LEGUME GROUND COVERS ALTER DEFOLIATION RESPONSE OF BLACK WALNUT SAPLINGS TO DROUGHT AND ANTHRACNOSE

J.W. Van Sambeek[1]

ABSTACT.—Growth and premature defoliation of black walnut saplings underplanted 5 or 6 years earlier with six different ground covers were quantified in response to a summer drought or anthracnose. Walnut saplings growing with ground covers of hairy vetch, crownvetch, and to a lesser extent sericea lespedeza continued to have more rapid height and diameter growth than saplings in resident vegetation. Walnut saplings in a dense cover of sericea lespedeza had more rapid defoliation during a summer drought than saplings growing in a ground cover of resident vegetation. During the following year with nearly normal precipitation, walnut saplings growing in ground covers of resident vegetation had more rapid defoliation than walnut saplings underplanted with hairy vetch, crownvetch, and sericea lespedeza. Walnut saplings that had been underplanted with annual legumes that had failed to reseed themselves (crimson clover or Korean lespedeza) had defoliation rates similar to walnut saplings in resident vegetation. Regression analysis with a full first and second-order polynomial indicated that approximately 50 to 70 percent of the variation in the subsequent annual growth increment was a function of premature defoliation and sapling stem diameter, trunk cross-sectional area, or stem volume.

Walnut anthracnose caused by the fungus *Gnomonia leptostyla* (Fr.) Ces. & de Not., is the most significant pathogen found in most black walnut (*Juglans nigra* L.) plantations (Kessler 1984, 1988). Berry (1960) reported that premature defoliation caused by anthracnose can result in reduced tree growth and development of poorly filled, low-quality nuts. Primary infections initiated from ascospores in May under favorable weather produce conidia that produce secondary infections. These infections can multiply rapidly and produce significant defoliation as early as July or August (Black and others 1977, Black and Neely 1978). Todhunter and Beineke (1984) found that the severity of mid-September defoliation, presumably in response to anthracnose, was correlated with annual stem diameter growth but not annual increment in stem height or stem volume. Conversely, Funk and others (1981) found that selection of seed sources with some resistance to anthracnose resulted in a 7 percent increase in height growth.

Neely (1979, 1986) suggested that the incidence or severity of anthracnose can be altered through site modification and increase in foliage nitrogen content. Kessler (1985) found that an overwinter cover of autumn olive leaves reduced the number of ascospores, the primary inoculum, discharged from infected fallen walnut leaves. In addition, nitrogen-fixed and released from autumn olive increases the walnut foliage nitrogen content and reduces walnut susceptibility to secondary infections initiated by conidia released from the primary infections. Use of nitrogen fertilizers can also reduce the severity of anthracnose (Neely 1981).

Underplanting herbaceous legumes in walnut plantations could potentially reduce the severity of anthracnose either in response to increased soil nitrogen or by disrupting ascospore dispersal. Underplanting walnut saplings with annual and perennial legumes has been shown to increase foliage nitrogen content (Van Sambeek

[1] Research Plant Physiologist, USDA Forest Service, North Central Research Station, 202 Natural Resources Building, University of Missouri, Columbia, MO 65211-7260. JWVS is corresponding author: to contact, call (573) 875-5341 extension 233 or e-mail at jvansambeek@fs.fed.us.

Citation for proceedings: Van Sambeek, J. W.; Dawson, J. O.; Ponder, F., Jr.; Loewenstein, E. F.; Fralish, J. S., eds. 2003. Proceedings, 13th Central Hardwood Forest conference; 2002 April 1-3; Urbana, IL. Gen. Tech. Rep. NC-234. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 565 p. [Peer-reviewed paper from oral presentation]

and others 1986). Underplanting herbaceous legumes that defoliate later in the growing season than walnut could also cover and accelerate overwinter decomposition of infected walnut leaves within the litter layer thereby reducing ascospore dispersal in the spring. In contrast, underplanting legumes such as the vetches, which initiate rapid vegetative growth in the spring, would cover the developing perithecia on fallen infected leaves and physically disrupt ascospore dispersal.

Quantifying the incidence and severity of leaf-spotting pathogens can be very time-consuming if the actual numbers of lesions are counted. In addition, premature defoliation of severily-infected leaflets early in the growing season can underestimate abscission rate and severity (Kessler 1984). Crown estimates of defoliation near the end of the growing season are also unreliable because black walnut can initiate a second flush following severe premature defoliation or under favorable environmental conditions continue new shoot growth late into the summer masking defoliation of older leaves (Reid, personal communication). Theoretically, quantifying leaflet abscission through the growing season could be a reliable alternative to making lesion counts or estimates of crown defoliation. The objective of my study was to quantify leaflet abscission through the growing season and to determine the impact of premature defoliation on the growth rate of black walnut saplings grown with six different ground covers.

