TEMPORAL AND SPATIAL CHANGES IN SOIL NITROGEN CONCENTRATION AROUND ALNUS GLUTINOSA STRESSED BY INTERPLANTED HYBRID POPLAR[1]

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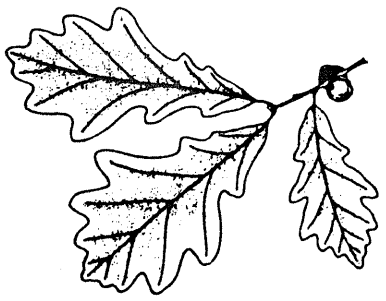

ABSTRACT.--Soil nitrogen concentration around alder trees [Alnus glutinosa L. (Gaertn.)] differed significantly with the composition of adjacent rows of trees, depth of soil sample, distance from the alder stem, and with the effects of interaction among time and spatial characteristics. Soil N concentration and fluctuation were always greatest in the surficial 4 cm of soil. After 6 years, the mean N concentration increased significantly with greater proximity to alder stems, whereas changes in soil N concentration with distance from an alder stem had not been significant after 4 years. Increases in soil N concentration coincided with stress and mortality of alder trees in a row as plants succumbed to competition from the more rapidly growing poplar. Conversely, decreases in soil N concentration around alder occurred where young trees were growing vigorously in cultivated soil, or after alder death.

INTRODUCTION

The intensification of forest management to increase productivity is the likely result of the increasing need for wood and fiber. Additional impetus for intensive forest culture comes from the decrease in forest land owing to mining, urbanization, industrialization, and agricultural development. Fertilization, especially with nitrogenous fertilizers, is one of the most effective means of increasing productivity of aggrading forest ecosystems, since most are N limited (Wollum and Davey 1975). An alternative to chemical fertilization with N is the use of N_2 fixing trees (Dale 1963, DeBell and Radwan 1979, Finn 1953, Gordon and Dawson 1979, McIntyre and Jeffries 1932, Red'ko 1958, Tarrant 1961). Among the most intensively studied silvicultural systems that take advantage of N_2-fixing trees are mixed plantations of alders (Alnus spp.) and poplars (Populus spp.) (DeBell 1975, Hansen and Dawson 1982, Tarrant and Trappe 1971).

In a 2-year coppice rotation, height and diameter growth of black cottonwood (Populus trichocarpa Torr. & Gray) were greater in stands containing 50 percent red alder (Alnus rubra Bong.) than in pure stands (DeBell and Radwan 1979). Total yield of the mixed planting was about 50 percent greater than that of either species planted alone. Heights of several conifer and hardwood species, including poplars, increased from 40 to 50 percent when European black alder [Alnus glutinosa L. (Gaertn.)] was interplanted as a 50-percent mix (Dale 1963, Plass 1977). An underplanting of European black alder accelerated both height and diameter growth of poplar (Van Der Meiden 1961). These studies demonstrate that poplar will grow faster when planted with alder than when planted without, and that in some cases total yield is increased.

Published results, however, indicate that poplar growth is not always stimulated by alders.

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Heights of a poplar clone were reduced, compared with a pure planting of the poplars, when intermixed with more rapidly growing red alder (Heilman and Stettler 1983). Total yield of other mixed plantings was generally less than that of pure poplar plantings, perhaps because of relatively high soil N fertility and rapid poplar growth.

Hansen and Dawson (1982) found that poplar height growth comparable to that obtained from optimal rates of ammonium nitrate fertilization occurred after 3 growing seasons where alders with effective nodules were directly adjacent to poplar rows and where alder comprised about 66% of a mixture at 1.2 m^2 spacing. However, a row of poplars surrounded by many rows of alder on either side did not grow as rapidly as poplar intermixed in alternating rows with alder. Soil samples revealed that soil N concentration around alders in a row near the isolated, slowly growing poplar row had actually decreased significantly from concentrations found prior to planting (Dawson *et al*. 1983). Where alder and poplar rows were intermixed in more equal proportions, the N concentration around alders increased significantly. Increased soil N was attributed to the stressful effects on alder of the faster-growing poplars.

Our study builds on this prior research to determine patterns of change over a longer, 6-year period of time around *A. glutinosa* in the mixed planting with hybrid poplar. The effects of time, row configuration around alders, depth of soil sample, distance from an alder stem and their interactions were determined and analyzed along with 4-year soil nitrogen concentrations previously determined from the same plantation (Dawson *et al*. 1983).

