EFFECT OF ALNUS GLUTINOSA ON HYBRID POPULUS GROWTH AND SOIL NITROGEN CONCENTRATION IN A MIXED PLANTATION

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Abstract.--Height growth of hybrid *Populus* and soil nitrogen concentration around *Alnus glutinosa* stems differed significantly both spatially and with the *Alnus*/*Populus* mixture in a short-rotation intensively cultured mixed planting. *Populus* height growth comparable to that obtained from optimal rates of ammonium nitrate fertilization occurred where *Alnus* rows were directly adjacent to *Populus* rows and where *Alnus* comprised about 66% of the mix. Soil nitrogen concentration around *Alnus* was greatest where *Populus* rows were directly adjacent to *Alnus* rows. Results are consistent with speculation that stress on young *Alnus* induced by competition from more rapidly growing *Populus* resulted in rapid accretion of nitrogen in soil.

Poplar (*Populus*) 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). 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 (*Alnus*) and hybrid poplars (Tarrant and Trappe 1971, DeBell 1975). Both alders and poplars have wood properties acceptable for chip and fiber products.

Published results by Zavitkovski and others (1979) show that height growth of trees incapable of symbiotic N_2 fixation decreases with distance from N_2-fixers for a number of species. Therefore, the spacing of N_2-fixing nurse trees in relation to associated trees needs to be considered if mixed plantations are to be efficient.

Another consideration when designing mixed plantations is the amount of N supplied by the N_2-fixers compared with the N demand of associated plants. Some of the probable factors affecting N supply by N_2-fixers to a mixed plantation are the percentage of N_2-fixers in the mix, the N_2-fixation rate, and the availability of N to the associated trees.

It is well documented that trees incapable of N_2 fixation usually show increased growth when mixed with N_2-fixers. Height and diameter growth of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) were greater in plantations containing 59 percent red alder (*Alnus rubra* Bong.) than in pure plantations (Tarrant 1961, Miller and Murray 1978). 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 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 *Populus*) increased from 4 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

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European black alder accelerated both height and diameter growth of *Populus* (Van der Meiden 1961). These studies demonstrate that *Populus* will grow faster when planted with *Alnus* than when planted without, and that in some cases total yield is increased. However, the percentage of a N_2-fixer in mixed plantings necessary to promote optimal growth of an associated species has not been addressed.

In our studies, the influence of *Alnus* and hybrid *Populus* mixture on *Populus* height growth and soil N concentration around *Alnus* were investigated over a range of mixtures in a short-rotation intensively cultured plantation at Rhinelander, Wisconsin (Hansen and Dawson 1982, Dawson and others 1983). Results of these studies are summarized in this report.

METHODS

A 30 x 30 m plot at the Harshaw Forestry Research of the U.S. Forest Service, North Central 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 a "Jiffy-7" peat pellets. The *Populus* consisted of an inadvertent mixture of two hybrid clones: *P. betulifolia* x *P. trichocarpa* Torr. & Gray and a *Populus* clone of indeterminate 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, 18, and 22.

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. Soil samples were taken at 4-cm depth intervals to 16 cm in the plow layer of this soil and analyzed for total Kjeldahl nitrogen. Weeds were controlled with a combination of mechanical and hand cultivation and directed herbicide spray.

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.

Tree heights were measured at the end of each growing season for 3 years. Diameters (15 cm above the first year's terminal bud scar) were measured at the end of the second growing season only. The relation of *Populus* height growth to the presence of *Alnus* was analyzed by regression. The dependent variable was the mean tree height in each *Populus* row. The independent variables were distance from a given *Populus* row to the nearest *Alnus* row and the percent of *Alnus* within various distances of the *Populus* row. Because of the planting design used, the percent of *Alnus* varied with distance from the *Populus* row. Consequently, distances of 2.4, 4.9, and 6.1 m either side of the *Populus* rows were selected to determine the "percentage of *Alnus*" that related best to *Populus* growth.

The roots of three alder trees in the *Alnus*/*Populus* mixed planting were excavated during their second growing season. A piece of root with attached nodules was removed from each tree and immediately assayed for nitrogenase activity. For the assay, root incubation techniques described in Dawson and Gordon (1979) and a portable gas chromatograph for the acetylene reduction assay (Mallard and others 1977) were used. The assay was performed to confirm N_2-fixation by *Alnus* nodules in the field plots of the study.

The plantation was coppiced after the third growing season and aboveground tissue was removed from the site. Soil samples were taken in spring following the fourth growing season. Three interior *Alnus* trees in each of rows 7, 11 and 15 were randomly selected as foci for soil sampling. Row 7 had *Alnus* rows on either side, row 11 had a row of *Populus* on one side and a row of *Alnus* on the other, while row 15 had rows of *Populus* 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 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 *Alnus* 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

Height of *Populus* increased with increased *Alnus* in the mixture and with proximity to the nearest *Alnus* row. The maximum *Populus* height occurred in the area of the plot with the highest proportion of *Alnus*. This *Populus* row (row 9) was bounded on either side by *Alnus*, which constituted 66 percent of the mixture for a 4.8-m-wide strip. Average height of 3-year-old *Populus* in row 9 was 4.9 m (21 percent higher than the *Populus* in rows 25 and 26). Another single *Populus* row (row 5) had an anomalous low height. Consequently, this low value was discarded from *Populus* growth analyses. *Alnus* height growth was considerably slower, averaging only 55 percent of the average of all *Populus* at the end of 3 years (2.5 vs. 4.5 m).

