Forest Ecology and Management, 17 (1986) 159-167
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

Legumes Increase Growth and Alter Foliar Nutrient Levels of Black Walnut Saplings

J.W. VAN SAMBEEK[1], FELIX PONDER, Jr.[1] and W.J. RIETVELD[2]

North Central Forest Experiment Station, Forestry Sciences Laboratory, [1]Carbondale, IL 62901 and [2]Rhinelander, WI 54501 (U.S.A.)

(Accepted 10 June 1986)

ABSTRACT

Van Sambeek, J.W., Ponder, F., Jr. and Rietveld, W.J., 1986. Legumes increase growth and alter foliar nutrient levels of black walnut. *For. Ecol. Manage.*, 17: 159-167.

Differences in herbaceous competition, growth, soil, and foliar nutrient levels were compared for black walnut (*Juglans nigra* L.) saplings growing on an upland and a bottomland site in southern Illinois, with covers of five different herbaceous legumes or naturally occurring forbs. Hairy vetch (*Vicia villosa* Roth.) increased walnut height and diameter growth on both sites when compared to walnut growing in the naturally revegetated plots. Growth trends in the other four covers were mixed. All five legumes suppressed growth of other herbaceous vegetation for one or more summers. Only hairy vetch increased soil nitrate nitrogen after one growing season on both sites. After three growing seasons, crownvetch (*Coronilla varia* L.) and sericea lespedeza (*Lespedeza cuneata* (Dumont) G. Dons.) have increased soil nitrate nitrogen on the upland plantation. Walnut foliar nitrogen concentration was the highest for trees growing in hairy vetch and crownvetch covers after three growing seasons.

INTRODUCTION

Large expenditures of time and money for weed control and fertilization are usually required to achieve rapid height growth of plantation-grown hardwoods such as black walnut (*Juglans nigra* L.). The potential benefits of using legume ground covers to control unwanted vegetation and increase tree growth have received little attention. Legumes seeded into a 2-year-old plantation of sycamore (*Platanus occidentalis* L.) increased both growth and foliar nitrogen levels of the trees (Haines et al., 1978). The survival and early growth of black walnut seedlings can also be significantly affected by the type of herbaceous ground cover (Roth and Mitchell, 1982; Van Sambeek and Rietveld, 1982).

The purpose of this study was to evaluate the effects of herbaceous legumes on the suppression of unwanted herbaceous competition and on black walnut establishment, growth, and foliar nutrient composition. Hardwood seedlings are often planted on lands no longer suitable for cultivation because of severe erosion, low fertility, or both. Although legumes are variable in their nutritional needs, most can become established and grow on such sites because they can fix atmospheric nitrogen. Potentially, hardwood seedlings interplanted with legumes might also benefit from the biologically fixed nitrogen.

METHODS

Two sites in southern Illinois (37° 34′ North latitude, 89° 16′ West longitude) were selected for the study. One was an upland flat that was cleared of abandoned peach trees in 1977. The soils are of the Alford silt loam series (fine-silty, mixed, mesic, Typic Hapludalfs). The other site was a bottomland agricultural field. The soils are of the Haymond silt loam series (coarse-silty, mixed, non-acid, mesic, Typic Udifluvents). Both sites are considered suitable for walnut (Losche et al., 1980).

Both areas were plowed in the spring of 1978 and kept fallow during the summer. Composite soil samples were collected in the summer of 1978 and analyzed for pH and available nutrients. To ensure adequate soil fertility for establishing the legume ground covers, each site was fertilized with 8.2 kg/ha nitrogen, 26.3 kg/ha phosphorus, and 27.2 kg/ha potassium, and limed to a calculated pH of 6.5 by applying 5.5 t/ha lime on upland and 11.0 t/ha on the bottomland prior to final discing and seedbed preparation.

