

# Impact of Forest Liming on Growth, Vigor, and Reproduction of Sugar Maple and Associated Hardwoods

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## Popular Summary

### Introduction

In 1985 a long-term study was initiated by the Pennsylvania Bureau of Forestry and the Northeastern Research Station to evaluate factors impeding regeneration of Allegheny hardwoods (Auchmoody, unpublished). The major factors suspected of limiting regeneration were high soil aluminum levels associated with low soil pH (typically 3.6 to 4.2 in surface mineral soils), deer browsing, and interfering vegetation such as hayscented fern (*Dennstaedtia punctilobula* (Michx.) Moore) and striped maple (*Acer pensylvanicum* L.). At that time, overstory sugar maple (*Acer saccharum* Marsh.) decline was just beginning to become a serious problem on the Allegheny Plateau. Subsequently, sugar maple decline became widespread across the unglaciated Allegheny Plateau in northwestern and north central Pennsylvania. A secondary objective of the study was to determine the effects of treatments on the growth and vigor of the three principal overstory species, sugar maple, American beech (*Fagus grandifolia* L.), and black cherry (*Prunus serotina* Ehrh.), and to evaluate the effects of treatments on sugar maple flower and seed production, and seedling regeneration. Results of this study through 1993 have been reported elsewhere (Long et al. 1997), and this report will summarize results through 1996 or 1997.

### Methods

Four replications of the study are located in the Susquehannock State Forest in Potter County, Pennsylvania on the unglaciated Allegheny Plateau. The study design was a split-plot with fencing (to exclude deer) the whole plot treatment and dolomitic lime (22.4 megagrams per hectare), herbicide (glyphosate), lime+herbicide, and untreated controls as the subplot treatments. Each of the 32 subplots was 45 meters X 45 meters. Herbicide to control interfering vegetation was applied with a backpack mist blower at a rate of 2.2 kg a.i. per hectare in August 1985. In October 1985, dolomitic limestone was applied with a tractor-spreader. In winter of 1985-1986, all stands were thinned to 50 percent relative density to provide lighting conditions sufficient to stimulate growth of regeneration, and in spring 1986 the electric fencing was installed.

Changes in soil chemistry were monitored by sampling soils in all 32 subplots by 2.5 centimeter increments to a depth of 15 centimeters in each year from 1986-1989 and in 1993 and 1996. Similarly, overstory growth and vigor were

measured each year from 1986 to 1990 and in 1993, 1996 (growth and vigor), and 1997 (vigor only). Sugar maple flower and seed crops were evaluated each spring and fall since 1987. Mid-crown foliage chemistry was evaluated by sampling overstory sugar maples (27 trees in limed plots, 27 trees in unlimed plots) in August 1994. Sugar maple seedling regeneration was monitored in nine permanently marked 1.13 meter radius plots in each treatment plot. Where tests of statistical significance are mentioned, 0.05 was the nominal indicator of significance.

### Results

#### Soil Chemistry

Soil chemistry was dramatically altered by the dolomitic limestone application. To simplify presentation, results are summarized for the 0-5 centimeter depth, the 5-10 centimeter depth, and the 10-15 centimeter depth. Exchangeable Ca increased in the 0-5 cm depth in 1986 to 1873 mg kg<sup>-1</sup> in limed plots compared with 340 mg kg<sup>-1</sup> in unlimed plots. By 1996, exchangeable Ca concentration was 2800 mg kg<sup>-1</sup> in limed plots compared with 360 mg kg<sup>-1</sup> in unlimed plots at the 0-5 centimeter depth. Similarly, exchangeable Mg at the 0-5 centimeter depth increased to 337 mg kg<sup>-1</sup> in limed plots compared with only 50 mg kg<sup>-1</sup> in unlimed plots in 1986; Mg continued to increase in limed plots to a high of 929 mg kg<sup>-1</sup> in 1996. There was a downward wave of changes in elemental concentrations in limed plots induced by direct addition of Ca and Mg or by pH changes. KCl extractable Al was reduced significantly only in the upper 0-5 centimeter depth in the first few years of the study, but by 1993 and 1996 there was evidence of decreasing Al concentrations even at the deeper depths. Exchangeable Mn also decreased in response to increased soil pH in the limed plots, although there was an anomalous increase in Mn at the 0-5 centimeter depth for unlimed plots in 1996. Both P and K decreased in response to liming, but only at the 0-5 centimeter depth. Soil pH responded rapidly to lime addition, increasing to 5.28 in limed plots in 1986 compared with only 3.70 in unlimed plots. Acidity changes also were evident at the 5-10 cm depths by 1987 in limed plots. By 1996, the upper 5 centimeter pH value averaged 6.30 in limed plots and 3.70 in unlimed plots.

