Interplanting Woody Nurse Crops Promotes Differential Growth of Black Walnut Saplings

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Abstract: Interplanting black walnut (*Juglans nigra*) with four different nitrogen fixing, woody nurse crops (*Alnus glutinosa, Elaeagnus umbellata, E. angustifolia* or *Caragana arborescens*) increased annual walnut height and stem diameter (dbh) growth overall by as much as 50% and doubled or tripled crown volume compared to all-walnut check plots during a 14-year period after plantation establishment. Walnut interplanted with non-nitrogen fixing, woody nurse crops (*Lonicera maackii, Acer ginnala,* or *Pinus sylvestris*) in a companion experiment of 12 years duration did not grow significantly more than walnut in check plots. Experimental plantings were established adjacent to one another in 1978 and 1980 in central Illinois. A split-split plot design divided by replications and sites was employed in both experiments with equal numbers of walnut and the interplanted nurse species intermixed alternately at a 3 x 3-m overall spacing in plots. Walnut trees at a floodplain site had less mortality and significantly greater growth than walnut trees at an upland site. Results indicate that nitrogen fixing nurse crops can be superior to non-nitrogen fixing nurse crops in promoting walnut growth, specifically confirming the possible importance of nitrogen fixation relative to other nurse crop benefits in promoting walnut growth on sites considered good to marginal for black walnut.

INTRODUCTION

The wood of black walnut (*Juglans nigra* L.) is highly esteemed for its rich brown color and pleasing luster. Black walnut trees also produce edible nut meats and shells used as an abrasive in industrial processes. There is a strong and increasing interest in planting black walnut seedlings both within and ouside of its native range. Black walnut requires deep, well-drained, fertile soils with high moisture availabiliy for optimal commercial growth (Losche 1973, Ponder 1980). Wind protection also significantlty improves growth of black walnut seedlings (Heiligmann and Schneider 1975). It follows that black walnut growth does in fact vary greatly with soil properties, associated vegetation, and topography together with climate, cultural practises, insects, and diseases (Williams 1990).

One promising technique for improving walnut growth in plantations is the use of woody nurse crops. Nurse crops are plants intended to foster another, generally more important crop (Ford-Robertson 1971). Nurse crops can affect walnut growth by altering soil properties, microclimatic conditions, associated vegetation, and interactions with disease organisms and insects (Schlesinger and Williams 1984). Nitrogen-fixing nurse crops have been reported to improve growth of black walnut on a range of sites in the midwestern United States and the benefits of interplanting seem to be inversely related to site productivity for walnut alone (Schlesinger and Williams 1984). Nitrogen fixed symbiotically by bacteria in root nodules of nitrogen-fixing plants probably becomes available to associated plants when soil is enriched by inputs of nitrogen rich

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litter and sloughed root tissue from the nitrogen-fixing plant (Friedrich and Dawson 1984). Non-nitrogen fixing conifers (von Althen and Nolan 1988) and woody angiosperms have also improved walnut growth through interplanting (von Althen 1989).

The mechanisms responsible for increased walnut growth in these complex, mixed silvicultural systems are not precisely known. Particularly lacking is site-specific information on the importance of nitrogen-fixation by a woody nurse crop relative to wind-protection and other interplanting benefits afforded equally by non-nitrogen fixing nurse crops. We address this question by providing information on walnut growth at two contrasting locations in central Illinois in replicated interplantings with nitrogen-fixing black alder (*Alnus glutinosa* [L.] Gaertn.), autumn olive (*Elaeagnus umbellata* Thunb.), Russian olive (*Elaeagnus angustifolia* L.), or Siberian pea shrub (*Caragana arborescens* Lam.), as well as with non-nitrogen fixing Amur honeysuckle (*Lonicera maackii* Maxim.), Ginnala maple (*Acer ginnala* Maxim.), Scots pine (*Pinus sylvestris* L.), or walnut check plots.