Treatments and experimental design

The experimental design at each planting site was a randomized complete block design with three replications (blocks) each containing 24 plots. In each block, four plots were allowed to revegetate naturally and four plots were seeded to each of the following legumes: (a) hairy vetch (*Vicia villosa* Roth.), a cool-season annual; (b) crownvetch (*Coronilla varia* L.), a cool-season perennial; (c) sericea lespedeza (*Lespedeza cuneata* (Dumont) G. Don.), a warm-season perennial; (d) Korean lespedeza (*Lespedeza stipulacea* Maxim.), a warm-season annual; (e) a mixture of crimson clover (*Trifolium incarnatum* L.), a cool-season annual, and Korean lespedeza. Korean lespedeza did not become established under the heavy stand of crimson clover, so the legume cover type was essentially crimson clover. The cover crops were seeded in the fall of 1978 or the spring of 1979 depending on the species requirements.

One half of the 12 m×18 m study plots at each site were planted with 24

---

t, (metric) tonne=1000 kg.

walnut seedlings on a 3 m$\times$3 m spacing in the spring of 1979, and the other half in the spring of 1980 after cover crops establishment. Herbaceous vegetation was controlled for the first 3 years on half of the study plots at each site by annually applying 6.4 l/ha of glyphosate plus 4.4 kg/ha simazine in a 1.5-m-diameter spot around each walnut seedling. The remaining plots received no chemical weed control.

Data collection and analysis

Height and basal diameter (3 cm above ground line) of the walnut seedlings were measured at the time of outplanting and annually each fall for 3 years. The percentage of each plot covered by dead vegetation and by legumes was estimated annually in late June or early July using the reconnaissance method (Forbes, 1955). After the first growing season, four soil samples were collected randomly at 20- to 25-cm and 40- to 45-cm depths for each cover type within each block and composited for each depth and treatment before being analyzed for pH and nutrients. Soil pH was determined in a 1 : 1 soil-water solution. Nitrate nitrogen and phosphorus were determined colorimetrically. Potassium, calcium, and magnesium were determined by atomic absorption. Walnut leaf samples were collected in late June during the third and fourth growing seasons by removing one exposed mature leaf from the upper crown on each of the eight trees nearest the center of each plot. All leaflets were counted, removed, oven-dried at 60°C, and weighed to determine average dry weight per leaf. Foliage was analyzed for potassium, calcium, and magnesium as above, for phosphorus by the vanadomolybdophosphoric yellow method, for total nitrogen by the Kjeldahl method.

The 3rd-year data presented here are limited to study plots which had 3 years of chemical weed control. Plot means were determined for each variable for each location and were subjected to separate analyses of variance and correlation analyses. Duncan's new multiple range test was used to identify significant differences among treatment means ($\alpha < 0.05$).

RESULTS AND DISCUSSION

Annual ground cover composition

All five legume covers were successfully established at both planting sites. In addition, each legume cover had more of the desired summer plantation ground cover (litter-covered ground + live legumes) than on the naturally vegetated plots for one or more years (Fig. 1). Hairy vetch and crimson clover, both annual legumes, established a uniform cover and suppressed most weeds during the first growing season following seeding. The annual legumes, however, declined in succeeding years because of their failure to reseed. In contrast,