#### Vigor and Growth Responses

Overstory crown vigor was estimated by two observers and rated on a scale from 1=dead to 6=healthy using the system of Mader and Thompson (1968). For American beech and black cherry, liming did not improve vigor (Figure 1). Beech bark disease was detected in the plots early in the study and trees started to die by 1987 or 1988. There also were droughts in 1988, 1991, and 1995 which likely affected tree vigor, and these were followed by elm spanworm (*Ennomos subsignaria* Hubner) defoliations in 1993 and 1994. While

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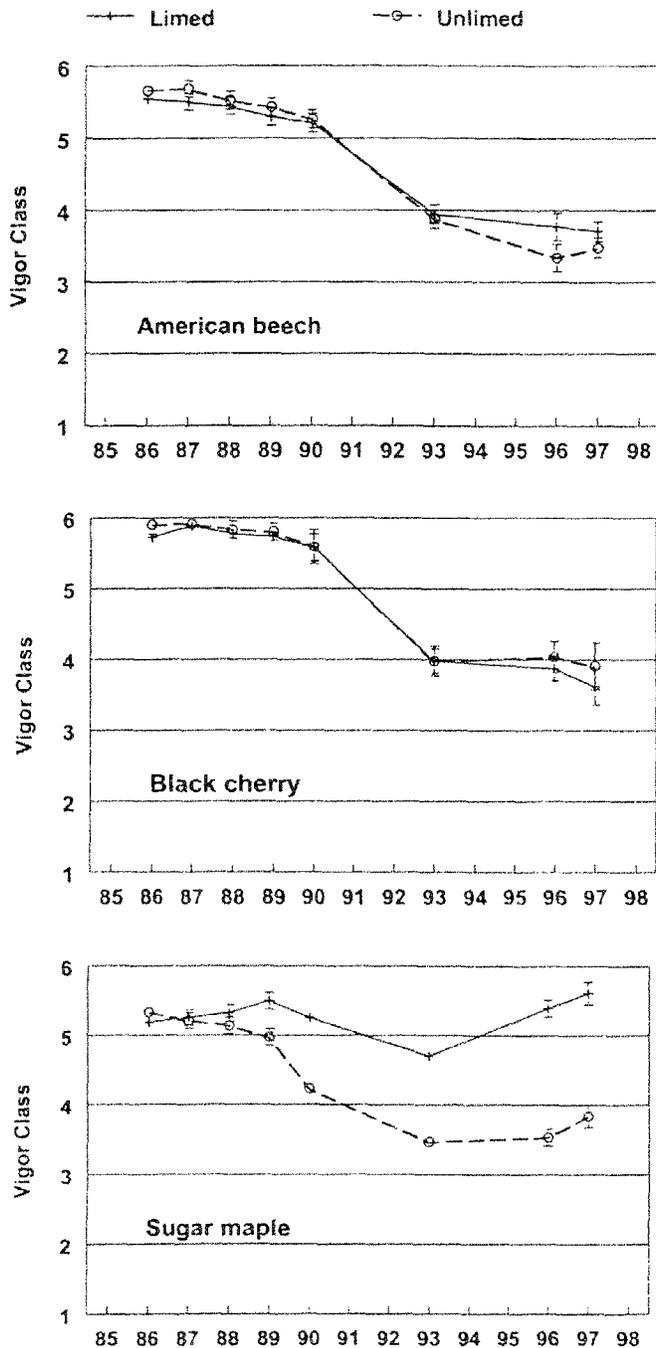