MATERIALS AND METHODS

Black walnut interplantings were established on a bottomland and an upland site in 1978 and 1980 at the Macon County Conservation District south of Decatur, Illinois (89o 01' west, 39o 50' north). The bottomland plantation was established on an agricultural field located in the Sangamon River floodplain. The soil is of the Lawson silt loam series and is a fine silty mixed mesic Cumulic Hapludoll (Carroll County Soil Survey 1975). This Mollisol has somehat poor internal drainage, having a silt loam surface layer and a silt clay loam subsoil. Because of the poor internal drainage these soils have been considered questionable for walnut (Losche *et al.* 1980), but otherwise are fertile with a high available water capacity. In the summer of 1991, understory vegetation on the bottomland site consisted primarily of perennial forbs with tall fescue invading from roadbanks along two sides.

The upland plantation was established in a hayfield on an upland flat. The upland soil is of the Birkbeck silt loam series, a fine silty mixed mesic Typic Hapludalfs (Champaign County Soil Survey 1982). This Alfisol is somewhat poorly to moderately well drained, having a silt loam surface layer and a silty clay loam subsoil, and have been considered suitable for supporting walnut growth (Losche et al. 1980). In the summer of 1991, understory vegetation on the upland site consisted of either a tall fescue or bromegrass sod with few annual or perennial forbs.

A split-split plot experimental design was used with treatment plots split by site and by replication. There were two sites and four plot replications per treatment. Treatments in the first experiment established in 1978 were mixed plantings of black alder, autumn olive, Russian olive, or Siberian pea shrub with black walnut plus a control treatment in which walnut trees were planted as the nurse-crop. The 1980 experiment was located adjacent to the 1978 experimental planting and consisted of Amur honeysuckle, Ginnala maple, or Scots pine interplanted with walnut plus a control treatment in which walnut trees were planted in the same manner as the nurse-crops. Each plot was 18 x 21 m and was planted with one-year-old nursery-grown walnuts spaced 6 m apart within rows and 3 m between rows using staggered rows so that walnuts were 4.2 m equidistant in a diamond configuration. Nurse-crop seedlings were planted between the walnuts in each row to achieve a 3 x 3 m overall spacing in a 1:1 ratio of walnut to nurse-crop seedlings. In the walnut check plots additional walnut seedlings were planted in place of the nurse-crop trees and were treated as nurse trees in statistical analyses.

Black alder, autumn olive, and Russian olive are actinorhizal (nodulated by the actinomycete *Frankia*), nitrogen-fixing host plants. Siberian pea shrub is a woody legume nodulated by rhizobial soil bacteria. The non-nitrogen fixing species were selected to approximate the form and growth rate of autumn olive or to provide year-around shading and wind protection.

Weeds were controlled for the first three years by directed spraying of a mixture of glyphosate (2.5 l active ingredient per ha) and simazine (2.2 kg active ingredient per ha) in 1.5-m-diameter circles around each seedling. Weeds around black alder trees were controlled by placing 1.2-m-wide black plastic squares around each tree due to the sensitivity of this species to herbicide. The plantations were mowed annually in July and again each autumn.

At the end of the 1991 growing season, total height and stem diameter at breast height (1.3 m) for the 10 interior walnut and the associated 10 interior interplanted trees, if they possessed a predominant or single main stem, were measured in each treatment plot. This allowed for a border row around each plot. We also measured the crown diameter along the cardinal directions for the interior 20 trees to provide another growth parameter particularly for the predominantly multistemmed, shrubby interplantings. Missing trees were tallied for estimating survival of woody plantings. Individual crown volumes were estimated as ellipsoids of revolution about the tree height or $4/3\ \pi$ (height/2) (mean crown radius^2).

Data for mean walnut height and stem diameter at breast height (dbh) annual growth rates were subjected to variance analyses together with means for estimated crown volume. The mean squares for the replication by site interaction were used as an error term in order to adjust for sampling error. The 1978 and 1980 data were analyzed as separate experiments, both of which employed a split-split plot experimental design. The generalized least-squares method of the Statistical Analysis System (SAS Institute Inc. 1985) was employed in order to adjust for unequal numbers of experimental units due to mortality. Comparisons among treatment and site plot means were made with Duncan's new multiple range test.

