ACTINORHIZAL SPECIES AS NURSE CROPS FOR BLACK WALNUT[1]

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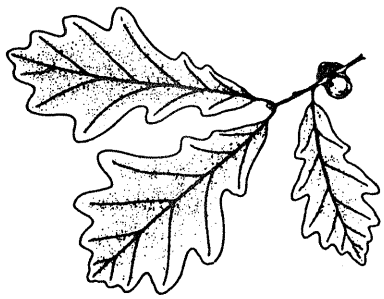

ABSTRACT.--Nitrogen-fixing nurse crops increase the growth of black walnut, but we do not know the mechanism involved. Nurse-crop effects on walnut growth were detected after the fifth growing season (1982) on a bottomland site in central Illinois but are not yet apparent after seven growing seasons on an adjacent upland site. Walnut height growth from 1982 through 1984 on the bottomland in mixtures with three actinorhizal plants, European alder, Russian olive, and autumn olive, was 36, 14, and 1 percent greater than in the pure walnut plots, respectively. Mixed plantings with the tree legume, Siberian peashrub, show no increase in walnut growth. All three actinorhizal plants were associated with increased walnut foliar nitrogen concentration, which in turn, was correlated with increased walnut height growth. No other differences related to nurse-crop treatments were found in walnut foliar nutrient concentrations, soil chemical composition, or understory vegetation composition and coverage.

INTRODUCTION

Nurse crops are plants introduced to foster another and generally more important crop (Ford-Robertson 1971). Nurse crops may alter a site through soil influences (e.g., nitrogen accretion, litter accumulation, aeration), microclimate changes (e.g., air movement and temperature modification), vegetation changes (e.g., amount and composition of competing vegetation), and/or pest habitat changes (e.g., leaf disease incidence) (Schlesinger and Williams 1984).

Planting nitrogen-fixing trees with black walnut (Juglans nigra L.) can improve walnut growth on many sites (Funk, Schlesinger, and Ponder 1979; Schlesinger and Williams 1984). After differences in walnut growth became apparent, Ponder (1983) found that black walnut foliage from mixed plantings with autumn olive (Elaeagnus umbellata Thunb.) had higher foliar nitrogen percentages and lower potassium levels than walnut in pure plantings. Nitrogen fixed by autumn olive is apparently made available to the walnut through increased organic matter accumulation and decomposition and is frequently associated with increased nitrate nitrogen in the soil (Ponder 1980).

Effects of nurse crops on walnut growth may also be due to other factors. Following crown overlap and closure, the dense crowns of nurse crops such as autumn olive and European alder (Alnus glutinosa (L.) Gaertn.) can reduce the average summer soil temperature, lessen daily fluctuations in air temperature, and reduce the herbaceous ground cover in mixed plots (Funk, Schlesinger, and Ponder 1979). The dense crowns of autumn olive can also decrease air movement through the stand, thus increasing the relative humidity, decreasing the incidence of leaf tattering, and disrupting spore dispersal of leaf diseases (Kessler 1985).

This paper presents results of the early effects of four woody nurse crop species (European alder, autumn olive, Russian olive, and Siberian peashrub) on the survival and growth of black walnut and examines those characteristics of the nurse-crop species that result in increased growth of the walnut trees.

According to Haines and DeBell (1979), European alder, black locust (Robinia pseudoacacia L.), and red alder (A. rubra Bong.) have the greatest potential as nurse crops in temperate forests. European

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alder increased growth of walnut on one site (Schlesinger and Williams 1984), so it was included in our study. Although black locust stimulates walnut growth (Finn 1953), it is unsuitable for mixed plantings because it rapidly outgrows and suppresses walnut on most sites. Siberian peashrub (Caragana arborescens Lam.) is potentially a suitable tree legume to use in place of black locust in mixed plantings. Autumn olive, an actinorhizal shrub, was included because it has been beneficial on the widest range of sites (Schlesinger and Williams 1984). However, because autumn olive is developing into a major plant pest (Ebinger and Lehnen 1980), we also included Russian olive (E. angustifolia L.), another shrubby actinorhizal tree with many of the same growth characteristics as autumn olive.