Although increases in soil N were associated with increased growth of poplars, no assessment of available N, which is difficult to relate to site productivity, was attempted. Forest soils are heterogenous (Usher 1970), and determining the amount of N in forest soils, let alone the problematical N availability, requires more intensive sampling than for other soil properties (Gessel *et al*. 1973). So our studies were limited to sampling soil in order to detect changes and variation in total soil N concentration. Advantage was taken of relatively homogeneous strata in the top 16 cm of tilled soil as a starting point for studying changes in N concentration over small distances and depths (Hansen and Dawson 1982).

METHODS

A 30 x 30 m plot at the Harshaw Forestry Research Farm of the United States 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 poplar rooted the previous fall in peat. The poplar consisted of an inadvertent mixture of two hybrid clones; *P. betulifolia* × *P. trichocarpa* Torr. & Gray and a poplar clone of unknown origin. 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 16 cm, disked, and harrowed prior to planting. Twenty soil samples were taken to 16 cm in the plow layer of this soil, divided into 4-cm depth increments, and analyzed for total nitrogen. Weeds were controlled with a combination of mechanical and hand cultivation and directed glyphosate herbicide spray.

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

Separate, randomly-selected soil samples for bulk densities were taken to 16 cm and divided into 4-cm depth increments at all plantation locations during the first growing season and in May or June following the fourth and sixth growing seasons. The plantation was coppiced in winter after the third growing season and aboveground leafless biomass was removed from the site. All alders and poplars produced coppice sprouts. Three interior alder trees in each of rows 7, 11, and 15 were randomly selected each spring 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 with 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 to remove rocks and intact roots prior to total soil N determination using a micro-Kjeldahl procedure (Nelson and Sommers 1973). An ANOVA was performed using a nested design to determine the variation in soil N concentration changes around alder stems associated with composition of adjacent rows of trees, time, depth of soil sample, and distance of sample from alder stem. The changes in soil nitrogen concentration were calculated by subtracting the mean value for the same soil depth of samples taken prior to plantation establishment from each later sample concentration. Nitrogen concentrations determined after the sixth growing season from the same distance from stems within sample rows were compared with mean soil N concentrations from corresponding depths prior to tree planting using a *t*-test.

RESULTS AND DISCUSSION

Mean change in soil N concentration around alders varied significantly with the row from which soil samples were taken (α = 0.0052), soil sample depth (α = 0.0001), distance from an alder stem (α = 0.0226), interaction between year and row (α = 0.0024), interaction between row and soil sample depth (α = 0.0171), interaction between year and soil sample depth (α = 0.0042), and interaction between year, row, and soil sample depth (α = 0.0034). Interactions are illustrated in Figure 1. Bulk densities of the soil cores averaged 1.15 g/cc with a standard deviation of .06 g/cc. There were no significant differences among bulk density values for time or depth of soil samples.

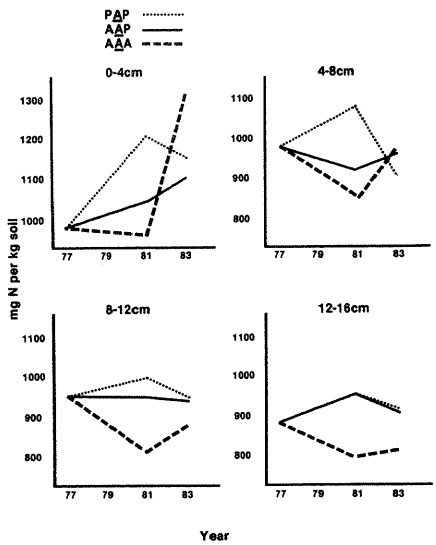

FIGURE 1.--Change over time in the mean soil nitrogen concentration (mg N per kg of oven-dried soil sample) at different soil sample depths near alders with differences in adjacent row composition. PAP denotes alder trees with rows of poplar on either side, AAP denotes alder with a row of poplar on one side and row of alder on the other, and AAA denotes alder with alder rows on either side.

Alder from a row surrounded by poplars had the greatest initial increase in associated soil N concentration after 4 years (Dawson et al. 1983), but during the next 2 years soil N concentration decreased rapidly. The initial increase in soil N concentration coincided with severe alder stress in this row, evidenced by severe branch dieback. All alders in this row were dead by the sixth year.

In the alder row with a row of poplar on one side and a row of alder on the other side, soil N concentration increases around alder were small after 4 and 6 years. Alder trees in this row were suppressed by competing poplars more slowly than the alders in a row surrounded by poplars. Symptoms of stress occurred more gradually in this row, and mortality was 95% by the sixth growing season.