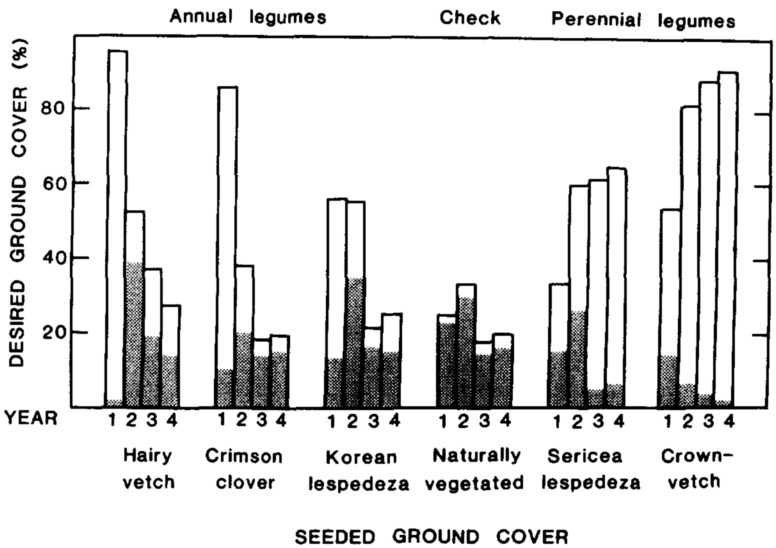

Fig. 1. Percentage of plot covered by dead vegetation (shaded area) and by live legumes (open area) during the first four summers following seeding of legume cover crops.

crownvetch and sericea lespedeza (perennial legumes) were slow to establish but have become increasingly more effective.

Black walnut survival

Overall black walnut survival did not differ between planting sites; however, differences did occur among cover types within each plantation (Table 1). Walnut survival was significantly reduced on the upland area by sericea lespedeza and on the bottomland by Korean lespedeza. Nearly all tree mortality occurred in the first growing season except in the sericea lespedeza and crownvetch plots where mortality continued until the trees were able to overtop the dense ground cover.

Black walnut growth

Tree heights and diameters after 3 years' growth averaged 30 and 37% more, respectively, on the upland than on the bottomland (Table 1). A hairy vetch cover improved walnut height on both sites and was significantly better than crownvetch, sericea lespedeza, and Korean lespedeza covers on the upland and Korean lespedeza and the naturally vegetated covers on the bottomland. Diameter of walnuts in hairy vetch plots significantly exceeded the diameter of walnuts in all other covers except for crownvetch on the bottomland.

On the upland area, 3rd-year walnut height and diameter were positively

TABLE 1

Third-year black walnut survival, height, and basal stem diameter for an upland (U) and bottomland (B) plantation

Cover type	Survival (%)		Height (m)		Basal diameter (cm)	
	U	B	U	B	U	B
Naturally vegetated	92 a	89 a	1.65 ab	1.14 b	3.6 b	2.6 b
Hairy vetch	92 a	90 a	1.94 a	1.42 a	4.6 a	3.2 a
Crownvetch	85 ab	90 a	1.58 b	1.31 ab	3.8 b	2.9 ab
Sericea lespedeza	73 b	78 ab	1.50 b	1.38 a	2.9 c	2.7 b
Korean lespedeza	88 ab	70 b	1.53 b	1.10 b	3.6 b	2.5 b
Crimson clover	88 ab	88 a	1.66 ab	1.23 ab	3.9 b	2.6 b

Means within each column followed by the same letter are not significantly different at the $\alpha = 0.05$ level according to Duncan's new multiple range test.

correlated with the average percentage of ground covered by dead vegetation but not with the percentage of ground covered by legumes (Table 2). In contrast, third-year walnut height and diameter on the bottomland were positively correlated with the percentage of ground covered by legumes, but not with the percentage of ground covered by dead vegetation (Table 2). These correlations suggest that moisture may be more critical for good growth on the upland and is preserved by the litter cover; while on the bottomland, nutrients are apparently more critical, especially those mobilized or fixed by legumes.

Soil nutrient levels

Before planting the cover crops and walnut in 1978, soil macronutrient concentrations on the upland plantation were higher than on the bottomland except for nitrate nitrogen. On the upland plantation, soil nitrate nitrogen, phosphorus, potassium, calcium, and magnesium averaged 33, 68, 329, 4080, and 500 mg/kg, respectively. On the bottomland, soil nitrate nitrogen, phosphorus, potassium, calcium, and magnesium averaged 45, 10, 82, 1810, and 110 mg/kg, respectively. Soil pH after liming averaged 5.26 and 5.28 on the upland and the bottomland plantations, respectively. Three years later only soil pH and nitrate nitrogen have been significantly altered among the cover crop treatments (Table 3). Soil pH under hairy vetch was significantly higher than the pH under Korean lespedeza or crownvetch on the bottomland. No changes in soil pH were found on the upland plantation.