MATERIALS AND METHODS

Black walnut plantations were established on a bottomland and an upland site in 1978 at the Macon County Conservation District south of Decatur, Illinois (89° 01' west, 39° 50' north). The bottomland plantation was established on a corn field located in the Sangamon River floodplain. The soils are of the Lawson silt loam series (fine-silty, mixed, mesic Cumulic Hapludolls). These soils are somewhat poorly drained, having a silt loam surface layer over a silt clay loam subsoil and are considered questionable for walnut (Losche et al. 1980).

The upland plantation was established in a red clover-bromegrass hayfield on an upland flat. The upland soils are of the Birkbeck silt loam series (fine-silty, mixed, mesic Typic Hapludalfs). These soils are somewhat poorly to moderately well drained, having a silt loam surface layer and a silty clay loam subsoil, and are considered suitable for walnut (Losche et al. 1980).

Both plantations were established in a randomized complete block design consisting of four blocks and five treatment plots. Treatments were mixed plantings of walnut with European alder, Russian olive, autumn olive, Siberian peashrub, or additional walnut (check). Each plot is 18 x 21 m and was planted with 1-0 nursery-grown walnuts 6 m apart within rows and 3 m between rows using a diamond-shaped pattern so that the walnut-to-walnut distance is 4.2 m. Nurse-crop seedlings were planted between the walnuts within each row to achieve a 3 x 3 m overall spacing in a 1:1 mixture of walnut to nurse-crop trees. In the check plot (pure walnut), additional walnut seedlings were planted as the nurse-crop trees and were analyzed as a nurse crop. Missing trees for all species were replaced annually for the first four growing seasons.

Weeds were controlled for the first 4 years by spot spraying a mixture of glyphosate (2.5 l a.i. per ha) and simazine (2.2 kg a.i. per ha) in 1.5-m-diameter circles around each tree. Due to sensitivity of European alder to herbicides, weeds around the alders were controlled by placing 1.2-m-wide black plastic squares around each tree. The plantations were mowed annually in July and again each fall.

At the end of each growing season since 1978, height and basal diameter (3 cm above soil line) were measured for the interior 20 trees in each plot. One composite core soil sample 0 to 25 cm deep was taken from each plot, dried at 60° C, and ground to pass a 500-μ mesh sieve. Soil samples were analyzed for pH with a glass electrode in a 2:1 mixture of distilled water and soil; for nitrate nitrogen and phosphorus using colorimetric procedures; and for potassium, calcium, and magnesium by atomic absorption spectrophotometry.

During late June of each growing season since 1980, we measured the crown diameter along the cardinal directions for the interior 20 trees (10 walnuts and 10 nurse plants) in each plot. Coverage of the major plant species in the understory vegetation was visually estimated annually for the interior of each plot and adjusted so that total coverage of all species plus any litter-covered ground added up to 100 percent. For analysis, these data were pooled into one of five categories--legumes, composites from the tribe Astereae, all other forbs, tall fescue, and the other grasses. All the legumes were pooled because of their potential to fix nitrogen. All composites in the tribe Astereae were combined because this tribe contains most of the forbs known to be allelopathic to hardwoods (Fisher 1980). Tall fescue was analyzed separately from the other grasses because it usually becomes the predominant ground cover in most pure walnut plantations, and because it is capable of producing phytotoxins that inhibit walnut growth (Rink and Van Sambeek, in press).

Composite foliar samples were collected in late June from five walnuts and from five nurse trees in each plot, dried at 60° C, and ground in a Wiley mill to pass a 500-μ mesh sieve. We analyzed foliar samples for total nitrogen using the Kjeldahl procedure; for phosphorus using colorimetric procedures; and for potassium, calcium, and magnesium using atomic absorption spectrophotometry.

