# SOIL NITROGEN PATTERNS AROUND *ALNUS GLUTINOSA* IN MIXED PLANTATION WITH HYBRID *POPULUS*

Jeffrey O. Dawson, Paul J. Dzialowy, George Z. Gertner,[1/] and Edward A. Hansen [2/]

*Abstract*.--Soil nitrogen concentration around *Alnus glutinosa* stems differed significantly both spatially and with the proportion of hybrid *Populus* in a four-year-old, mixed plantation near Rhinelander, Wisconsin. Single rows of *Alnus* bounded by adjacent rows of hybrid *Populus* had the greatest increase and concentration of nitrogen in the top 16 cm of soil. *Alnus*, with an adjacent row of *Populus* and an adjacent row of *Alnus*, had less total nitrogen concentration in the soil and there was little significant increase in total nitrogen concentration. Where *Alnus* trees had a row of *Alnus* on either side, the total nitrogen concentration was least, having decreased significantly from concentrations in soil prior to tree planting. Soil nitrogen accretion and concentration was always highest in the top 4 cm of soil.

Results are consistent with speculation that competition-induced stress from shading by *Populus* or *Populus* allelochemicals results in early accretion of nitrogen in soil around *Alnus* intermixed with *Populus*. This pattern may explain the fact that *Populus* in a row with many rows of nitrogen-fixing *Alnus* on either side did not grow as rapidly as *Populus* intermixed with *Alnus*.

*Keywords*: Nitrogen fixation, nurse crops, alder, hybrid poplar.

## INTRODUCTION

*Populus* or poplar plantations under intensive cultural conditions use large quantities of nitrogen. Aboveground components of young poplar plantations may take up as much as 90 kg/ha/yr (Hansen and Baker 1979). Since most forest soils lack sufficient nitrogen to support optimal tree growth; nitrate, urea or ammonia are sometimes added to forest soils to increase their productivity. However, nitrogen fertilization is expensive. Therefore, forest managers contemplating meeting increased raw material needs in part through nitrogen fertilization should be interested

[1/] Associate Professor, Research Assistant and Assistant Professor, Department of Forestry, University of Illinois, Urbana, Illinois.

[2/] Project leader, North Central Forest Experiment Station, U.S. Forest Service, Rhinelander, Wisconsin.

This study was supported in part by the North Central Forest Experiment Station, U.S. Forest Service, through Cooperative Agreement 23-82-02 and by the Illinois Agricultural Experiment Station, Hatch Project 55-366.

in the extent to which nitrogen-fixing plants can be used to enhance wood yields.

The possibility of using nitrogen-fixing trees to supply nitrogen has been extensively discussed (McIntyre and Jeffries 1932, Finn 1953, Red'ko 1958, Tarrant 1961, Dale 1963, DeBell and Radwan 1979, Gordon and Dawson 1979). Among the most intensively studied silvicultural systems that take advantage of nitrogen-fixing trees are mixed plantations of alders and hybrid poplars (Tarrant and Trappe 1971, DeBell 1975). Both alders and poplars have wood properties acceptable for chip and fiber products. Furthermore, both have considerable genetic diversity that could be exploited in their further improvement.

In a recent study on the effect of Alnus glutinosa L. (Gaertn.) on hybrid poplar (Hansen and Dawson 1982), height growth of poplar in a short-rotation intensively cultured Alnus/Populus mixture was affected by both the percentage of Alnus or alder and distance between species. Height of 3-year-old poplar increased significantly with increasing alder in the mixture and decreased with increasing distance between poplar and alder. The mixtures containing higher percentages of alder had poplar heights comparable to those obtained from optimal rates of ammonium nitrate fertilization. The greatest growth of hybrid poplar occurred where alder comprised 66 percent of the mix and where alder rows were directly adjacent to poplar rows. An apparently anomalous finding was that a row of poplar with many rows of nitrogen-fixing alder on either side did not grow as rapidly as poplar intermixed with alder. This led us to investigate the effects of hybrid poplar on the accretion of nitrogen in soil around alder stems. Our hypothesis was that the plants in the rows adjacent to an alder row influenced the soil nitrogen concentration around the affected alder stems in that row.

## METHODS

A 30 x 30 m plot at the Harshaw Forestry Research Farm of the U.S. Forest Service, North Central Forest Experiment Station, near Rhinelander, Wisconsin was planted in May of 1977. Planting stock consisted of 1-year-old, bare-root seedlings of an unknown seed source of A. glutinosa from a commercial nursery and greenwood tip cuttings of Populus rooted the previous fall in "Jiffy-7" peat pellets. The Populus consisted of an inadvertent mixture of two hybrid clones: P. betulifolia x P. trichocarpa Torr & Gray (clone A) and Populus spp. (clone B). The trees were spaced at 1.2 x 1.2 m in 26 rows with 26 trees per row. Each row was planted with either alder or poplar. The mix of taxons graded from four consecutive poplar rows on one side of the plot through increasing frequency of alder rows to four consecutive rows of alder on the opposite side of the plot. Rows planted with alder were numbers 1, 2, 3, 4, 6, 7, 8, 10, 11, 13, 15, 18, and 22 (Hansen and Dawson 1982).