TABLE 2

Pearson's r correlation matrices for the upland site (upper right corner) and the bottomland site (lower left corner)

Variables	HT	BD	%LC	%LL	%SN	L/L	LDW	%FN
				Correlation coefficients for upland plantation				
Height (HT)		0.808	0.363	−0.242	0.135	0.272	0.135	0.125
Basal diameter (BD)	0.795		0.384	−0.169	0.111	0.490	0.452	0.257
% litter-covered ground (%LC)	−0.281	−0.185		−0.813	−0.311	0.207	0.128	0.035
% live legume cover (%LL)	0.370	0.414	−0.742		0.628	−0.223	−0.088	0.255
% soil nitrate nitrogen (%SN)	0.432	0.591	−0.296	0.633		0.053	0.141	0.494
Leaflets per walnut leaf (L/L)	0.096	0.394	0.077	0.060	0.251		0.825	−0.018
Leaflet dry weight per leaf (LDW)	0.310	0.389	−0.031	0.095	0.162	0.771		−0.003
% walnut foliar nitrogen (%FN)	0.187	0.384	0.154	0.170	0.152	0.336	0.192	
		Correlation coefficients for bottomland plantation						

Significance levels: > ±0.330, 5%; > ±0.425, 1% (n=36).

TABLE 3

Soil pH and nitrate nitrogen under six ground covers on the upland (U) and bottomland (B) plantation

Cover type	Soil pH		Soil nitrate nitrogen (mg/kg)			
	After third Growing season		After first growing season		After third growing season	
	U	B	U	B	U	B
Naturally revegetated	5.27 a	5.23 ab	31 b	42 b	29 c	30 b
Hairy vetch	5.30 a	5.39 a	67 a	65 a	79 ab	43 b
Crownvetch	5.23 a	5.17 b	31 b	35 b	94 a	75 a
Sericea lespedeza	5.29 a	5.25 ab	37 b	48 ab	64 b	42 b
Korean lespedeza	5.54 a	5.17 b	33 b	48 ab	34 c	32 b
Crimson clover	5.58 a	5.34 ab	31 b	36 b	34 c	37 b

Means within each column followed by the same letter are not significantly different at the $\alpha=0.05$ level according to Duncan's new multiple range test.

After the first growing season soil nitrate nitrogen concentrations in hairy vetch plots exceeded the average amount in other treatments by 35 mg/kg on the upland and by 23 mg/kg on the bottomland. Although crimson clover formed a dense cover which suppressed all weeds during the spring of 1978, it failed to show any increase in soil nitrate nitrogen in the fall of 1979.

After the third growing season, soil nitrate nitrogen levels on the upland site were significantly higher in the hairy vetch, crownvetch, and sericea lespedeza plots than in the naturally vegetated plots (Table 3). On the bottomland, soil nitrate nitrogen was significantly higher only in crownvetch plots as compared to the amount found in the other plots.

At both plantations, the average soil nitrate nitrogen levels were positively correlated with the summer coverage by live legumes (Table 2). Soil nitrate nitrogen levels were negatively correlated with the percent litter-covered ground on the plots. Walnut height and diameter were positively correlated with both the average soil nitrate nitrogen level and the change in soil nitrate nitrogen following cover crop establishment for the bottomland only. Even though nitrate nitrogen is easily leached and represents only a fraction of the total nitrogen pool, these results indicate that soil nitrate nitrogen can be an important indicator of a site's potential to support black walnut growth.

Black walnut foliar nutrient composition

The average number of leaflets per leaf and their dry weight were higher on the upland than on the bottomland (Table 4). At both plantations the number of leaflets per leaf and leaflet dry weight were positively correlated with the basal diameter of the walnut trees (Table 2). Von Althen (1985) also found that leaf size is a good indicator of potential growth for walnut.