Data were summarized annually to determine mean plot values and were subjected to variance and correlation analyses. Comparisons among means were made with Duncan's new multiple-range test and, in some cases, the least significant difference test for planned comparisons. An alpha = 0.10 level was chosen because we were looking for early indications of nurse-crop treatment differences and were willing to accept a high probability of making a type II error. Individual tree data for the principal crop and the nurse crop were averaged annually to determine plot means for crown diameter, area, and volume; height and height growth; and basal diameter and diameter growth. Individual tree crown volumes were estimated as ellipsoids of revolution about the tree height or 4/3 (π) (height/2) (mean crown radius^2).

Survival was calculated in terms of the number of years that the original seedlings and the replants survived. For example, the survival for five growing seasons included the original seedlings alive at the end of the 5th year after planting, 2nd-year replants alive at the end of the 6th year, and 3rd-year replants alive at the end of the 7th year. This procedure provided a measure of how

difficult it was to establish and maintain the nurse crops.

The average walnut height growth rate for each plot from the second through the fourth growing seasons (the period before nurse-crop effects would be expected) was used as a covariable to adjust for differences in initial growth rates. Data from annual nutrient analyses and vegetation surveys, before and after nurse-crop treatment effects were found in walnut height growth, were averaged together and were subjected to separate analysis of variance. Because of the wide range of values among plots at both locations for most variables, simple correlation coefficients were run for each location using plot means and tested at the alpha = 0.1 level.

Micrometeorological equipment was set up on the upland site in 1981 in one plot of each nurse-crop treatment to record: soil temperatures at depths of 5, 10, and 20 cm; air temperature below walnut crown (stem-space); wind speed at the average height of the trees the previous fall; and relative humidity at 50 to 70 cm. Solar radiation and precipitation were recorded near the center of the micrometeorology study area.

RESULTS AND DISCUSSION

Walnut Performance

Walnut survival on the bottomland area exceeded that on the upland flat (table 1). Survival on the bottomland averaged 94 percent after the first growing season and 93 percent after seven growing seasons. Walnut survival on the upland flat averaged only 89 percent after the first growing season and slowly declined to 79 percent after seven growing seasons. No differences in walnut survival due to nurse-crop treatment occurred at either location.

TABLE 1. Walnut survival in the bottomland and upland plantations during the first seven growing seasons.

Plantation	Growing season 1	2	3	4	5	6	7
	- - - - - - - -			%	- - - - - - - -		
Bottomland	94	94	94	94	94	93	93
Upland	89	85	84	82	81	79	79

Differences in walnut height and diameter growth among plots within and among blocks were found after the third and fourth growing seasons in both plantations due, apparently, to unforeseen site variation. Average walnut height growth for the second through the fourth growing seasons ranged from 30 to 54 cm among plots in the bottomland plantation. Similarly, average walnut height growth for the same period ranged from 9 to 31 cm among plots in the upland plantation.

For the bottomland plantation, walnut height growth, after adjusting for these initial differences, was greater in the European alder-walnut plantings than in the pure walnut plantings in 1983 and 1984 (table 2). During the last 3 years, black walnut height growth in mixture with European alder was 36 percent greater than in pure walnut plots. For walnut interplanted with Russian olive, autumn olive, and peashrub, growth was 14, 1, and 0 percent greater, respectively. After seven growing seasons, only the walnut interplanted with European alder was significantly taller than the walnut interplanted with peashrub.

TABLE 2. Annual walnut height growth for fifth, sixth, and seventh growing seasons, and total height after seven growing seasons.[1]

Nurse crop treatment	Walnut height growth 1982	1983	1984	Total height
	- - - -	cm	- - - - -	
Bottomland Plantation				
European alder	47 a	50 a	52 a	310 a
Russian olive	50 a	33 b	42 ab	284 ab
Autumn olive	36 b	29 b	56 ab	268 ab
Peashrub	38 ab	29 b	36 b	262 b
Pure walnut	46 a	31 b	32 b	274 ab
Upland Plantation				
European alder	16 ab	5 a	11 a	136 a
Russian olive	20 a	3 a	8 a	134 a
Autumn olive	16 ab	7 a	11 a	131 a
Peashrub	12 b	3 a	9 a	122 a
Pure walnut	15 ab	2 a	2 a	116 a

[1]Adjusted means within same column and plantation followed by same letter are not significantly different at the alpha = 0.1 level.