Coefficients for regressions show that in a 3-year-old plantation, *Populus* height increases with increasing *Alnus* in the mixture and decreases with distance the *Populus* is from the *Alnus*. Both independent variables were significantly related to *Populus* height growth ($P = 0.05$).

Other regressions were run to test for possible bias from the *Populus* clonal mixture and for possible plot border effects. Although there was no noticeable height growth difference between the two *Populus* clones at the end of the second year, there was a significant height difference between them at the end of the third year. Also, the two clones were not randomly distributed over the plot but tended to be segregated by rows. Consequently, the mean row tree height was adjusted by an amount that depended on the relative proportion of the two clones in the row and the ratio of the average height of each clone. However, analysis using unadjusted data still resulted in R^2 values of 0.85 to 0.88, and deletion of all *Populus* rows containing some of both clones (rows 9, 21, 23, 25 and 26) resulted in R^2 values of 0.92 and 0.98. Therefore, it seems that although the mixture of two *Populus* clones complicated the analysis somewhat, it did not change the interpretation of the results. In all cases the two independent variables, distance and percent *Alnus*, were significant regardless of the order in which they were entered into the equation, and the model had a consistently good fit as evidenced by the high R^2.

It is apparent that *Populus* height growth decreases sharply near the plot border. To test whether plot border effects were unduly influencing the model, regressions were run using adjusted clonal height data and deleting the three border rows (rows 24, 25, and 26). The effect on the model of deleting the three border rows was minor; R^2 values still ranged from 0.83 to 0.92.

Since diameter growth of the two *Populus* clones was markedly different throughout the study, diameter was not used as a variable to test treatment response. However, since both diameter and height of *Populus* were related similarly to *Alnus*, it follows that proximity to *Alnus* increases *Populus* biomass as well as height growth.

The three samples of root nodules assayed were capable of reducing acetylene to ethylene, indicating nitrogenase activity and, thus, N_2-fixing capability of the planted *A. glutinosa*.

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.

Analysis of variance revealed highly significant differences in total soil nitrogen concentration after 3 years around *Alnus* 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 *Alnus* was bracketed by *Populus*, and showed a 13 percent increase in soil-nitrogen concentration over levels measured prior to planting. Soil nitrogen concentration was only 1 percent higher than initial levels where alder had an adjacent row of poplar and an adjacent row of alder. Soil nitrogen concentration was lowest, with a significant net nitrogen loss of 10 percent where alder was associated with rows of alder on either side.

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 continuous *Alnus* strip were greatest at depths from 4-12 cm.

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.

DISCUSSION

A contiguous plot of pure *Populus* (same two clones as in the mixed plot) was fertilized annually with a gradient of NH_4NO_3. It was therefore possible to compare height growth response in fertilized *Populus* with that in an *Alnus*/*Populus* mixture. Since the plot treated with commercial fertilizer was planted earlier (August 1976 compared with May 1977 for the *Alnus*/*Populus* mixture), the tree heights of the mixed plot were adjusted upward by assuming that the untreated control portions of each plot (rows 24-26, which had no fertilizer or contained no *Alnus*) would have otherwise had equal height growth. This assumption resulted in increasing the tree heights of the mixed plot by 0.2 m. At the end of 3 years, maximum *Populus* height from commercial fertilizer was 5.25 m, compared with about 5.10 m for the adjusted heights from the mixed plot. Thus, the height difference between the two treatments was 0.15 m or 3 percent greater in the commercial fertilizer plot. If the difference in planting date were ignored, the height growth difference at 3 years would be 0.35 m or 7 percent.

Although more *Alnus* was better from the standpoint of *Populus* growth, *Alnus* growth lagged considerably behind that of the *Populus*. Similar results with European black alder and hybrid poplar have been reported by Wittwer and Immel (1977) and for red alder and black cottonwood by Harrington and others (1979). It was evident in this study that single rows of *Alnus* would soon be completely shaded by the *Populus* and perhaps eventually eliminated from the mix. It appears that *Alnus* may have difficulty surviving when mixed with *Populus* except perhaps for shorter rotations such as the 2-year coppice tested by DeBell and Radwan (1979) or on sites relatively favorable to *Alnus* (Harrington and others 1979). One strategy might be to interplant *Alnus* with the realization that it may be suppressed and eliminated from the plantation before harvest. There is also the possibility that *Alnus* growth can be substantially improved by selection and breeding. A series of sequential selections of *Alnus glutinosa* grown from seed in a greenhouse study resulted in the identification of fast-growing *Alnus* clones that performed as well as a fast-growing *Populus* clone in a controlled environment optimized for hybrid *Populus* (Bajuk and others 1978).

Alnus in this study was effective in symbiotically fixing N_2 as demonstrated by acetylene reduction ability and the zones of soil N accretion around some individual *Alnus* stems.

One 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 *Populus* intermixed with *Alnus*. This led us to investigate the effects of hybrid poplar on the accretion of nitrogen in soil around alder stems. 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 occurring 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* Michx. on nitrogen fixation by *Alnus rugosa* (Du Roi) Spreng. 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.

Hansen and Dawson (1982) found that localized regions of soil nitrogen accretion 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*. 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 in 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 together 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 completely inhibited or eliminated in young mixed plantations.

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