THE EFFECTS OF ALTERNATE-ROW INTERPLANTING OF FIVE SPECIES ON BLACK WALNUT GROWTH

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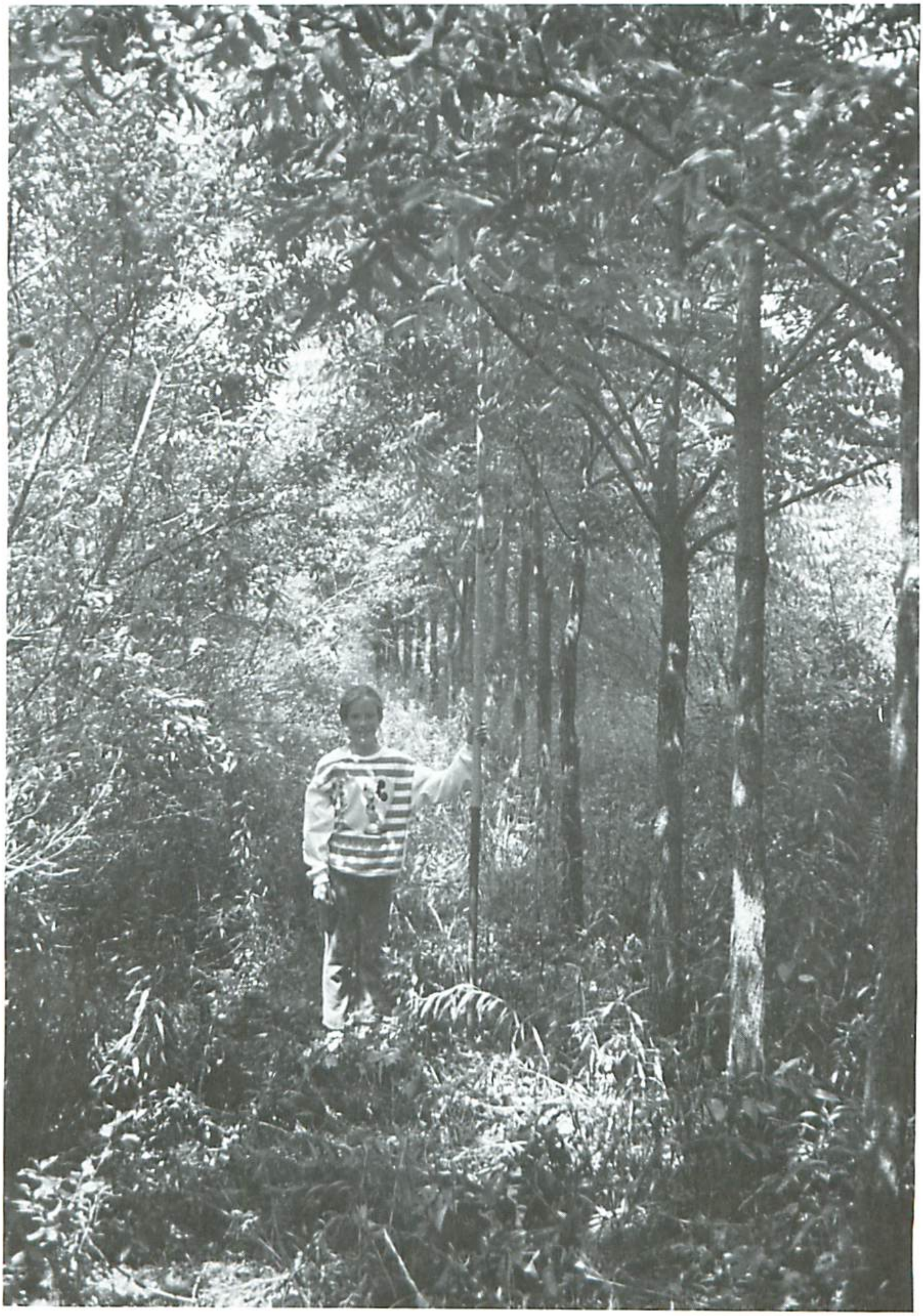

Frontispiece

Ten-year-old black walnut planted in alternate rows with autumn olive. (Mean height of the walnut is 5.8 m, mean DBH is 7.8 cm.)