For the upland plantation, walnut height growth, after adjusting for initial growth differences before 1982, ranged from less than 3 cm in the pure walnut plots during 1983 to still only 20 cm for walnut mixed with Russian olive in 1982 (table 2). Height growth of walnut mixed with Russian olive exceeded that of mixed walnut with peashrub in 1982; however, this pattern did not continue during the droughty years of 1983 and 1984. Nevertheless, average height growth of walnut during the last 3 years has been slightly greater in all the mixed plantings than in the pure walnut plots. Likewise, total height after 7 years is greater, although not statistically so, in all the mixed plantings than in the pure walnut plots.

The overall growth of walnut, especially on the upland site, has been much less than usual for this species. In the Decatur area, normal annual precipitation is 100 cm with about 60 cm occurring during the growing season (April 1 through September 30). Average maximum temperature for July is 25° C. Precipitation during the study period did not deviate greatly from the normal (table 3). The distribution of the rainfall, however, was not uniform. For example, the 1983 growing season had

three periods of 22, 19, and 18 days with no measurable rainfall. Indeed, the 48-day period following a 1.7 cm rain on July 4 until a 1.2 cm rain on August 22 included only 2 days with any rainfall (0.8 and 0.2 cm, respectively). The was combined with maximum temperatures >38° C on 16 days and >31° C on an additional 25 days during the same 48-day period.

TABLE 3. Climatological summary for Decatur, Illinois.[1]

Year	Precipitation[2] Dormant season	Growing season	>0.25 cm	Days with maximum air temperature >31 ° C
	- - - - cm - - - -		No.	No.
1978	42	61	39	44
1979	44	55	31	33
1980	29	44	34	56
1981	22	80*	49*	11*
1982	43	54*	41*	17*
1983	42	56*	29*	84*
1984	61	41*	34*	36*

[1]Data marked with * collected on upland site, other data based on NOAA climatological station 1.6 km NE of upland and 1.5 km E of bottomland plantation

[2]Precipitation during dormant season from October of previous fall through March, during growing season from April through September, and number of days during growing season with precipitation >0.25 cm

Nurse Crop Performance

To be beneficial to the principal species, the nurse-crop species must become established and grow satisfactorily. Seedling survival of nurse-crop walnuts, Russian olive, and peashrub after one growing season was better than for European alder and autumn olive in both plantations (fig. 1). The high mortality of European alder may be due to the use of rooted cuttings taken from three slow-growing alders. Many of these rooted alder cuttings died during the summer of 1978; those that died or failed to grow were removed and replaced with 1-0 nursery-grown seedlings in subsequent years. We cannot explain the unusually high mortality of the autumn olive seedlings planted in 1978.

Once established, nurse-crop walnuts and European alder have persisted on the bottomland area; however, additional peashrub, Russian olive, and autumn olive have died each year (fig. 1). On the upland site, nurse-crop walnuts, Russian olive, and peashrub have persisted, while both autumn olive and European alder showed additional annual mortality. Autumn olive and, to a lesser extent, Russian olive showed extensive dieback and increased mortality following the winter of 1983-1984 on both sites. We believe this resulted from a combination of the 1983 summer drought, an abnormally cold