The soil was a silt loam of the Padus series overlying sand and gravel at depths of 30 to 60 cm. The site was plowed to a depth of 16cm, disked and harrowed prior to planting. Soil samples were taken at 4 cm depth intervals to 16 cm in the plow layer of this soil and analyzed for total nitrogen. Weeds were controlled with a combination of mechanical and hand cultivation and directed herbicide spray (Hansen and Dawson 1982).

An irrigation gradient was superimposed on the plot at an angle of 90 degrees to the alder/poplar gradient. Analyses showed little evidence of interaction between irrigation and the species or clonal mixtures (Hansen and Dawson 1982).

The plantation was coppiced after the third growing season and aboveground tissue was removed from the site. Soil samples for this study were taken in spring following the fourth growing season. Three interior alder trees in each of rows 7, 11 and 15 were randomly selected as foci for soil sampling. Row 7 had alder rows on either side, row 11 had a row of poplar on one side and a row of alder on the other, while row 15 had rows of poplar on either side. Soil samples were taken using a soil probe adjacent to an alder stem and at 15, 30, 45, and 60 cm distances at a randomly selected azimuth for each distance from a stem. The probe samples were taken to a depth of 16 cm and divided into 4-cm depth increments. Soil samples were oven-dried at 70°C and sieved through a 2-mm mesh screen prior to soil nitrogen determination using a micro-Kjeldahl procedure. An ANOVA was performed using a nested design to determine the variation in soil nitrogen concentration around alder stems associated with composition of adjacent rows of trees, depth of soil sample, and distance of sample from alder stem. Nitrogen concentrations from the same distance from stems within sample rows were compared with soil nitrogen concentrations from corresponding depths prior to tree planting using a T-test.

## RESULTS

Analysis of variance revealed highly significant differences in total soil nitrogen concentration around alder stems ($\alpha = 0.0009$) and these differences were associated with composition of rows adjacent to alder. Levels of total nitrogen concentration were highest where the alder was bracketed on either side by poplar, and showed an increase in soil-nitrogen concentration over levels measured prior to planting (Table 2). Soil nitrogen concentration was slightly higher than initial levels where alder had an adjacent row of poplar and an adjacent row of alder (Table 3). Soil nitrogen concentration was lowest, with a significant net loss of nitrogen where alder was associated with rows of alder on either side (Table 4).

Soil nitrogen concentration around alder stems also varied significantly by depth ($\alpha = 0.0001$). Nitrogen concentration was highest in the top 4 cm of soil. Significant losses in soil nitrogen from the contiguous alder strip were greatest at depths from 4-12 cm (Table 4).

The distance from the alder stem at which soil samples were taken was not associated with significant change in soil nitrogen concentration. There was no significant interaction between composition of adjacent rows and distance from alder stem (Table 1).

Soil nitrogen concentration in the top 16 cm of soil at this study site prior to planting was uniform with no significant differences among depths and little variation among samples from the same depth. Soil nitrogen concentrations of the plow layer before planting were 966 mg/kg dry weight in the top 4 cm of soil, 986 at the 4-8 cm depth, 962 at the 8-12 cm depth, and 888 at the 12-16 cm depth. Alder trees in this plantation were nodulated and nodules exhibited nitrogen-fixing capability (Hansen and Dawson 1982).

Table 1.--ANOVA for soil nitrogen concentration around the stems of *A. glutinosa*.

| Source of variation | Degrees of Freedom | Sum of squares | F value | Probability > F |
|---|---|---|---|---|
| Row configuration | 2 | 0.0133 | 27.57 | 0.0009 |
| Distance from *Alnus* stem | 4 | 0.0010 | 0.65 | 0.6354 |
| Row x distance | 8 | 0.0012 | 0.41 | 0.9030 |
| Soil depth | 3 | 0.0066 | 19.10 | 0.0001 |
| Row x depth | 6 | 0.0014 | 2.04 | 0.1157 |
| Trees within rows | 6 | 0.0014[a] | | |
| Trees x distance within rows | 24 | 0.0089[b] | | |
| Tree x depth within rows | 17 | 0.0019[c] | | |
| Residual | 109 | 0.0181 | | |
| Corrected Total | 179 | 0.0538 | | |

[a] Used to compute error term for tests of hypothesis concerning row configuration

[b] Used to compute error term for tests of hypothesis concerning distance and row x distance.