Soil N concentration around alders with alder rows on either side exhibited a net decrease after 4 years, but increased rapidly to surpass the initial level during the next 2 years. After 4 years, alders in this row were vigorously growing, but competition by poplar trees several rows away and in an adjoining plantation probably resulted in the rapid decline and 70% mortality over the next 2 years. Possible contributing factors to the initial decline in soil N concentration include leaching of nitrate N from the tilled soil, the lack of weeds to capture and retain N, net uptake of N from soil by alders, and little turnover of tissue N by growing alders.

It is also possible that nitrification was increased in the plantation where alders predominated. High nitrification rates have been observed in red alder stands (Bollen and Lu 1968), and oxygen diffusion in plowed soil is facilitated, thereby increasing the potential for nitrification. Increased nitrification could have resulted in increased leaching loss, particularly since weed cover was lacking. Weed removal in an adjacent poplar plantation has been linked with increased nitrogen loss from soil (McLaughlin et al. 1984).

Poplar in this plantation grew twice as rapidly as alder, shading them and undoubtedly competing for soil water and nutrients. The net result of competitive factors was alder dieback and mortality, and soil N concentration around alder increased as symptoms of stress became evident. Thus, alder stress seems to have resulted in the release of N into soil.

Other research results lend support to the suggestion that increased soil N concentration around N_2-fixing plants may be related to plant stress. After N_2-fixing lupine plants were subjected to shading and defoliation stress in greenhouse experiments, N availability to radiata pine seedlings planted in the same substrate increased (Gadgil 1971). In a related study at this site, it was found that localized regions of higher soil nitrogen concentration occurred 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 (Hansen and Dawson 1982). This pure alder plantation consisted of clones that suffered severe frost damage. However, soil sampled away from this localized zone and around more vigorously growing alders showed a net decrease in total soil nitrogen concentration. This localized pattern of increased soil nitrogen concentration conformed to the zone of maximum root activity in the 2-year-old plantation.

The greatest total concentration and the greatest fluctuation in soil N concentration occurred in the uppermost 4 cm of soil (fig. 1). This suggests that N incorporation and turnover is greatest in a very narrow surficial soil stratum.

Mineralized N from litter would have been most rapidly incorporated into the uppermost layers of soil, as, seemingly, would sloughed roots and mycorrhizae which predominate in the surficial soil. Changes in soil N concentration at levels below 4 cm in some cases reflected trends in the top 4 cm, but were of lesser magnitude (fig. 1).

Soil N concentration increases, where they occurred around young alders in this plantation, were greatest near alder stems (fig. 2). Furthermore, the N concentration generally decreased at both sample times with increasing distance from the alder stem, although we found that differences were statistically significant only when all data for both sample times were combined for analysis of variance. Where there were decreases in soil N concentration around alder, they were generally smaller nearest to the alder stem. Soil N increase was greatest nearest to the alder stems, where root turnover, root nodules and stemflow might provide a significant input of N into soil (Henderson and Harris 1975).

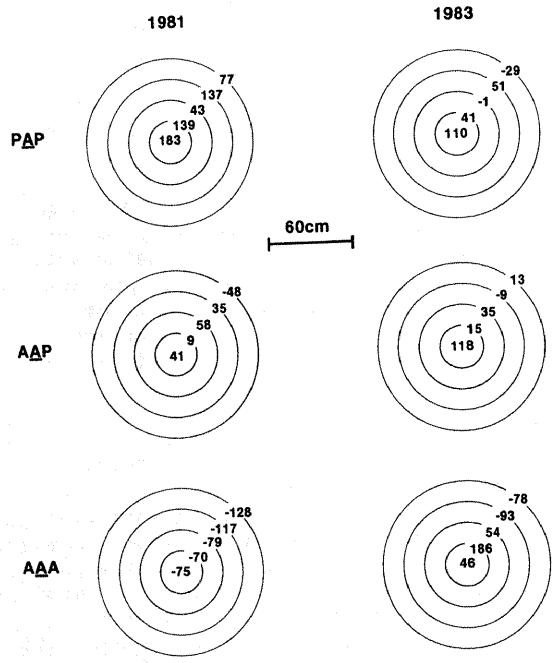

FIGURE 2.--Change in mean soil nitrogen concentration (mg N per kg of oven-dried soil sample) in the surficial 16 cm of soil with distance from an alder stem at different times and for alders with differences in composition of adjacent rows. PAP denotes alder trees with rows of poplar on either side, AAP denotes alder with a row of poplar on one side and alder on the other, and AAA denotes alder with alder rows on either side.