Figure 1.—Mean vigor ratings in limed and unlimed plots.

elm spanworm has a broad host range, beech is a preferred species for spanworm feeding. Overall beech vigor decreased from 5.6 in 1986 to 3.5 in 1997 (Figure 1). Black cherry has suffered similarly, with mean vigor averaging 5.7 through 1988 and then declining to 5.5 by 1990 and to 3.8 in 1993 as a result of elm spanworm defoliation. In addition, black cherry was affected by cherry scallop shell moth (*Hydria prunivora* Ferguson) in 1995 and trees were slow to recover through 1997.

Sugar maple vigor shows a different response (Figure 1). There was some initial indication of an increase in sugar maple vigor for limed trees from 5.1 in 1986 to 5.3 in 1989, but this was not statistically significant ( $p > 0.05$ ). However, by 1990, a trend of decreasing sugar maple vigor was evident for both limed and unlimed trees, but the limed trees maintained significantly higher vigor by 1993. By 1996 and 1997, vigor for both limed and unlimed sugar maple increased. For limed trees mean vigor in 1997 was 5.6, the highest mean vigor for the duration of the study, compared with 3.8 for unlimed trees. As with beech and black cherry, sugar maple vigor of both limed and unlimed trees was negatively affected by droughts in 1988, 1991, and 1995 and by elm spanworm defoliations in 1993 and 1994. We speculate that in the absence of these stressors, sugar maple in limed plots would have continued to increase in vigor after 1989.

The progression of mortality in the course of the study is similar to the vigor results. By 1997 (12 years after treatment applications), mean mortality based on plot means shows sugar maple mortality in the unlimed plots was 18% while in limed plots it was only 9%. For beech there was no significant difference in mean mortality between limed plots (14 percent) and unlimed plots (17 percent). For black cherry, mean mortality was 15 percent on limed plots and only 10 percent on unlimed plots, but these differences were not statistically significant.

Cumulative mortality, by 1997, based on individual tree data rather than plot means showed sugar maple mortality on unlimed plots was 24 percent compared with only 9 percent on limed plots. For beech cumulative mortality was 25 percent on limed plots and 24 percent on unlimed plots. Black cherry mortality was higher on limed plots, 11 percent, compared with unlimed plots, 4 percent, suggesting that liming may be deleterious to black cherry.

Growth responses indicate that liming did not significantly affect mean basal area increment of beech or black cherry through 1996 (Figure 2). However, for black cherry, there is again the suggestion that limed trees have been growing more slowly. For sugar maple, basal area growth for limed and unlimed trees started to diverge as early as 1990, but was not significantly different until 1993 when limed trees averaged 890 square centimeters of basal area and unlimed trees