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ABSTRACT

Black walnut (*Juglans nigra* L.) was planted alone and in alternate rows with black locust (*Robinia pseudoacacia* L.), autumn olive (*Elaeagnus umbellata* Thumb.), white pine (*Pinus strobus* L.), European alder (*Alnus glutinosa* [L.] Gaertn.) and bur oak (*Quercus macrocarpa* Michx.) near Parkhill, Middlesex County, Ontario. There were three replications of the pure walnut plots and of the walnut mixtures with black locust, autumn olive and white pine. European alder and bur oak were planted in only one and two plots, respectively. The planting site was a former field of marginal fertility for black walnut. Spacing was 3 m between rows and 1.5 m within rows.

Ten years after planting, species mixtures had no effect on walnut survival. However, height of black walnut was significantly greater in plots in which walnut was interplanted with autumn olive than in the pure walnut plots or the walnut/white pine mixture. In addition, DBH of black walnut was significantly higher in plots in which walnut was interplanted with autumn olive than in the pure walnut plots or the mixtures with black locust or white pine. Nitrogen concentrations in black walnut leaves were also significantly higher in plots in which black locust or autumn olive were interplanted than in the pure walnut plots or the plots in which white pine was interplanted.

RÉSUMÉ.

Des noyers noirs (*Juglans nigra* L.) ont été plantés en parcelles pures et mélangées près de Parkhill, dans le comté de Middlesex, en Ontario; dans les parcelles mélangées, les rangs de noyer noir alternaient avec des rangs de robinier faux-acacia (*Robinia pseudoacacia* L.), de chalef en ombelles (*Elaeagnus umbellata* Thumb.), de pin blanc (*Pinus strobus* L.), de verne (*Alnus glutinosa* [L.] Gaertn.) et de chêne à gros fruits (*Quercus macrocarpa* Michx.). Les parcelles pures de noyer noir et les parcelles mélangées avec le robinier faux-acacia, le chalef en ombelles et le pin blanc étaient assorties de répétitions. Le verne et le chêne à gros fruits n'étaient plantés respectivement que dans 1 et 2 parcelles. Les parcelles ont été établies dans un ancien champ offrant une fertilité marginale au noyer noir. L'écartement des rangs était de 3 m et l'espacement des plants de 1,5 m.

10 ans après la plantation, la composition des espèces n'avait aucun effet sur le taux survie du noyer noir. La croissance en hauteur du noyer noir était cependant beaucoup plus importante dans les parcelles où le noyer noir alternait avec le chalef en ombelles que dans les parcelles pures ou de noyer/pin blanc. De plus, le dhp du noyer noir étaient considérablement plus élevé dans les parcelles de noyer noir/

chalef en ombelles que dans les parcelles pures ou dans les parcelles où il alternait avec le robinier faux-acadia ou le pin blanc. Les teneurs en azote des feuilles de noyer noir étaient beaucoup plus élevées dans les parcelles où il alternait avec le robinier faux-acacia ou le chalef en ombelles que dans les parcelles pures ou les parcelles de noyer noir/pin blanc.

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INTRODUCTION

High timber value and the potential for income from nut production make black walnut (*Juglans nigra* L.) a preferred species for the afforestation of former farmland in southern Ontario. However, black walnut is very demanding in its site requirements and grows well only in deep, fertile, well drained sandy loams, loams or clay loams (Carmean 1966, Taylor and Jones 1986, Ponder 1989). Since these soils are also the best agricultural lands, they are seldom available in quantity for afforestation, and walnut plantings are often relegated to sites of marginal fertility.