[c] Used to compute error term for tests of hypothesis concerning depth and row x depth.

Table 2.--Mean change in total soil N around the stems of *A. glutinosa* with a *Populus* row on either side (mg N per kg of air-dry soil sample). Mean values are for 3 plantation soil samples minus the mean value (n = 20) for soil N concentration at the corresponding depth prior to planting.

| Soil depth (cm) | Distance from alder stem | | | | |
|---|---|---|---|---|---|
| | 0 cm | 15 cm | 30 cm | 45 cm | 60 cm |
| 0-4 | 329** | 236** | 177* | 236** | 231** |
| 4-8 | 286** | 87 | 52 | 146* | -29 |
| 8-12 | 18 | 156** | -29 | 41 | 30 |
| 12-16 | 115 | 92 | 45 | 139 | 92 |

**Significantly different from mean N concentration at corresponding soil depth prior to plantation establishment ($\alpha = 0.01$).

*Significantly different from mean N concentration at corresponding soil depth prior to plantation establishment ($\alpha = 0.05$).

Table 3.--Mean change in total soil N around the stems of *A. glutinosa* with a *Populus* row on one side and an *Alnus* row on the other (mg N per kg of air-dry soil sample). Mean values are for 3 plantation soil samples minus the mean value (n = 20) for soil N concentration at the corresponding depth prior to planting.

| Soil depth (cm) | Distance from alder stem | | | | |
|---|---|---|---|---|---|
| | 0 cm | 15 cm | 30 cm | 45 cm | 60 cm |
| 0-4 | 84 | 166* | 107 | 61 | 2 |
| 4-8 | -6 | -64 | -76 | -41 | -99 |
| 8-12 | 6 | -64 | -29 | 6 | 41 |
| 12-16 | 80 | 10 | -90 | 127 | 22 |

*Significantly different from mean N concentration at corresponding soil depth prior to plantation establishment ($\alpha = 0.05$).

Table 4.--Mean change in total soil N around the stems of *A. glutinosa* with an *Alnus* row on either side (mg N per kg of air-dry soil sample). Mean values are for 3 plantation soil samples minus the mean value (n = 20) for soil N concentration at the corresponding depth prior to planting.

| Soil depth (cm) | Distance from alder stem | | | | |
|---|---|---|---|---|---|
| | 0 cm | 15 cm | 30 cm | 45 cm | 60 cm |
| 0-4 | -98 | 61 | -33 | 61 | -33 |
| 4-8 | 6 | -169* | -123 | -193** | -169** |
| 8-12 | -145* | -157* | -122* | -157** | -122* |
| 12-16 | -48 | -1 | -25 | -165* | -174 |

**Significantly different from mean N concentration at corresponding soil depth prior to plantation establishment ($\alpha = 0.01$).

*Significantly different from mean N concentration at corresponding soil depth prior to plantation establishment ($\alpha = 0.05$).

## DISCUSSION AND CONCLUSIONS

Since alder height growth at the end of three years in this plantation averaged 45 percent less than poplar height growth, and since relative growth rates remained constant after coppicing, the alder was shaded by the poplar at least during the 3 years prior to the time of our soil sampling. Some alder mortality was occuring in the fifth year of growth in single and double rows of alder. This shading may have resulted in tissue death and decay with release of N into soil. Similarly, input of nitrogen from tissue killed by poplar allelochemicals is possible. Younger and Kapustka (1982) note an allelochemic effect of *Populus tremuloides* on nitrogen fixation by *Alnus rugosa* in northern Wisconsin, and work in progress at the Forestry Department of Laval University in Quebec City indicates that phenolic acids present in leaf or bud leachates and extracts of *Populus balsamifera* L. are inhibitory for the juvenile development of *Alnus crispa* var. *mollis* Fern. (Thibault, personal communication). The competitive factors of shading and possible allelopathy due to poplar in our plantation study cannot be excluded as causes for early nitrogen accretion in soil around alder grown in close proximity to hybrid poplar. Leaf, twig, nodule, and fine-root tissue sloughed from plants would occur in highest quantities near the soil surface, perhaps explaining the significant differences in soil nitrogen concentration associated with depth of soil sample.