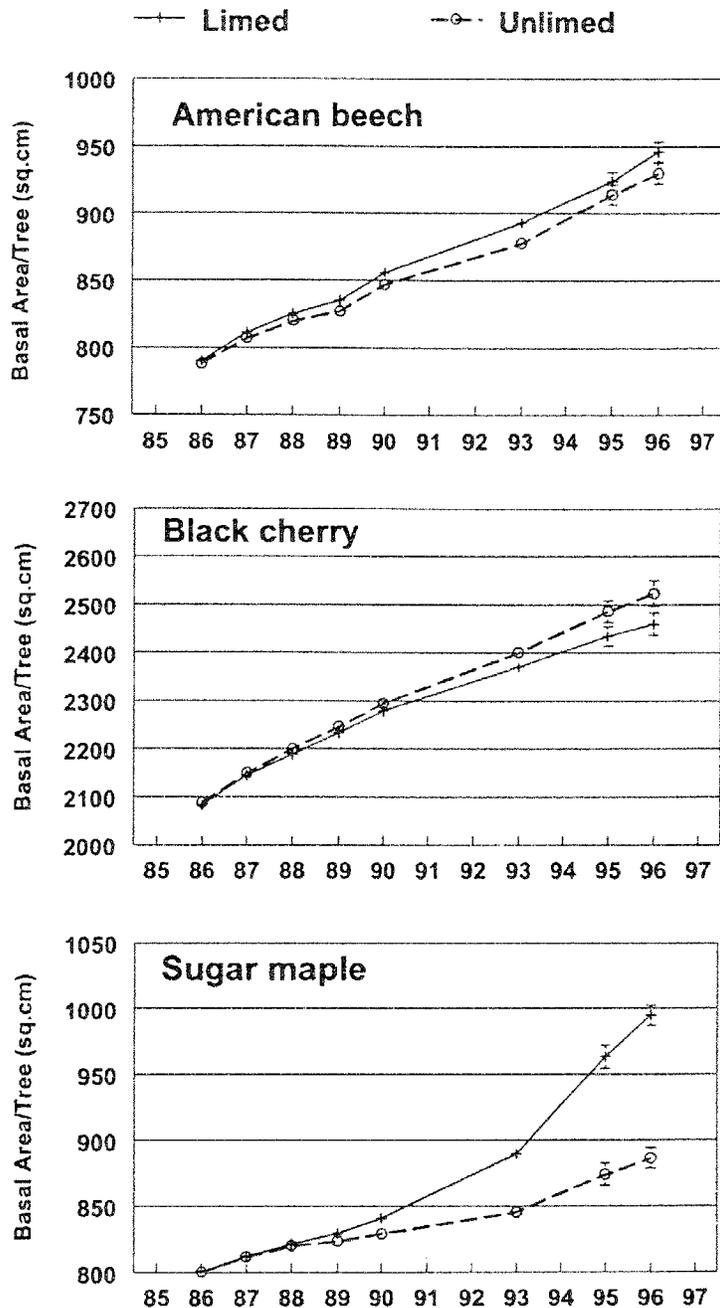


Figure 2.—Mean basal area per tree in limed and unlimed plots from 1986 to 1996. Plotted values are corrected by covariance analysis for differences in initial basal area.

averaged 845 square centimeters of basal area. By 1995, unlimed sugar maple increased slightly in growth rate, while limed trees continued to accelerate in growth rate (Figure 2). Over the course of the study (1986-1996), limed sugar maple increased in basal area by 24 percent and unlimed trees by only 11 percent, and mean annual basal area increment for sugar maple averaged 19.5 square centimeters per year for limed trees and 8.6 for unlimed trees.

### Foliage Chemistry

In 1994, mid-crown foliage samples were obtained from 54 sugar maple trees, 27 in limed and 27 in unlimed plots. Foliage chemistry reflected many of the changes observed in soil chemistry. Foliar Ca levels were doubled to 8777 mg kg<sup>-1</sup> in limed trees compared with only 4031 mg kg<sup>-1</sup> in unlimed trees, and Mg concentrations increased fourfold to 2655 mg kg<sup>-1</sup> in limed trees compared with only 617 mg kg<sup>-1</sup> in unlimed trees. Both Al and Mn concentrations were reduced in foliage from limed trees compared with unlimed trees, likely due to the pH-induced decrease in availability of these cations. Foliar P concentrations were unaffected by liming, while K concentrations decreased from 7136 mg kg<sup>-1</sup> in unlimed trees to 4811 mg kg<sup>-1</sup> in limed trees. The decreased foliar K concentration probably indicates soils were overlimed, and, based on results from other studies, K may now be nearing a deficiency threshold in limed plots. Molar ratios of Ca:Al were 75 in foliage from unlimed trees and 233 from limed trees.