One possible way of making these marginal soils suitable for walnut afforestation is through fertilization (Pope et al. 1982). Phares (1973) reported a 34% increase in diameter growth of pole-sized black walnut growing on an upland site of marginal productivity after fertilization with 254 kg/ha of nitrogen. Fertilization with 200 kg/ha of nitrogen revitalized the growth of a stagnating 8-year-old walnut plantation growing on a well drained sandy loam in southern Ontario (von Althen 1985). However, fertilization with 200 kg/ha of nitrogen and 100 kg/ha each of phosphorus and potassium at the time of planting failed to improve significantly either survival or growth of black walnut planted in a clay loam of marginal fertility (von Althen 1976). Phares (1973) also advised against the fertilization of walnut seedlings and small saplings because fertilization rarely increases walnut growth; instead, it stimulates weed growth and thereby increases the intensity of weed control required.

Another possible method of improving the fertility of former farmland for black walnut afforestation is through the interplanting of walnut seedlings with nitrogen-fixing tree or shrub species. Clark and Williams (1979) interplanted black walnut with the nitrogen fixers autumn olive (*Elaeagnus umbellata* Thumb.), European alder (*Alnus glutinosa* [L.] Gaertn.) and black locust (*Robinia pseudoacacia* L.). Ten years later, the black walnut interplanted with autumn olive was 94 cm taller than black walnut interplanted with locust, the second-best nurse species, and 256 cm taller than walnut in the control plots. Similar improvements in walnut growth after interplanting with autumn olive were reported by Ponder et al. (1980) and, after interplanting with European alder, Russian olive (*Elaeagnus angustifolia* L.) and autumn olive, by Van Sambeek et al. (1985).

Although most of the growth improvement has been attributed to the addition of soil nitrogen supplied by the interplanted actinorhizal species (Ponder 1980, Paschke and Dawson 1989), improved weed control provided by shading from the interplanted species also appears to have contributed to improved walnut growth (Friedrich and Dawson 1984, Van Sambeek et al. 1985).

To determine the effects of interplanting black walnut with black locust, autumn olive, white pine (*Pinus strobus* L.), European alder and bur oak (*Quercus macrocarpa* Michx.) on the survival and the height and diameter increments of black walnut in southern Ontario, a plantation was established in 1980 on former farmland of marginal site quality for black walnut. This report presents the 10-year results.

EXPERIMENTAL AREA

The experimental site is a farm field on gently rolling topography located near Parkhill, Middlesex County, Ontario. The soil, classified by the Ontario Soil Survey (Hoffman and Richards 1952) as a Perth clay loam, has developed from a heavy ground moraine that has been modified, to some extent, by marine waters and lacustrine depositions. The parent material consists of clay with a coarse, blocky structure. Depth to parent material and drainage vary with topography. On the level areas, average depth to parent material is 50 cm and drainage is imperfect. In the shallow depressions, average depth to parent material is 30 cm and drainage is poor. At the time of planting, the pH of the plow layer was 7.2 and the organic-matter content was 3%.

METHODS

After harvesting a crop of wheat, the entire field was plowed and disked in the autumn of 1979. In April 1980, 1+0 black walnut seedlings were machine planted alone or in alternate rows with 2+0 black locust, 2+0 autumn olive, 3+0 white pine, 2+0 European alder or 2+0 bur oak. All seedlings were grown from local seed sources and were raised in the St. Williams tree nursery. Spacing in all plots was 3 m between rows and 1.5 m within rows.

Shortly after planting and in April of the next 2 years, 5.6 kg a.i./ha of simazine (Princep Nine-T^{R}) were broadcast over the entire experimental area and 2.0 kg a.i./ha of glyphosate (Roundup^{R}) were sprayed between the rows of trees and shrubs in late June of the fifth growing season. During the summer of the third and fifth growing seasons, one side of each forked leader and the lowest branches of each walnut tree were pruned. Finally, during the summer of the eighth growing season, the lower branches of all walnut trees were pruned to approximately one-third the height of the trees.