In a previous study Hansen and Dawson (1982) found that localized regions of soil nitrogen accretion occured within 15 cm of stems and in the top 4 cm of soil in a 2-year-old, 1 x 1-m plantation of A. glutinosa. This pure alder plantation consisted of clones that suffered severe frost damage. However, soil sampled away from this localized zone showed a net decrease in total soil nitrogen concentration. This localized pattern of soil nitrogen accretion conformed to the zone of maximum root activity in the 2-year-old plantation. Alder roots and soil nitrogen accretion are more extensive in the upper soil stratum of the 4-year-old plantations in this study, consistent with the differing results. Recent measurements in a 3-year-old A. glutinosa plantation growing vigorously on a well-drained terrace site in southern Illinois revealed no net increase in soil nitrogen concentration (Dawson, unpublished). Gadgil (1971) subjected nitrogen-fixing lupine plants to shading and defoliation stress in greenhouse experiments. The results suggested that damage to lupine plants could increase nitrogen availability to Pinus radiata seedlings planted in the same substrate. These observations lend support to the suggestion that early soil nitrogen accretion around nitrogen-fixing A. glutinosa may be related to plant stress.

Nitrogen losses from soil around alder planted in contiguous rows may be due to the retention of symbiotically fixed nitrogen by alder in growing tissue combined with a net uptake of combined nitrogen from soil by alder. When soil is plowed, oxygen diffusion into soil is facilitated, thereby increasing the potential for nitrification by soil bacteria. Nitrate resulting from this aerobic process is readily leached out of surficial soil. Where this loss is not balanced by nitrogen inputs, such as those from nitrogen-rich alder litter and sloughed root tissue, net losses are easily possible. Bollen and Lu (1968) found high nitrification rates in red alder stands. Increased nitrification could have resulted in both increased leaching loss and increased uptake of nitrate with increased percentages of alder in our mixed planting. The effects of coppicing and irrigation in this study on alder root dynamics and nitrogen transformations in soil are not known. Further study will be required to explain fully the differences in soil nitrogen that we found.

We conclude that the configuration of mixed alder/poplar plantations is important if an early increase in potential nitrogen fertility of soil is expected. We also suggest that stress may precipitate early input of nitrogen into soil around nitrogen-fixing trees. Thus early nitrogen input may be inconsistent with greater longterm inputs of nitrogen where nitrogen-fixing nurse trees are competitively inhibited or eliminated in young mixed plantations.

## LITERATURE CITED

Bollen, W. B., and K. C. Lu. 1968. Nitrogen transformations in soils beneath red alder and conifers. In: Biology of alder. p. 141-148. USDA Forest Service, Pac. NW For. Range Exp. Sta., Portland, Oregon.

Dale, M. E. 1963. Interplant alder to increase growth in strip-mine plantations. USDA Forest Serv. Res. Note CS-14, 4p.

DeBell, D. S. 1975. Short rotation culture of hardwoods in the Pacific Northwest. Iowa State J. Res. 49:345-352.

DeBell, D. S., and M. A. Radwan. 1979. Growth and nitrogen relations of coppiced black cottonwood and red alder in pure and mixed plantations Bot. Gaz. 140:S97-S101.

Finn, R. F. 1953. Foliar nitrogen and growth in certain mixed and pure forest plantings. J. For. 51:31-33.

Gadgil, R. L. 1971. The nutritional role of Lupinus in coastal sand dune forestry. II. The potential influence of damaged lupin plants on nitrogen uptake by Pinus radiata. Plant and Soil 34:575-593.

Gordon, J. C., and J. O. Dawson. 1979. Potential uses of nitrogen-fixing trees and shrubs in commercial forestry. Bot. Gaz. 140:S88-S90.

Hansen, E. A., and J. B. Baker. 1979. Biomass and nutrient removal in short rotation intensive culture plantations. In: Proc. Symposium on the impact of intensive harvesting on forest nutrient cycling. p. 130-151. State Univ. of New York, Syracuse, NY.

Hansen, E. A., and J. O. Dawson. 1982. Effect of Alnus glutinosa on hybrid Populus height growth in a short-rotation intensively cultured plantation. Forest Sci. 28:49-59.

McIntyre, A. C., and C. D. Jeffries. 1932. The effect of black locust on soil nitrogen and growth of catalpa. J. For. 30:22-28.

Red'ko, G. I. 1958. Influence of the black adler (Alnus glutinosa Gaertn.) on the productivity of the Canadian poplar (Populus canadensis Mich.). TT 66-61093, 4p. US Dep. Comm. Clearinghouse for Fed. Sci. Tech. Inf., Springfield, VA.

Tarrant, R. F. 1961. Stand development and soil fertility in a Douglas-fir-red alder plantation. Forest Sci. 7:238-246.

Tarrant, R. F., and J. M. Trappe, 1971. The role of Alnus in improving the forest environment. Plant Soil, Special Vol.:335-348.

Younger, P. D., and L. A. Kapustka. 1982. Acetylene reduction ($N_2$ fixation) by Alnus rugosa (DuRoi) Sprengel and allelochemic effects of Populus tremuloides (Michx.) in the northern hardwood forest. Amer. J. Bot. (in press).