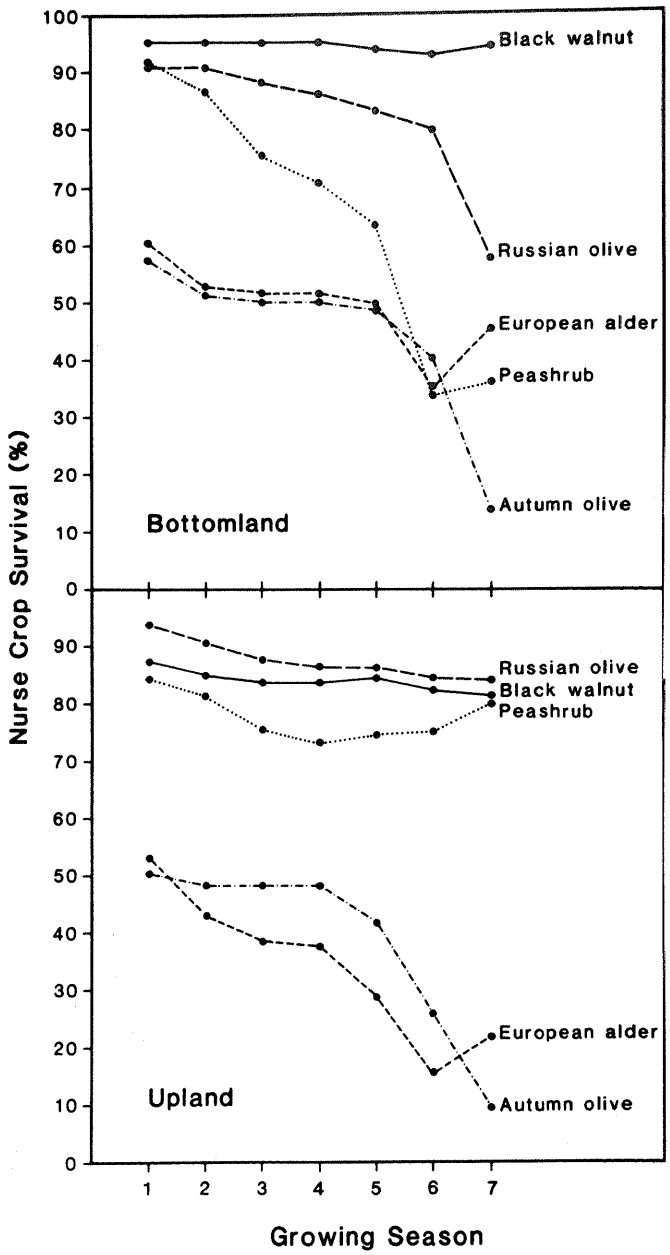

FIGURE 1. Survival of nurse-crop plants on the bottomland and upland plantations after indicated number of growing seasons.

winter, and an unidentified disease characterized by numerous bleeding stem cankers.

We expected that crown volume of the nurse-crop trees would be most closely related to the effects of nurse plants on walnut growth, especially if benefits are related to nutrient cycling. On the bottomland, initial plot crown volumes for walnut exceeded those for all the nurse crops except Russian olive (fig. 2). After the 5th year, plot crown volume for the European alder was also greater than that for walnut. Fewer than 32 percent of the European alder planted in 1978 and replanted in 1979 have survived; thus, the European alder-walnut plantings were essentially established in the spring