The experiment was laid out in a randomized-block arrangement with three replications of each of four species combinations. Because of a shortage of European alder seedlings, only one plot was planted with alder; two additional plots were planted with bur oak. Each plot consisted of 7 rows, each of 34 trees. In the plots with alternating rows of nurse-tree species, three rows of black walnut alternated with four rows of the interplanted species. The total numbers of seedlings planted were 1938 black walnut; 408 each of black locust, autumn olive, and white pine; 272 bur oak; and 136 European alder.

DATA COLLECTION AND ANALYSIS

The intensity of competition was assessed by visually rating the percentage of ground cover in July of each of the first 5 years after planting and in July of year 10. Survival and heights of all planted tree and shrub species were recorded at the end of years 1, 3, 5, 7 and 10. The diameter at breast height (DBH) of all walnut trees was recorded at the end of the tenth growing season. Five composite foliage samples (two walnut leaves from mid-crown of each of five trees) were collected in each plot in late July of years 5 to 10 and were analyzed for nitrogen content by the semi-micro Kjeldahl method.

The 10-year survival, height, DBH and foliar-nitrogen data for black walnut were subjected to analyses of variance and Tukey's multiple range test, with the exception of data from plots interplanted with European alder and bur oak; because these species were interplanted with black walnut in only one and two plots, respectively, no analysis of variance could be conducted on these data because of the lack of replication.

RESULTS

Site

In depressed areas in the field, which covered approximately one-fifth of the total experimental area, black walnut growth was very poor and mortality of the interplanted species was high. To eliminate the confounding effects of site differences, survival and growth data for black walnut and the interplanted species in the depressions were excluded from the analyses of treatment results.

Weed Control

Application of 5.6 kg a.i./ha of active simazine shortly after planting and in April of the next 2 years provided 70 to 80% competition control during the first 3 years (Table 1). However, when the herbicide treatments were discontinued after 3 years, competition greatly increased. The most common weed species were tall fescue (*Festuca arundinaceae* Schreb.), quack grass (*Agropyron repens* [L.] Beaur.), goldenrod (*Solidago* spp.) and wild aster (*Aster* spp.). Application of 2 kg a.i./ha of glyphosate in late June of the fifth year effectively controlled competition for the next 2 years. However, by year 10, dense herbaceous vegetation covered 80% of the soil in all plots except those that contained autumn olive or black locust (Fig. 1-6).

Figure 1. Pure stand of 10-year-old black walnut. Note the dense ground cover, mainly of goldenrod.

Figure 2. Alternate rows of 10-year-old black walnut and black locust.

Figure 3. Alternate rows of 10-year-old black walnut and autumn olive. Note the dense shade under the walnut trees.

Figure 4. Alternate rows of 10-year-old black walnut and white pine. Note the dense herbaceous competition under the walnut trees.

Figure 5. Alternate rows of 10-year-old black walnut and European alder. Note the dieback of alder on the right side of the photograph.

Figure 6. Alternate rows of 10-year-old black walnut and bur oak. Note the columnar crown of the oak, which provides little competition control for the walnut trees.

Table 1. Competition control, by treatment and number of years since planting.

Plantation mixture	Competition control (%), by years since planting 1	2	3	4	5	10
Pure black walnut	80	80	70	30	90	20
Black walnut - black locust	80	80	70	30	90	30
Black walnut - autumn olive	80	80	80	40	90	50
Black walnut - white pine	80	80	70	30	90	20
Black walnut - European alder	80	80	70	30	90	20
Black walnut - bur oak	80	80	70	30	90	20

Survival

Ten-year survival of black walnut ranged from 88 to 95%, with no significant differences among treatments (Table 2). Most of the mortality of black locust and white pine occurred during the first 3 years after planting and was probably caused by simazine toxicity. Survival of autumn olive and bur oak was 81 and 87%, respectively, with no apparent single cause of mortality. Survival of European alder was 85% at the end of the seventh growing season. However, starting in the summer of the seventh year after planting, many alder branches and tops began to die. This dieback progressed rapidly and resulted in additional mortality of 28% during the next 2 years.