Only walnut growing with either hairy vetch or crownvetch on the upland site had significantly higher foliar nitrogen levels than walnuts growing in the naturally revegetated plots (Table 4). Walnut foliar nitrogen at both sites, however, was positively correlated with the soil nitrate nitrogen levels but not tree height (Table 2). The relatively high foliar nitrogen levels even in the trees growing in the naturally revegetated plots suggest that currently there is an adequate supply of available soil nitrogen at both sites and that differences in walnut growth result from competition for either soil moisture or some other soil nutrient in addition to changes in soil nitrogen levels.

Foliar levels of phosphorus, potassium, calcium, and magnesium were higher in the walnuts on the upland site than on the bottomland site; however, no differences due to cover type were found at either plantation. On the upland, foliar phosphorus, potassium, calcium, and magnesium averged 0.33, 1.28, 1.02, and 0.25%, respectively. On the bottomland, foliar phosphorus, potassium, calcium, and magnesium averaged 0.28, 1.20, 0.87, and 0.18%, respectively.

TABLE 4

Average number of leaflets/leaf, foliar dry weight/leaf, and foliar nitrogen levels in black walnut for the upland (U) and bottomland (B) plantation

Cover types	Leaflets/leaf (#)		Leaflet dry weight/leaf (g)		Foliar nitrogen (%)	
	U	B	U	B	U	B
Naturally vegetated	17.4 ab	16.2 a	2.34 ab	1.95 ab	3.23 b	3.04 a
Hairy vetch	18.1 a	15.7 a	2.76 a	1.83 ab	4.44 a	3.52 a
Crownvetch	17.1 ab	15.1 a	2.43 ab	1.67 ab	4.56 a	3.30 a
Sericea lespedeza	16.2 b	15.5 a	2.04 b	2.00 a	2.93 b	3.20 a
Korean lespedeza	17.6 ab	15.2 a	2.51 ab	1.50 b	3.23 b	3.69 a
Crimson clover	17.3 ab	14.8 a	2.34 ab	1.70 ab	3.33 b	3.03 a

Means within each column followed by the same letter are not significantly different at the $\alpha = 0.05$ level according to Duncan's new multiple range test.

CONCLUSIONS

Herbaceous legumes can stimulate early walnut growth and alter the soil pH and nitrate nitrogen concentrations. Improved walnut growth appears to result from a combination of enhanced nitrogen nutrition and suppression of other vegetation; however, these factors do not account for all the differences observed. Walnut growth was best in treatments with cool-season legumes which increased the percentage of litter-covered ground during the summer and produced comparatively high soil nitrate nitrogen levels.

ACKNOWLEDGMENT

The authors acknowledge the assistance of Danny McBride and Darrell Alley for plantation establishment, Valerie D. Roe for sample collection, Lisa Lambus and Judy Hintze for nutrient analysis, and Dave Polak for data analysis. The authors also wish to thank the Shawnee National Forest and the State of Illinois for providing the planting sites.

REFERENCES

Forbes, R.D. (Editor), 1955. Forest range management. Section 11 in: Forestry Handbook. The Ronald Press Company, New York, pp. 11-1-11-34.

Haines, S.G., Haines, L.W. and White, G., 1978. Leguminous plants increase sycamore growth in northern Alabama. Soil Sci. Soc. Am. J., 42: 130–132.

Losche, C.K., Clark, W.M., Voss, E.E. and Ashley, B.S., 1980. Guide to the selection of soil suitable for growing black walnut in Illinois. Special Publication, Northeastern Area State and Private Forestry, USDA Forest Service, Broomall, PA, 45 pp.

Roth, P.L. and Mitchell, B.J., 1982. Effect of selected cover crops on the growth of black walnut. In: Black Walnut for the Future. USDA For. Serv. Gen. Tech. Rep. NC-74, pp. 110–113.

Van Sambeek, J.W. and Rietveld, W.J., 1982. Leguminous cover crops can suppress weeds and accelerate growth of black walnut seedlings in intensively cultured plantations. In: R.N. Muller (Editor), Proc. 4th Central Hardwood Forest Conference, University of Kentucky, Lexington, KY, pp. 229–243.

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