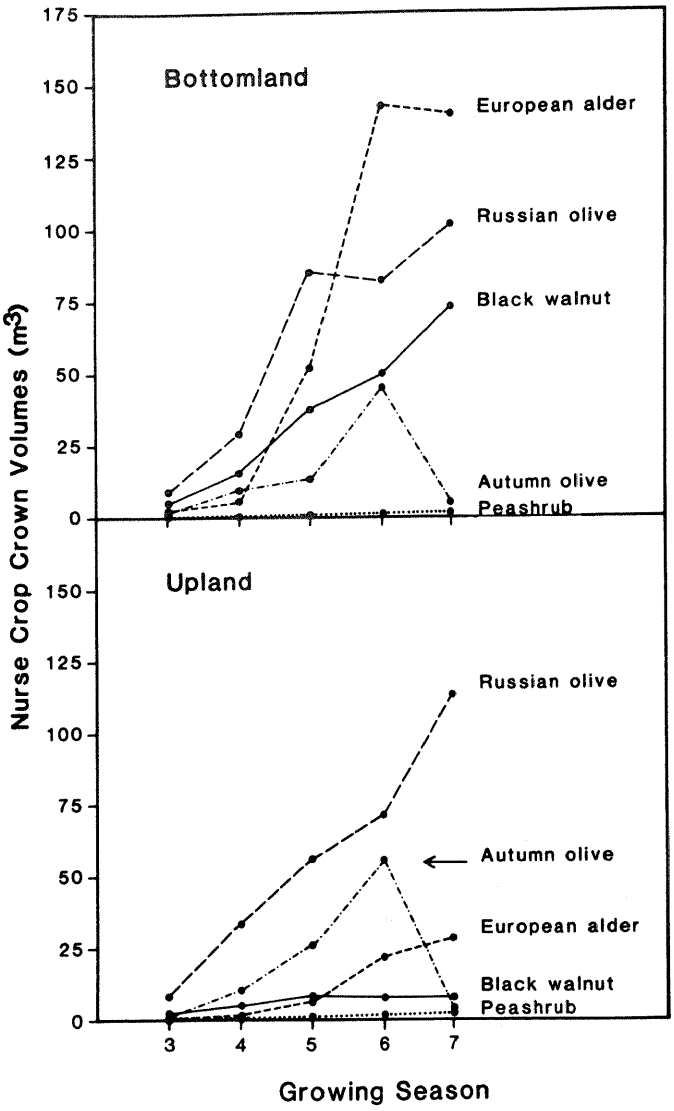

FIGURE 2. Average total crown volume for the interior ten nurse-crop plants on the bottomland and upland plantations for the third to seventh growing seasons.

of 1980. If 1-0 European alder planting stock had been used in the spring of 1978, we might have seen a pattern for crown volume similar to that for Russian olive and the overtopping of the walnut usually encountered with European alder.

Plot crown volumes for Russian olive, autumn olive, and peashrub in the upland plantation have followed a pattern similar to that in the bottomland (fig. 2). Crowns of European alder and nurse-crop walnuts have developed much slower on the upland site than on the bottomland area. Crown development of the peashrub has been extremely slow at both sites. Most of the surviving peashrub have a compact, cylindrical shape with multiple upright stems and few, if any, branches. Average plot crown volumes for peashrub after 7 years are 1.5 and 0.7 m^3 on the bottomland and upland sites, respectively.

Although foliage samples from each nurse crop were collected and analyzed, litterfall was not determined; therefore, nutrients returned to the soil could not be estimated. Dawson and Funk (1981) showed that only a small percentage of the European alder leaf nitrogen is retranslocated back into the stem in the fall compared to most deciduous trees. Assuming this is also true for the other nitrogen-fixing trees, the amount of nitrogen being cycled would be a function of the product of the percent foliar nitrogen in the nurse crops and their crown volumes. Similar indices can be calculated for the other foliar nutrients, especially if they are not readily retranslocated within the plants.

Crowns have not closed in any of the treatments at either plantation. Actual crown area coverage in the 180 m^2 plots ranges from 115 m^2 for the European alder-walnut plantings to 56 m^2 for the autumn olive-walnut plantings on the bottomland area. In the upland plantation, actual crown area coverage ranges from 55 m^2 for Russian olive-walnut plantings to 9 m^2 for the peashrub-walnut plantings. As crowns begin to close, we can expect more differences in the microenvironmental parameters and in the ground cover.

Factors Affecting Walnut Height Growth

By definition, a nurse-crop species should increase the survival, growth, and/or quality of the primary crop species. If benefits to the primary crop species can be detected, it then becomes important to determine what characteristics of the nurse crops are responsible for these benefits. We have not yet detected any meaningful differences in walnut height growth due to nurse crops on the upland site, so data from this plantation were not used in our analyses of the characteristics of nurse crops responsible for the benefits observed in the bottomland plantation. We expect, however, the nurse crops will have a detectable effect on walnut growth on the upland flat within the next couple of years. The micrometeorological equipment was placed on the upland site because we observed more pronounced nurse-crop effects on an upland in an earlier study (Schlesinger and Williams 1984). At this time, we have not found any microenvironmental changes due to nurse-crop species for soil or stem-space temperature, air movement, or relative humidity within the plots.

