot, deer tongue grass was always greater than the pre-treatment year and on the high lime plot, deer tongue abundance was greater in 1986, 89, and 90. Within year differences were significant between the control and high and low lime plots in 1989 and low lime plot in 1990. There appeared to be an increase in deer tongue grass on the plots receiving the most lime.

Numbers of blueberry on the medium lime plot declined after the 1986 high, but this decline is confounded by an equally steady decline in numbers on the control plot. The relatively low pre-treatment numbers on high and low lime plots also appeared to decline after treatment. None of the within year differences were statistically significant.

Hay-scented fern (Figure 2), a plant that seems to be increasing in prominence in the forests of Pennsylvania, appeared to decline on medium and low lime plots. The high lime plot showed no decrease in fern numbers. Pre-treatment and 1985 fern numbers were not significantly different between the control and medium and low lime plots; however, in 1986 all limed plots had significantly fewer ferns than the control. By 1990, differences between plots were similar to those prior to treatment.

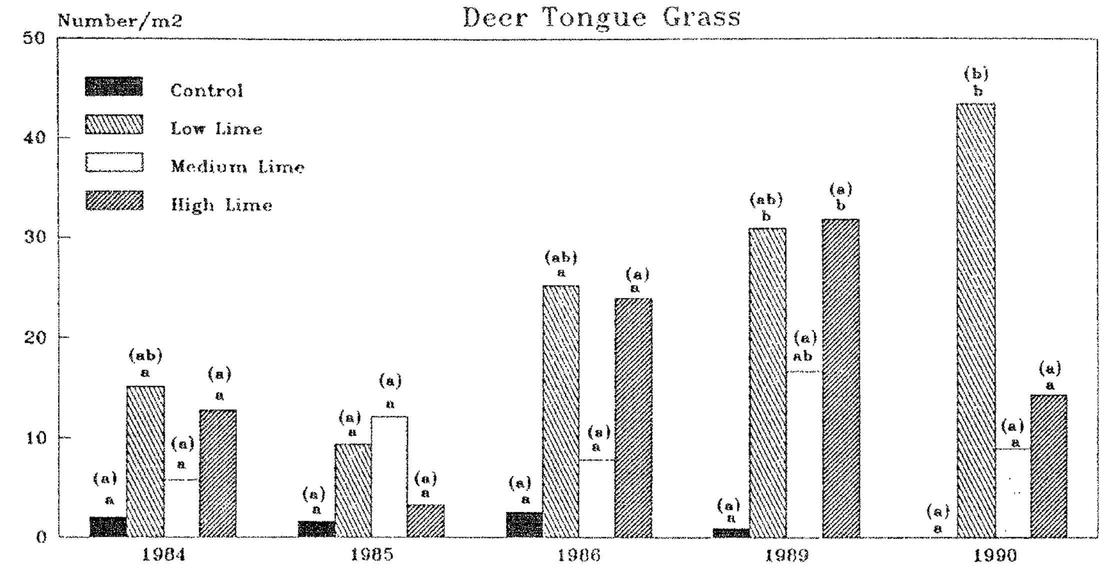

Figure 1. Trends in abundance of deer tongue grass on the control (unlimed) and each limed plot from 1984 to 1990. Different letters above bars indicate a significant difference ($\alpha = 0.05$) within a given year. Different letters in parentheses above bars indicate a significant difference ($\alpha = 0.05$) between years for that plot.