Correlations between soil and foliage nutrients provide some additional insights into nutrient relationships. There were significant positive correlations between exchangeable K, Ca, Mg, Mn and Al and corresponding foliar chemical concentrations. Correlations of overstory vigor measurements from sampled trees with soil chemical constituents revealed a negative correlation between vigor and soil Al concentrations ( $r=-0.59$ ) while soil Ca and Mg were positively correlated with vigor ( $r=0.52$  and  $0.54$ , respectively). The foliar molar Ca:Al ratio was also positively correlated with overstory vigor ( $r=0.64$ ) suggesting that low Ca:Al ratios are associated with low sugar maple vigor.

### Flower and Seed Crops

Sugar maple flower and seed crops were also affected by liming, but not by fencing or herbicide. Lime increased the size, but not the frequency of sugar maple flower and seed crops. Three sugar maple flower crops were initiated during the study in 1988, 1989 and 1992. The 1988 flower crop did not develop into an appreciable seed

crop though differences between limed and unlimed trees were statistically significant ( $p < 0.001$  for flower crops;  $p = 0.13$  for seed crops). To assess flower crops, the percent of crown with flowers was rated on about 200 trees, using a scale where 0=no flowers present, 1 percent=trace flowering, and 5-100 percent estimated to the nearest 5 percent class. In 1989 and 1992, the percent of crown with flowers increased from 22 percent (1989) to 225 percent (1992) in trees on limed plots compared with unlimed trees. Seed crops were rated with a different scale where 0=no seed, 1=trace-5 percent, 2= 6-25 percent, 3=26-50 percent, 4=51-75 percent, and 5=76-100 percent of crown with seed. Lime increased the mean seed crop rating from 2.8 (unlimed trees) to 3.8 (limed trees) in 1989 and from 0.6 to 2.8, respectively, in 1992. Sugar maple seed crop frequency was unaffected by lime application; over the past 31 years area-wide seed crops have appeared the year following summer drought events when the mean June-July Palmer Drought Severity Index (PDSI) became more negative than -1. Seed crop size, even on limed plots, was only 5 to 15 percent of that found in the Lake States and New England (Curtis 1959, Godman and Mattson 1976, Graber and Leak 1992). Thus, seed supply appears to be an important factor influencing sugar maple regeneration.

### Sugar Maple Regeneration

Prior to 1990, there were few sugar maple seedlings on plots in any treatment; those present typically were <5 centimeters tall and did not survive from year to year. Cohorts of sugar maple seedlings occurred on study plots in 1990 and 1993 following the seed crops in 1989 and 1992, respectively. These seeds fell into vegetation established 5 to 8 years earlier. Unfenced areas typically were dominated by ferns, grass, striped maple and birch (*Betula spp.*), which are all species that are low in preference to deer or resilient to repeated deer browsing. Fenced areas were dominated by a variety of tree species and by *Rubus*.

Establishment of sugar maple seedlings was positively correlated with overstory sugar maple basal area and with

grass abundance. There was more sugar maple basal area on unfenced than on fenced plots; basal area was equally distributed on lime and herbicide treatment plots. There was more grass ground cover on unfenced, limed, and herbicided plots than on fenced, unlimed, and unherbicided plots. Sugar maple seedlings were more abundant on unfenced and limed plots; herbicide made no difference.

Survival of sugar maple seedlings during the 24 months following cohort appearance in 1990 and 1993 was affected by liming and herbicide, but not by fencing. Survival was higher on limed and herbicided treatments.

Mean height of the tallest sugar maple seedling was also increased by lime application; fencing and herbicide had no effect. Seedlings on both limed and unlimed plots were buried in vegetation established prior to sugar maple seedling appearance, so the data probably do not reflect the growth potential of sugar maple.

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