Height

Ten-year height of black walnut was significantly higher in plots interplanted with autumn olive than in pure walnut plots or those in which white pine was interplanted (Table 2). There was no significant height difference between black walnut trees interplanted with autumn olive and those interplanted with black locust, which was 172 cm taller than the interplanted black walnut. There was little height difference between black walnut and the interplanted white pine or European alder, but black walnut was 105 and 213 cm taller, respectively, than the interplanted bur oak and autumn olive.

Table 2. Ten-year survival, height, and DBH of black walnut, and 10-year survival and height of interplanted species.

	Survival (%)[a]		Height (cm)[a]		DBH (cm)[a]
Plantation mixture	black walnut	nurse species	black walnut	nurse species	black walnut
Pure black walnut	96 a	--	436 a	--	5.2 a
Black walnut - black locust	92 a	50	518 ab	690	6.2 a
Black walnut - autumn olive	95 a	81	575 b	362	7.8 b
Black walnut - white pine	96 a	64	449 a	441	6.1 a
Black walnut - Eur. alder	97	57	476	491	6.6
Black walnut - bur oak	88	87	472	367	6.5

a Mixtures of black walnut with European alder and bur oak were not fully replicated. These mixtures were therefore excluded from the analyses of variance. For other treatments, means of height followed by different letters differ significantly at the 95% probability level. Means of DBH followed by different letters differ significantly at the 99% probability level.

Diameter

Mean 10-year DBH of black walnut planted in alternate rows with autumn olive was highly significantly greater than that of walnuts planted either alone or in alternate rows with black locust or white pine (Table 2). Mean diameter of black walnut planted in alternate rows with European alder or bur oak was substantially greater than that of trees in the pure walnut plantation, but this difference was not analyzed statistically.

Foliar Nitrogen Content

Ten years after planting, foliar nitrogen concentration was significantly higher ($p<0.01$) in the leaves of walnut trees interplanted with black locust or autumn olive than in the leaves of walnut trees interplanted with white pine or planted alone (Table 3). Although not verified by statistical analyses, the nitrogen concentrations in the leaves of walnut trees interplanted with European alder or bur oak were very similar to those in the pure walnut plantation. The lowest nitrogen concentration was recorded in walnut trees interplanted with white pine. All nitrogen concentrations had declined greatly between years 5 and 10 after planting.

Table 3. Foliar nitrogen content of black walnut trees planted alone or in alternate rows with nurse species.

Plantation mixture	Foliar nitrogen content (%) of black walnut, by number of years since planting					
	5	6	7	8	9	10
Pure black walnut	2.64	2.13	1.62	1.40	1.40	1.53 a
Black walnut - black locust	2.82	2.55	2.55	2.14	2.14	2.35 b
Black walnut - autumn olive	2.66	2.19	2.19	2.18	2.24	2.03 b
Black walnut - white pine	2.76	2.10	1.65	1.40	1.40	1.37 a
Black walnut - European alder[a]	2.68	2.24	2.05	1.78	1.75	1.59
Black walnut - bur oak[a]	2.73	2.44	1.97	1.67	1.72	1.55

a Mixtures of black walnut with European alder and bur oak were not fully replicated. These mixtures were therefore excluded from the analyses of variance. Ten-year foliar nitrogen concentrations followed by different letters differ significantly ($p<0.01$).

DISCUSSION

The planting site was a former field that had produced good crops of wheat, corn and other agricultural commodities for many years. Although the topography was slightly rolling, no obvious differences in crop production had been noted between the flat areas and the depressions. However, shallow depth to parent material and poor drainage in the depressions caused stagnation in the growth of the planted walnut trees. This stagnation became apparent only in the fourth year after planting, but by year 10, dieback of tops and branches was widespread, the bark was very dark, and numerous epicormic sprouts had emerged along the upper stems and lower sections of the largest branches. Despite the obvious stress, walnut survival remained high. This shows that black walnut is very tenacious even on sites that are too poor for adequate growth.