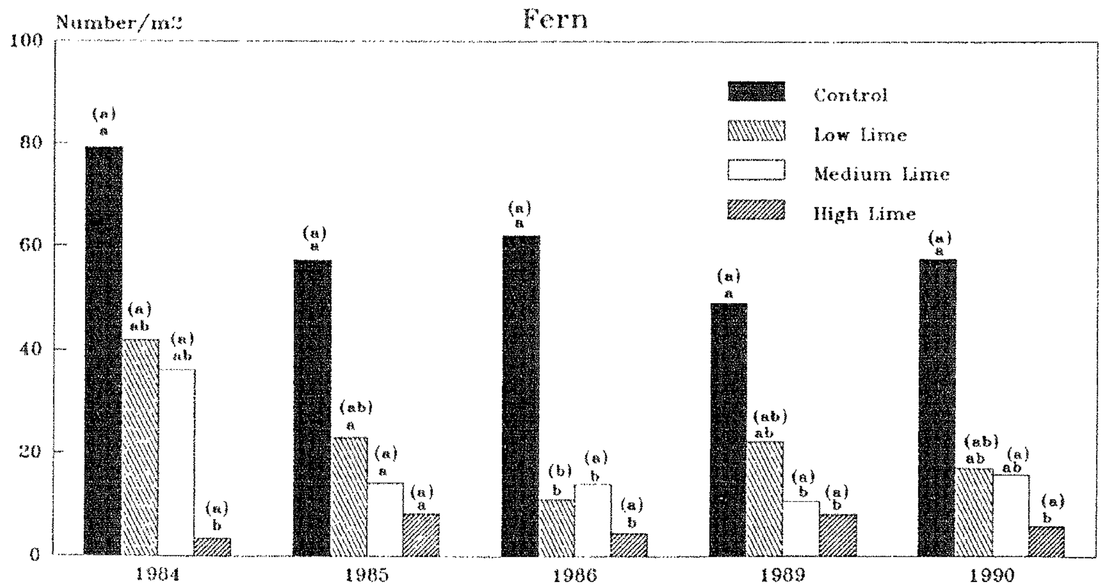

Figure 2. Trends in abundance of ferns on the control (unlimed) and each limed plot from 1984 to 1990. Different letters above bars indicate a significant difference (at $\alpha = 0.05$) within a given year. Different letters in parentheses above bars indicate a significant difference ($\alpha = 0.05$) between years for that plot.

Rubus spp. an important food species for white-tailed deer, appeared to increase on all plots after treatment with the exception of 1986 when no *Rubus* spp. were encountered on any of the plots. Numbers were low in all cases; consequently, there were no significant differences among the plots in any year.

Red maple seedlings did not appear to respond to liming with the exception of 1985, when the low lime plot had significantly more seedlings than any of the other plots. All plots had consistently higher numbers of red maple seedlings after treatment; however, with the exception of 1985, the limed plots and the control were never significantly different. It would appear that red maple did not respond to liming.

The data for black cherry are portrayed in Figure 3. Only the high lime plot appeared to have increased black cherry reproduction following liming. More black cherry seedlings were counted on the low lime plot, but the total numbers were low. Black cherry seedlings did not increase on the control plot.

As can be seen from Figure 4, red oak seedlings were scarce on all of the test plots. Only the medium lime and control plots had any oak seedlings in 1984. No plots had oak seedlings in 1985 and only the medium lime plot had seedlings in 1986. Following an exceptionally good seed crop in the fall of 1989, all plots except the control had oak seedlings in 1990.

A Shannon Diversity Index (Margalef 1968) was computed for all plots for each year that survey data were collected. The diversity of forest floor vegetation increased on the limed plots after 1985, but decreased on the control plot (Figure 5). The indicies computed for all limed plots in 1990 were significantly different ($\alpha = 0.05$) from those for 1984. The control plot index in 1990 was not significantly different from that of 1984.

These plots were not fenced to exclude deer. The area in which the plots were located had a high deer population. During the study, an average of 41 deer were harvested from this 324 ha management unit each year (Fritz, personal communication). With the exception of 1990, all vegetation surveys were done in September. In all years except 1990 every tree seedling was browsed and no seedlings were observed to attain a height greater than 20 cm throughout the course of the study.