Tables 1-3 illustrate specific zones in soil around alder in this mixed plantation which exhibited significant changes after 6 years. Data for changes after 4 years are tabularized in the research report antecedent to this update (Dawson et al. 1983).

TABLE 1.--Mean change between 1977 and 1983 in soil N concentration around the stems of alder planted with a poplar row on either side (mg N per kg of oven-dried soil sample). Mean values are for 3 soil samples minus the mean value (n = 20) for soil N concentration at the corresponding depth prior to planting.

Soil depth	Distance from alder stem				
(cm)	0 cm	15 cm	30 cm	45 cm	60 cm
0- 4	339**	204*	76	98	164
4- 8	- 55	- 72	- 51	52	-269**
8-12	19	- 31	-108*	102	7
12-16	138	31	78	- 48	- 18

*Significantly different from mean N concentration at corresponding soil depth prior to plantation establishment (α = 0.05).
**Significantly different from mean N concentration at corresponding soil depth prior to plantation establishment (α = 0.01).

TABLE 2.--Mean change between 1977 and 1983 in soil N concentration around the stems of alder planted with a poplar row on one side and an alder row on the other (mg N per kg of oven-dried soil sample). Mean values are for 3 soil samples minus the mean value (n = 20) for soil N concentration at the corresponding depth prior to planting.

Soil depth	Distance from alder stem				
(cm)	0 cm	15 cm	30 cm	45 cm	60 cm
0- 4	155	127	148	97	129
4- 8	152	- 4	- 81	- 44	-128*
8-12	78	- 43	38	-120*	- 17
12-16	85	- 20	33	31	29

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

The tables reveal variability in soil N concentration change over relatively small distances in the plantation soil. For this reason, large numbers of soil samples and sensitive ANOVA techniques are necessary to reveal patterns in variation that simple paired comparisons cannot. Nonetheless, as in the ANOVA, differences in patterns among alder rows with different levels of poplar competition are discernible in these detailed tables, as is the greater accretion of soil N in the surficial 4 cm nearest the alder stem. Because of the dynamic nature of soil N, it would be dangerous to draw conclusions about soil N accretion based on limited data. Because we were unable to sample soil at seasons other than spring, we neglected a potential important source of variation, and can extrapolate from year to year only with a note of caution concerning our uncertainty about seasonal changes in soil N concentration. Since all trees were coppiced after 3

TABLE 3.--Mean change between 1977 and 1983 in soil N concentration around the stems of alder with an alder row on either side (mg N per kg of oven-dried soil sample). Mean values are for 3 soil samples minus the mean value (n = 20) for soil N concentration at the corresponding depth prior to planting.

Soil depth	Distance from alder stem				
(cm)	0 cm	15 cm	30 cm	45 cm	60 cm
0- 4	329**	524**	433**	188*	137*
4- 8	89	142	- 48	-132	-144*
8-12	- 59	- 43	-111*	- 69	-174**
12-16	-176	122	- 60	- 80	-129

*Significantly different from mean N concentration at corresponding soil depth prior to plantation establishment (α = 0.05).
**Significantly different from mean N concentration at corresponding soil depth prior to plantation establishment (α = 0.01).

years, it was not possible to determine the effect of coppicing on changes in soil N concentration.

Nevertheless, the combined evidence from this updated study strengthens the suggestion that stress on actinorhizal alder from interplanted poplar can promote the accumulation of N in affected soil. Changes in soil N concentration were most dramatic in a surficial layer of soil 4 cm in depth around alder trees in the plantation studied. In addition, changes in soil nitrogen concentration, where they occurred, were greatest near the alder stems. This might be attributed to stemflow and consistent differences in distribution of alder roots and litter on the plantation studied, though we did not measure these variables. The magnitude and direction of change also varied significantly over small distances and after only a few years in surficial soil around alder stems. Researchers should carefully note variability in soil N that can occur over short distances and times around a nitrogen fixing tree.

If stress and mortality of a nitrogen-fixing tree result in more rapid soil N accretion, then, perhaps management systems can be designed to take advantage of the situation. For instance, herbicide application to actinorhizal brush might be timed to promote N release when it will most benefit a target tree crop, though stress-related N input precludes long-term N input.

Results indicate that managers of mixed plantations with N_2-fixing trees should not necessarily expect immediate N accretion in soils or immediate growth increases of interplanted crops in every situation. Managers also need to be aware that different plantation configurations can result in different patterns of soil N accretion around N_2-fixing woody plants; thus it may be important to consider the possible localization of soil N accretion near the stems of young N_2-fixing trees in planning spacings for mixed short-rotation plantations.

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