RESULTS AND DISCUSSION

Analysis of variance for the 1978 experiment with interplanted nitrogen fixing woody species as treatments indicated that both interplanting treatment and site contributed significantly to overall variation for all walnut growth variables ($P = 0.01$). Treatment by site interaction was significant only in the case of crown volumes, with the relative differences among crown volume means for treatments being much greater on bottomland than on upland sites. Linear correlation coefficients indicate that the experimental model accounted for 93% of the total variation in annual walnut height growth, 98% of the total variation in annual walnut dbh increment, and 93% of the total variation in walnut crown volume. Comparison of treatment and site means indicates that walnut interplanted with nitrogen fixing trees and shrubs grew significantly more than walnut in check plots with additional walnut in place of other interplantings (Table 1). Black alder and Russian olive promoted walnut growth better than autumn olive or Siberian pea shrub in cental Illinois. Walnut growth on the bottomland site was significantly greater than walnut growth on the upland site (Table 2).

Table 1.—Overall differences among interplanting treatments in mean annual height growth, annual dbh increment, and estimated crown volume of walnut trees for the 1978 experiment (14-y-old trees) employing nitrogen fixing interplantings. Whole plot mean values are used to calculate treatment mean differences in the split-split plot design (n=8).

Interplanted species	Annual ht increment (m)	Annual dbh increment (cm)	Crown volume (m^3)
Alder	0.42 a*	0.57 a	35.94 a
Rus. olive	0.36 a	0.56 a	34.77 a
Aut. olive	0.29 b	0.46 b	27.48 a
Pea shrub	0.29 b	0.45 b	28.50 a
Walnut	0.23 b	0.35 c	12.15 b

* Means in a column followed by the same letter are not significantly different (P = 0.05).

Table 2.—Overall differences between upland and bottomland sites in mean annual height growth, annual dbh increment, and estimated crown volume of walnut trees for 1978 experiment (n=20)

Topographic position	Annual ht increment (m)	Annual dbh increment (cm)	Crown volume (m^3)
Upland	0.15 a*	0.15 a	1.88 a
Bottomland	0.48 b	0.80 b	53.66 b

* Means in a column followed by the same letter are not significantly different (P = 0.01).

In the 1980 experiment employing interplanted woody plants of species incapable of nitrogen fixation as treatments, the interplanted species did not contribute significantly to overall variation for any walnut growth variable, whereas site contributed significantly to overall variation of all walnut growth variables (P = 0.01). Linear correlation coefficients indicate that the experimental model accounted for 89% of the total variation in annual walnut height growth, 87% of the total variation in annual walnut dbh increment, and 75% of the total variation in walnut crown volume. Treatment mean comparisons illustrate the similarity among growth-variable means of walnut where trees and shrubs incapable of nitrogen fixation were the interplanting treatments (Table 3). There was a pronounced difference in walnut growth between upland and bottomland sites as in the 1978 experiment (Table 4). There was little difference in mean values for walnut growth in check plots between the 1978 and 1980 experimental plantings (Tables 1 and 3).

Table 3.—Overall differences among interplanting treatments in mean annual height growth, annual dbh increment, and estimated crown volume of walnut trees for the 1980 experiment (12-y-old trees) employing interplantings incapable of nitrogen fixation. Whole plot mean values are used to calculate treatment mean differences in the split-split plot design (n=8).

Interplanted species	**Annual ht increment (m)**	**Annual dbh increment (cm)**	**Crown volume (m^3)**
Scots pine	0.28 a*	0.40 a	12.22 a
Amur maple	0.24 a	0.33 a	11.37 a
Honeysuckle	0.24 a	0.34 a	14.17 a
Walnut	0.24 a	0.36 a	9.02 a

* Means in a column followed by the same letter are not significantly different (P = 0.05).

Table 4.—Overall differences between upland and bottomland sites in mean annual height growth, annual dbh increment, and estimated crown volume of walnut trees for 1980 experiment (n=20)

Topographic position	**Annual ht increment (m)**	**Annual dbh increment (cm)**	**Crown volume (m^3)**
Upland	0.09 a*	0.11 a	0.22 a
Bottomland	0.40 b	0.58 b	23.17 b

* Means in a column followed by the same letter are not significantly different (P = 0.01).