DISCUSSION

These limited results, present evidence that addition of ground limestone to the forest floor increased the Ca concentration of soil in the rooting zone. The heaviest applications of lime produced the greatest increases in exchangeable Ca. Within five years after application, exchangeable Ca had returned to near pre-treatment levels in the treated soils. These results are in close agreement with the findings of Marschner et al. (1989) for a limed plot experiment conducted in Berlin, Germany. Plants growing on the plots were undoubtedly involved in removing a portion of this calcium through uptake and cycling through the forest

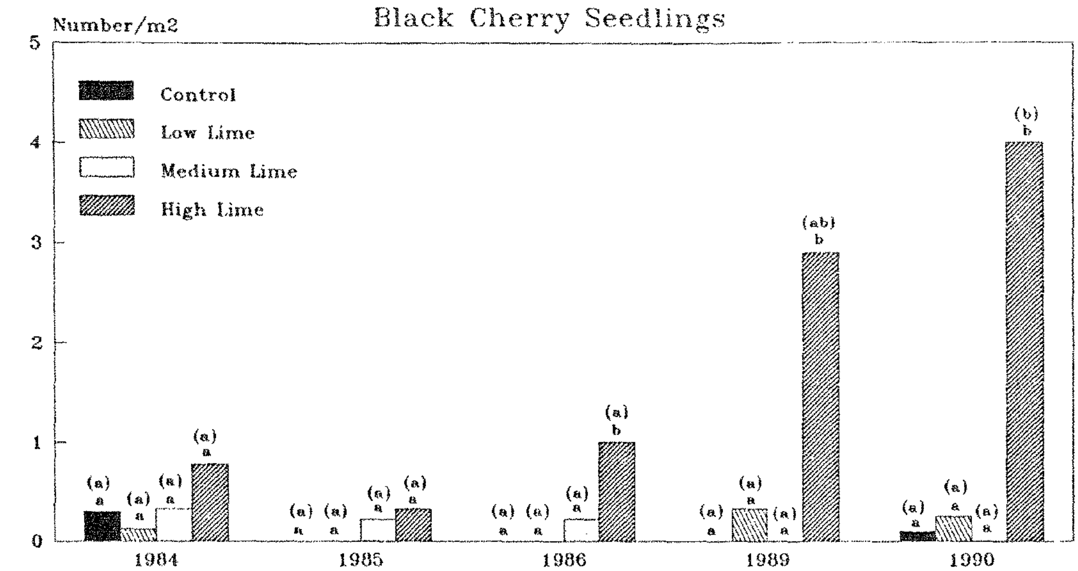

Figure 3. Trends in abundance of black cherry seedlings on the control (unlimed) and each limed plot from 1984 to 1990. Different letters above bars indicate a significant difference (α =0.05) within a given year. Different letters in parentheses above bars indicate a significant difference (α =0.05) between years for that plot.