In the depressions, up to 80% of the black locust, autumn olive, European alder and white pine seedlings died during the first 3 years after planting. This mortality was most likely caused by simazine poisoning. Although all nurse species had tolerated annual applications of 5.6 kg a.i./ha of simazine on other sites with similar soil textures (von Althen, unpublished data), simazine was probably washed into the depressions from the surrounding higher ground. Evidence of simazine accumulation in the depressions was provided by the near-total absence of herbaceous vegetation in the depressions and higher-than-normal densities of vegetation on the flat areas surrounding the depressions. This is a good example of the potential danger of trying to obtain optimum competition control by applications of simazine at doses close to the tolerance level of the crop species. Black walnut and bur oak were not affected by the simazine applications because both species have a very high level of simazine tolerance (von Althen 1979).

The rapid deterioration of European alders planted in alternate rows with black walnuts was most likely caused by the allelopathic effect of juglone, a chemical found in the leaves, fruit hulls, inner bark and roots of walnut trees (Rietveld et al. 1983). Rain washes juglone from living leaves and it is also released from dead leaves, fruit and twigs. When other species are interplanted with black walnut, a certain period of time is required for walnut trees to grow to sufficient size to have a significant effect on the interplanted species (Rietveld 1982). In the present study, juglone did not affect European alder until the seventh year after planting.

Low survival of the interplanted black locust and European alder probably affected the growth of black walnut adversely because nitrogen production was lower and natural weed control was poorer than in a fully stocked plantation. The low survival of white pine probably did not greatly affect black walnut growth because, at a spacing of 3 m between rows, the black walnut trees did not yet derive much benefit from natural weed control provided by the white pine (Fig. 4).

Autumn olive provided the best natural competition control. Shading by the large number of spreading stems, with dense foliage, effectively eliminated tall fescue and quackgrass and greatly reduced the number and vigor of all other weed species. Where black locust survival was high, herbaceous competition was also reduced. There were fewer weed species present, and these were less vigorous than those in the pure walnut plots or the mixtures with white pine, European alder or bur oak. Weed suppression in the plots containing European alder and bur oak was less effective than in the autumn olive plots because the narrow rows of the columnar European alder and bur oak produced less shade than the spreading branches of the autumn olive.

Planting black walnut in alternate rows with autumn olive significantly increased the 10-year height and diameter of the walnut trees. Similar growth improvements have been reported by Clark and Williams (1979), Ponder (1980), Ponder et al. (1980) and Van Sambeek et al. (1985), who attributed the improved walnut growth to increased soil nitrogen supplied by the actinorhizal autumn olive. Paschke and Dawson (1989) measured soil nitrogen mineralization under black walnut trees interplanted with autumn olive, and reported that plots containing actinorhizal interplantings produced 118 to 236 kg/ha/yr of net mineral nitrogen in the upper 20 cm of soil, in comparison with only 65 to 90 kg/ha/yr in pure walnut plantations. Mineralization of nitrogen proceeded by nitrification throughout the growing season, with peak values occurring in August.

In the present experiment, foliar nitrogen of black walnut was significantly higher in plots interplanted with autumn olive or black locust than in plots of pure walnut or walnut interplanted with white pine. It should be noted that foliar nitrogen was lowest in walnut trees interplanted with white pine. Similar results were found in a plantation of alternate rows of black walnut and silver maple (von Althen 1989). This probably indicates active competition from the interplanted white pine and silver maple trees for a limited supply of soil nitrogen.

Ten years after planting, levels of foliar nitrogen were relatively low in all walnut trees. Previous studies have shown that rapidly growing walnut trees generally have a foliar nitrogen content of over 3% (Finn 1966; Maeglin et al. 1977; Pope et al. 1982; von Althen 1985, 1989). Concentrations of between 2.5 and 3% indicate an adequate supply of this nutrient; between 2 and 2.5%, a possible nitrogen deficiency; and below 2%, a definite nitrogen deficiency, with serious stress likely (von Althen 1985).