Before any nurse-crop effects on height growth were found on the bottomland area, we observed wide variation in walnut growth among plots. Correlation analyses between the walnut growth responses and 28 other variables being examined during the period 1978 to 1982 showed that only two were correlated with walnut growth. They were the percentage of ground covered by composites of the tribe Astereae ($r = 0.437$) and percentage of ground covered by tall fescue ($r = -0.452$). Following detection of nurse-crop effects on walnut growth in 1982, 7 of the 28 variables were correlated with walnut growth--percent foliar nitrogen in walnut foliage ($r = 0.500$), an estimate of the nitrogen and calcium in the nurse-crop foliage ($r = 0.385$

and 0.487, respectively), the soil pH (r = -0.693), the percentage of ground covered by legumes (r = 0.399), the percentage of ground covered by composites in the tribe Astereae (r = 0.419), and the percentage of ground covered by tall fescue (r = -0.547).

The seven variables correlated with walnut growth on the bottomland area were then examined to see if changes in these variables were related to the nurse-crop treatments. European alder and Russian olive have significantly increased the walnut foliar nitrogen compared to that of nurse-crop walnuts in the pure plots (table 4). Because of the high foliar nitrogen levels and large average crown volumes of European alder and Russian olive (table 4), we could expect to see either a decrease in the total soil nitrogen if the nurse crops are acting as a sink or potentially an increase if they are fixing nitrogen. Analysis of soil samples taken from the 0- to 25-cm layer showed no differences in nitrate nitrogen due to the nurse crop. This, however, may be due to fluctuations in the nitrate pool or our sampling method. Differences in soil nitrate, when they occur, are usually more apparent near the soil surface and diminish with increasing depth. Hansen and Dawson (1982) found that the mean total soil nitrogen decreased by more than 50 percent between sampling depths of 0-4 cm and 8-12 cm from the soil surface in a young European alder plantation. Similar differences in soil nitrogen between soil depths were found in another mixed planting in southern Illinois (Friedrich and Dawson 1984).

TABLE 4. Factors correlated with nurse-crop effect on walnut height growth from 1982 to 1984.

Nurse crop treatment	Change in walnut foliar nitrogen[1]	Nurse crop[2] Foliar nitrogen	Nurse crop[2] Foliar calcium	Crown volume
	- - - - -	mg/g - - - - - -		m^3
European alder	6.4	32.8	12.1	112
Russian olive	5.7	42.3	11.0	90
Autumn olive	4.1	38.4	9.3	22
Peashrub	1.5	34.4	10.4	1
Pure walnut	1.2	26.8	13.0	54

[1]Differences in average foliar nitrogen before (1980 and 1981) and after (1982, 1983, and 1984) nurse-crop effects were found on walnut growth. The least significant difference is 3.1 mg/g

[2]Values are averages from 1982, 1983, and 1984

Although differences in the estimated amount of calcium being cycled in the European alder-walnut and Russian olive-walnut plantings were higher than those for the pure walnut plots, these differences were not reflected in increased calcium concentrations in either the walnut leaves or the soil samples. Changes in soil pH and average ground covered by legumes, composites of the tribe Astereae, and tall fescue were apparently in response to factors other than nurse-crop treatments.

Because micrometeorological equipment was not placed in the bottomland plantation, we do not know if the nurse crops are influencing the microenvironment. In addition, we did not examine the incidence and severity of foliar pathogens and their relation to walnut growth and nurse crops.

Although nurse-crop effects on walnut growth were found after the fifth growing season in the bottomland plantation, we cannot explain why walnut benefitted from the association with European alder, Russian olive, and, potentially, autumn olive. Siberian peashrub was not a suitable tree legume for planting with walnut. Russian olive appears to be a suitable alternative to autumn olive for the northern part of the walnut range. Increased growth of walnut was correlated with high nitrogen levels in the walnut foliage and with estimated amounts of nitrogen being cycled through the European alder and Russian olive foliage. No differences related to nurse crop were found in soil chemical composition or ground cover competition.

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