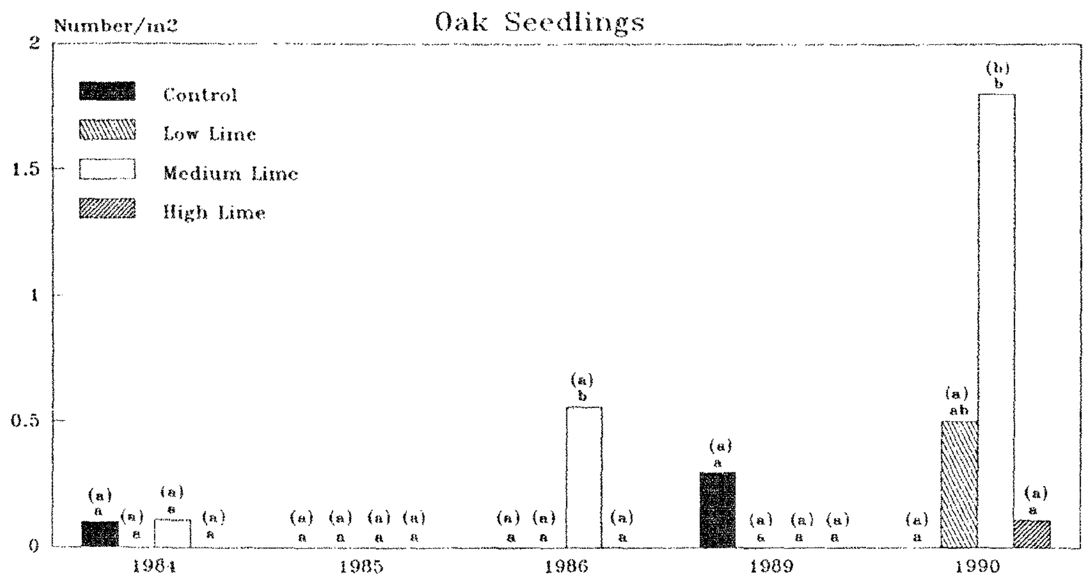

Figure 4. Trends in abundance of oak seedlings on the control (unlimed) and each limed plot from 1984 to 1990. Different letters above bars indicate a significant difference (α =0.05) within a given year. Different letters in parentheses above bars indicate a significant difference (α =0.05) between years for that plot.

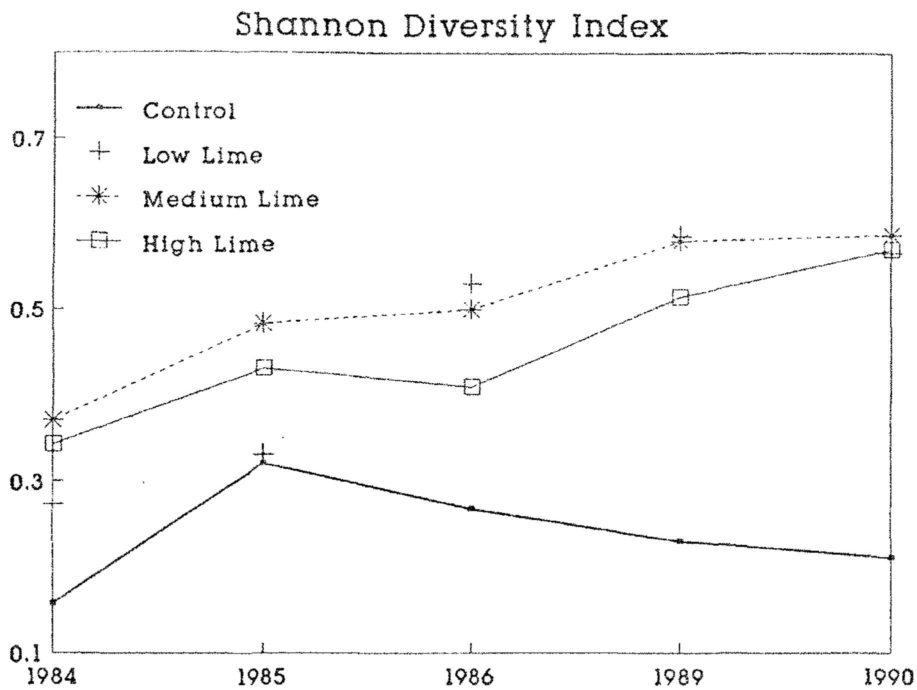

Figure 5. Trends in the Shannon Diversity Index on the control (unlimed) and each limed plot from 1984 to 1990.

floor and humus back to the above ground portions of the plants. Leaching of Ca by percolating soil water also probably contributed to the depletion of the Ca applied to the test plots. Unfortunately, long-term soil water measurements were not made to enable an assessment of the relative importance of these Ca sinks.

Forest floor herbaceous and woody vegetation appeared to respond positively to liming. Species diversity increased on the limed plots as did the numbers of some plant species. Black cherry, deer tongue grass and red oak seedlings all increased significantly in relation to the control plot after liming. Hay-scented fern declined significantly on the plot that received 5.9 tonnes/ha of lime. Other species that declined, but not significantly, were blueberry and red maple. Species increasing in number, but not significantly, were grass and blackberry with the highest numbers generally occurring on the plot that received the heaviest lime application. As mentioned previously, all of these changes occurred despite the presence of large numbers of deer and evidence of considerable deer browsing on the test plots.