Five years after planting, the nitrogen content of walnut leaves in all plots was 2.65% or higher. This was probably largely the result of excellent weed control after the application of 2.0 kg a.i./ha of glyphosate in late June of the fifth growing season. Between 5 and 10 years from planting, foliar nitrogen declined to levels of serious deficiency in all but the walnut trees planted in alternate rows with autumn olive or black locust. At this time, it is not known how much of the nitrogen concentration in the leaves of walnut trees interplanted with autumn olive or black locust is a result of the nitrogen-fixing ability of these species and how much is a result of improved competition control provided by these same species. Nevertheless, foliar nitrogen concentrations and the growth of the walnut trees are positively correlated.

There are further benefits to interplanting black walnut with other tree or shrub species. Kessler (1985) suggested that interplanting black walnut with autumn olive helps to control walnut anthracnose by blocking the movement of spores from infected walnut litter. Schneider et al. (1970) reported that wind can be a critical factor in the early establishment of black walnut by damaging the long, tender compound leaves. Planting silver maple in alternate rows with black walnut increased walnut growth by providing natural competition control and protection from wind, and by forcing walnut height growth (von Althen 1989). Johnston (1979) suggested interplanting of white pine to shade out herbaceous vegetation, to protect the walnut trees from damaging wind, to shade out lower branches of the walnut (thereby improving the tree's stem form), and to enhance thinning by means of juglone, which is expected to kill some of the white pine 25 to 30 years after planting. However, a survey of 141 black walnut/white pine plantations in Ontario revealed that although some excellent plantations were produced, interplanting white pine with black walnut is no substitute for artificial weed control (von Althen and Nolan 1988).

CONCLUSIONS

The results of this study confirm previous findings that black walnut growth can be significantly improved by interplanting nitrogen-fixing species. The species that provided the most consistent improvement has been autumn olive. This species is not only an efficient nitrogen producer, but also provides excellent natural competition control. It also has a greater resistance to juglone poisoning than European alder, which is an efficient nitrogen producer and, as a result of its rapid juvenile height growth, provides excellent protection from wind damage.

The only disadvantage of planting autumn olive is its tendency to spread into adjacent areas. The greatest disadvantage of interplanting European alder is its susceptibility to juglone poisoning.

LITERATURE CITED

Carmean, W.H. 1966. Soil and water requirements. p. 32-34 *in* Black Walnut Culture. USDA For. Serv., North Central For. Exp. Stn., St. Paul, Minn.

Clark, P.M. and Williams, R.D. 1979. Black walnut growth increased when interplanted with nitrogen-fixing shrubs and trees. p. 88-91 *in* Proc. Indiana Acad. Sci., Bedford, Ind.

Finn, R.F. 1966. Mineral nutrition. p. 35-41 *in* Black Walnut Culture Workshop Proc. USDA For. Serv., North Central For. Exp. Stn., St. Paul, Minn.

Friedrich, J.M. and Dawson, J.O. 1984. Soil nitrogen concentrations and *Juglans nigra* growth in mixed plots with nitrogen-fixing *Alnus*, *Elaeagnus*, *Lespedeza* and *Robinia* species. Can. J. For. Res. 14:864-868.

Hoffman, D.W. and Richards, N.R. 1952. Soil survey of Perth county. Can. Dep. Agric., Exp. Farm Serv., Soil Surv. Rep. 15. 65 p.

Johnston, E.F. 1979. How to grow black walnuts. Your For. 12(1):22.

Kessler, K.J. 1985. Comparison planting of black walnut with autumn olive to control *Mycosphaerella* leaf spot of walnut. p. 285-288 *in* J.O. Dawson and K.A. Magerns, *Ed*. Proc. Fifth Central hardwood forest conference, Univ. Illinois, Urbana, Ill.

Maeglin, R.R., Hallock, H., Freese, F. and McDonald, K.A. 1977. Effect of nitrogen fertilization on black walnut growth, log quality and wood anatomy. USDA For. Serv., Madison, Wisc. Res. Pap. FPL 294. 11 p.