Walnuts interplanted with woody, nitrogen-fixing nurse crops were 30 to 50% taller and had more than twice the mean value for crown volume on a floodplain site than did walnuts interplanted with non-nitrogen fixing woody plants or in pure walnut plantings with walnut substituted for a nurse crop (Table 5). Walnut mortality was low on this bottomland site, but interplanted autumn olive, Russian olive, Siberian pea shrub, and Scots pine, which survive and grow better under drier soil conditions, had high mortality. Mortality of black alder, which characteristically tolerates moist soil conditions, was also high on the bottomland site. Black alder is particularly sensitive to walnut's allelochemical juglone (Rietveld 1983, Rietveld *et al.* 1983).

Walnut survival and growth on the upland site were less than on the bottomland site (Table 6). Height and diameter growth of walnut on the upland site were greatest where walnut trees were interplanted with nitrogen-fixing trees that also possessed large crown volumes, indicative of an ability to afford shelter. Large crown volumes would also indicate a higher capacity to fix nitrogen, since nodular nitrogen fixation is closely related to the amount of host-plant leaf tissue providing

Table 5.—Mean survival percentage and dimensions of 12- to 14-year-old walnut trees and nurse trees interplanted in equal proportions in floodplain plots with 3 x 3-m spacing

Paired species	Survival % (initial no.)	Height (m)	Dbh (cm)	Crown volume (m^3)
Alder	7 (40)	5.95	5.3	23.59
Walnut	00 (40)	7.50	4.5	45.35
Aut. olive	30 (40)	2.64	-	11.21
Walnut	100 (40)	6.48	4.5	49.00
Rus. olive	7 (40)	4.30	2.8	29.13
Walnut	95 (40)	7.44	4.3	52.10
Pea shrub	40 (40)	1.70	1.2	0.50
Walnut	100 (40)	6.52	3.6	48.51
Honeysuckle	90 (40)	3.51	-	32.25
Walnut	97 (40)	4.80	4.1	20.48
Gin. maple	100 (40)	4.28	-	24.32
Walnut	95 (40)	4.83	4.1	23.11
Scots pine	57 (40)	3.88	4.4	18.38
Walnut	95 (40)	4.90	5.5	21.27
Walnut int.	89 (80)	5.22	5.0	20.98
Walnut	94 (80)	5.09	5.2	20.73

nodular symbionts with photosynthate to support fixation of atmospheric nitrogen (Dawson and Gordon 1979). Middle values for walnut growth occurred in interplantings with nitrogen-fixing trees having smaller crown volumes and in an interplanting with a non-nitrogen fixing tree with a large crown volume. Walnut growth was least on the uplands in check plots of pure walnut and in interplantings with small non-nitrogen fixing trees or shrubs.

Autumn olive, Russian olive, Siberian pea shrub, and Scots pine all survived and grew better on the drier, upland site than on the floodplain site. However autumn olive survival was only 50% even on the more-favorable upland site. It is common knowledge that locally-available autumn olive genotypes lack cold hardiness at this latitude in central North America. Black alder survival was greater on the upland site, perhaps because the growth and survival of interplanted walnuts, hence their probable capacity to release juglone into the soil, were less than on the bottomland site.

Growth of black walnut in the bottomland plots was at least three times greater overall than walnuts in the upland plots (Tables 2 and 4). Early detection of increased walnut growth associated with this experimental interplanting was possible only at the bottomland site (Van Sambeek *et al.* 1985) where only the walnut interplanted with alder had begun to significantly differentiate from any of the other interplanting treatments during the fifth, sixth, and seventh growing seasons.