SUMMARY

Lime application to several test plots on Hazelton-Dekalb soil located on Pea Vine Hill in southwestern Pennsylvania resulted in increased diversity of plants growing on the plots. Numbers of black cherry seedlings increased and hay-scented fern numbers decreased. Deer tongue grass also increased significantly on the limed plots. Increases in exchangeable Ca in the A horizon of this soil were still evident but approaching pre-treatment levels within five years after liming. Soil water sampling probably did not continue long enough after liming ($\leq$ 5 mo) to detect Ca leaching. In general, the plot receiving the heaviest lime application (11.1 tonnes/ha) showed the greatest overall vegetation response; however, even the plot receiving the lowest application (2.9 tonnes/ha) appeared to demonstrate positive response to liming. It would appear that moderate (5.9 tonnes/ha) or light (2.9 tonnes/ha) lime applications would be sufficient to produce favorable changes in rooting zone soil chemistry. To maintain such changes on this site, additional lime in these amounts would have to be applied at approximately four-year intervals.

LITERATURE CITED

Auchmoody, L.R. 1983. Using fertilizers to regenerate Allegheny hardwoods. 1983 Penn State Forestry Issues Conference Proceedings Regenerating Hardwood Stands March 15-16, 1983 University Park, PA 16802:160-171.

Auchmoody, L.R. 1985. Response of young black cherry to thinning and fertilization. In Proc. of Fifth Central Hardwood Forest Conference, University of Illinois, Urbana-Champaign, Ill, April 15-17, 1985:53-61.

Bondietti, E.A. and W.C. Shortle. 1990. The use of radial trends in wood cations to reconstruct the timing of the impact of acidic deposition on exchangeable cations in eastern North American forests. NAPAP 1990 International Conference on "Acidic Deposition: State of Science and Technology", February 11-16, Hilton Head Island, USA 4pp.

DeWalle, D.R., W.E. Sharpe and P.J. Edwards. 1988. Biogeochemistry of two Appalachian deciduous forest sites in relation to episodic stream acidification. Water, Air and Soil Pollution 40:143-156.

Federer, C.A., J.W. Hornbeck, L.M. Tritton, C.W. Martin, R.S. Pierce and C.T. Smith. 1989. Long-term depletion of calcium and other nutrients in eastern US forests. Environ. Mgt. 13(5):593-601.

Fritz, D. 1990. Personal communication.

Johnson, D.W. and D.E. Todd. 1990. Nutrient cycling in forests of Walker Branch Watershed, Tennessee: Roles of uptake and leaching in causing soil changes. J. Environ. Qual. 19:97-104.

Joslin, J.D. and M.H. Wolfe. 1989. Aluminum effects on northern red oak seedling growth in six forest soil horizons. Soil Sci. Soc. Am. J. 53:274-281.

Ke, J. and J.M. Skelly. 1990. Norway spruce symptoms in NE-USA and their relationships to soil and foliar nutrient deficiencies. NAPAP 1990 International Conference on "Acidic Deposition: State of Science and Technology", Hilton Head Island, USA 4pp.

Margalef, R. 1968. Perspectives in Ecological Theory, Chicago, University of Chicago Press, 112 pp.

Marschner, B., K. Stahr and M. Renger. 1989. Potential hazards of lime application in a damaged pine forest ecosystem in Berlin, Germany. Water, Air and Soil Pollution 48:45-57.

Matzner, E., P.K. Khanna, K.J. Meiwes and B. Ulrich. 1983. Effects of fertilization on the fluxes of chemical elements through different forest ecosystems. Plant and Soil, 74:343.

Roberts, T.M., R.A. Skeffington and L.W. Blank. 1989. Causes of Type 1 Spruce Decline in Europe. Forestry 62(3):179-222.

Swistock, B.R., J.J. Yamona, D.R. DeWalle and W.E. Sharpe. 1990. Comparisons of soil water chemistry and sample size requirements for pan vs tension lysimeters. Water, Air and Soil Pollution 50:387-396.

Ward, W.W. and T.W. Bowersox. 1970. Upland oak response to fertilization with nitrogen, phosphorus and calcium. Forest Science 16:113-120.