Paschke, M.W. and Dawson, J.O. 1989. Soil nitrogen mineralization under black walnut interplanted with autumn-olive or black alder. p. 120-128 *in* Proc. Central Hardwood Forest Conference VII. USDA For. Serv., North Central For. Exp. Stn., St. Paul, Minn. Gen. Tech. Rep. NC-132.

Phares, R.E. 1973. Managing immature trees for more high-quality logs and related products. p. 49-54 *in* Symp. Black Walnut as a Crop. USDA For. Serv., Carbondale, Ill., Gen. Tech. Rep. NC-4.

Ponder, F. 1980. Soil properties under pure and mixed plantings of young black walnut. p. 83-90 *in* H.E. Garrett and G.S. Cox, *Ed.* Central Hardwood Forest Conference III. Univ. Missouri, School For. Fish. and Wildl., Columbia, Missouri.

Ponder, F. 1989. Evaluating and selecting sites for black walnut. p. 30-33 *in* J.E. Phelps, *Ed.* The Continuing Quest for Quality. Proc. Fourth Black Walnut Symposium, Walnut Council, Indianapolis, Ind. and Carbondale, Ill.

Ponder, F., Schlesinger, R.G. and Funk, D.T. 1980. Autumn-olive stimulates growth of black walnut. Southern Lumberman 240 (2970): 14-16.

Pope, P.E., Holt, H.A. and Chancy, W.R. 1982. Interaction of nitrogen fertilization and chemical weed control of 4-year volume growth of a black walnut plantation. p. 105-109 *in* Black Walnut for the Future. USDA For. Serv., North Central For. Exp. Stn., St. Paul, Minn. Gen. Tech. Rep. NC-74.

Rietveld, W.J. 1982. The significance of allelopathy in black walnut cultural systems. Northern Nut Growers Assoc., Annu. Rep. 72:117-134.

Rietveld, W.J., Schlesinger, R.C. and Kessler, K.J. 1983. Allelopathic effects of black walnut on European black alder co-planted as a nurse species. J. Chem. Ecol. 9:1119-1133.

Schneider, G., Khatta, K.G. and Bright, J.N. 1970. Modifying sites for the establishment of black walnut. p. 155-159 *in* Tree Growth and Forest Soils. Oregon State Univ. Press, Corvallis, Oregon.

Taylor, E.P. and Jones, R.K. 1986. Soil interpretation and training for forestry, 1981-1985 in central and southwestern regions, site regions 6E and 7E. Ont. Inst. Pedol., Univ. Guelph, Guelph, Ont. 99 p. + appendices.

Van Sambeek, J.W., Schlesinger, R.C., Ponder, F. and Rietveld, W.J. 1985. Actinorhizal species as a nurse crop for black walnut. p. 257-263 *in* J.O. Dawson and K.A. Magevus, *Ed.* Proc. Fifth Central Hardwood Forest Conf., Univ. Illinois, Urbana, Ill.

von Althen, F.W. 1976. Fertilization at time of planting fails to improve growth of hardwood seedlings. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Inf. Rep. 0-X-249. 13 p.

von Althen, F.W. 1979. Preliminary guide to site preparation and weed control in hardwood plantations in southern Ontario. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Inf. Rep. 0-X-288. 26 p. + appendices.

von Althen, F.W. 1985. Revitalizing a black walnut plantation through weed control and fertilization. For. Chron. 61:71-74.

von Althen, F.W. 1989. Early height growth increased in black walnut-silver maple intermixtures. p. 170-174 *in* G. Rink and C.A. Budelsky, *Ed.* Proc. Central Hardwood Forest Conference VII. USDA For. Serv., North Central For. Exp. Stn., St. Paul, Minn. Gen. Tech. Rep. NC-132.

von Althen, F.W. and Nolan, J.D. 1988. Performance of black walnut-white pine plantations in southwestern Ontario. Gov't of Can., Can. For. Serv., Sault Ste. Marie, Ont. Joint Rep. 13. 30 p.