Table 6.—Mean survival percentage and dimensions of 12- to 14-year-old walnut trees and nurse trees interplanted in equal proportions in upland plots with 3 x 3-m spacing

Paired species	**Survival % (initial no.)**	**Height (m)**	**Dbh (cm)**	**Crown volume (m^3)**
Alder	88 (40)	7.09	5.3	51.54
Walnut	77 (40)	3.79	2.9	4.25
Aut. olive	50 (40)	2.72	-	18.30
Walnut	77 (40)	1.61	1.7	1.08
Rus. olive	85 (40)	6.23	5.3	50.12
Walnut	70 (40)	2.83	2.6	3.79
Pea shrub	92 (40)	1.61	1.4	1.04
Walnut	57 (40)	1.22	1.3	0.56
Honeysuckle	50 (40)	1.68	-	2.22
Walnut	77 (40)	0.88	1.1	0.07
Amur maple	95 (40)	2.70	-	6.74
Walnut	70 (40)	1.04	1.1	0.25
Scots pine	92 (40)	4.58	4.1	43.41
Walnut	57 (40)	1.76	1.7	0.51
Walnut int.	80 (80)	1.13	1.1	0.20
Walnut	70 (80)	1.06	1.0	0.28

In bottomland plots the four nitrogen-fixing species were superior to the other interplanted nurse crops and the walnut check plantings in promoting walnut growth. In the upland plots alder promoted walnut growth to a greater extent than did Russian olive, autumn olive or Siberian pea shrub. The difference in the ability of bottomland and upland Russian olive interplantings to promote walnut growth relative to black alder may be due to the absence of actinorhizal nodules on Russian olive on the upland site, while Russian olive trees on the bottomland site and alder on both sites were nodulated and fixing nitrogen (Zitzer and Dawson 1989). Siberian pea shrub and autumn olive were observed to be nodulated only on the bottomland site, but were not systematically sampled, tested for nitrogen-fixation activity, nor carefully studied for patterns of nodulation as were the other two nitrogen-fixing species (Zitzer and Dawson 1989, 1992). The upland site had an acidic soil pH of 5.4 compared to a more neutral pH of 6.8 on the bottomland site (Zitzer and Dawson 1992), and pH optima for both actinorhizal and rhizobial nodulation are generally near neutral (Gordon and Wheeler 1983).

It is important to examine host plants capable of symbiotic nitrogen fixation for nodulation and nodule effectivity before assuming that they are symbiotically fixing nitrogen. It is possible for a host plant to have nodules ineffective at fixing nitrogen. It is also possible that a host plant can lack nodules but grow better on a suitable site than nodulated plants on an unsuitable site. In this study bottomland, nodulated Russian olive were visibly less vigorous but apparently better able to promote the growth of associated walnut trees than larger, more-vigorous, but non-nodulated Russian olive at the upland site. Walnut growth was enhanced by woody nurse crops in this study even where there was poor survival of some of the nurse crops after 12 to 14 years. Earlier nurse benefits have probably been carried over in these cases. In fact, death of a nitrogen-fixing tree can accelerate the rate at which fixed nitrogen is released into the soil from host tissue (Dawson *et al.* 1983), and the effects of nitrogen taken up by a tree can last a number of years due to internal nitrogen conservation mechanisms (Kramer and Kozlowski 1979).

In these two experiments, walnut growth is shown to be significantly greater than in check plots only where interplanted with nitrogen-fixing nurse crops (Tables 1 and 3). The difference is particularly distinct for estimated crown volume of walnuts. The experiment employing non-nitrogen fixing nurse treatments was established two years later than the nitrogen-fixing nurse planting experiment. However, the age difference between experiments cannot likely account for differences in experimental results because growth values for check plots established at each of the two planting dates did not differ from one another (Tables 1 and 3). Furthermore, values for walnut check-plot growth in the two experiments are similar not only to one another, but also to the walnut growth values for the non-nitrogen fixing nurse treatments (Tables 1 and 3).

Interplanting black walnut with four different nitrogen fixing, woody nurse crops significantly increased walnut growth, whereas walnut growth was not increased in a companion experiment in which walnut was interplanted with non-nitrogen fixing, woody nurse crops. Walnut trees at a floodplain site had better survival and at least three times the growth overall of walnut trees at an eroded upland site. Nurse species and walnut trees varied in survival, growth and nitrogen fixation ability with site confirming the primary importance of site selection in silviculture. Woody nurse crops capable of symbiotic nitrogen fixation can increase the growth of black walnut trees compared to walnut check plantings and non-nitrogen fixing nurse crops on sites considered good to marginal for black walnut.

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