MATERIALS AND METHODS

The study was initiated in a 5-year-old walnut plantation affected by anthracnose during the previous summer. The plantation was on an upland ridge in Jackson County, IL (37° 34′ latitude north, 89° 16′ longitude west) on soils of the Alford silt loam series (fine-silty, mixed, mesic, Typic Hapludalfs). The planting was established using a randomized complete block design with three blocks and factorial combinations of six ground covers, with and without spot weed control, and co- or post-establishment of walnut seedlings with ground covers. Each block consisted of twenty-four 12 x 21 m plots that were planted with 24 or 28 walnut seedlings on 3 x 3 m spacing.

The following six ground covers were seeded the preceding fall and overseeded in the spring:

1) control consisting of old-field resident vegetation,
2) seeding with hairy vetch (*Vicia villosa* Roth),
3) crownvetch (*Coronilla varia* L.),
4) sericea lespedeza (*Lespedeza cuneata* (Dum. Cours.) G. Don),
5) Korean lespedeza (*L. stipulacea* Maxim.), and
6) a mixture of Korean lespedeza and crimson clover (*Trifolium incarnatum* L.).

Korean lespedeza did not become established under the heavy stand of crimson clover, thus this treatment was essentially crimson clover. Half of the walnut seedlings were planted with the cover crop and the other half the following spring after ground covers were established.

Weed control around each walnut seedling consisted of spraying 6.4 liters per hectare glyphosate and 4.4 kilograms per hectare simazine in 1.5-m diameter spots each spring for 3 years in one half of the plots for each ground cover. Whether walnut saplings were established with or after the ground cover and with or without chemical weed control had no effect on defoliation rate during the fifth and sixth growing season, so these factors and their interaction terms were pooled into the analysis of variance error term. Percentage plot coverage as either live legume or as bare ground and dead vegetation was visually estimated in the spring, summer, and fall, and averaged to estimate percentage desired ground cover. Rainfall and temperature data are averages from NOAA reporting stations at Carbondale, IL (13 km north of the planting) and Anna, IL (19 km south of the planting).

Eight trees near the center of each plot were selected for evaluating defoliation in year 5 and year 6. A fully expanded leaf was selected midway along the new growth of the terminal shoot and four mid-crown branches (one in each cardinal direction) and marked with plastic flagging both years. Mid-June was selected for selecting and marking because most shoots were setting terminal buds and little if any defoliation from secondary infections had occurred.

A leaf midway along the new shoot was used because the number of expanding leaflets could not be counted on the more apical leaves. The more basal leaves were not used because they are the sites for both primary and secondary anthracnose infections. The total number of leaflets on all five marked leaves on each tree was recounted in early August and mid-September of year 5 and in mid-July, mid-August, and mid-September of year 6. Defoliation was determined on an individual tree basis as the percentage of abscised leaflets compared to the original number of leaflets recorded on the five marked leaves.

Marked trees were measured annually in centimeters for stem height (h) and stem basal diameter at ankle height (d.a.h.) and used to calculate trunk cross-sectional area as 0.78 $(d.a.h.)^2$ and stem volume as $(d.b.h.)^2h$ for each marked tree. For each plot, mean defoliation was determined, tested for normal distributions, subjected to analysis of variance, and then means were separated using the Duncan's new multiple range test when significant differences existed at the $p < 0.05$ percent level. Correlation between defoliation and annual growth increment of current and subsequent year were done using either individual tree data or plot means. Because both ground cover treatments and defoliation affected walnut growth, size variables and mid-season defoliation were fitted to a full first- and second-order polynomial followed by analysis of variance on coefficients to determine which terms had a significant effect on the following year's growth.

PERSISTENCE OF GROUND COVERS

During the fifth growing season, crownvetch, a cool-season perennial with decumbent stems, had the highest percentage of the desired ground cover (bare or mulch-covered soil and live legume vegetation) when averaged across the spring, summer, and fall survey (table 1). Sericea lespedeza, a warm-season perennial, also had a higher percentage of the desired ground cover than the other four ground cover treatments.

Although both ground covers had effectively suppressed the resident vegetation, they had very different growth phenologies. The crownvetch ground cover had actively growing vegetation and flowered during the spring inventory with mostly dormant vegetation during the summer and fall inventories. In contrast, the sericea lespedeza ground cover had actively growing vegetation during the summer and was flowering during the fall inventories. All treatments were bush-hogged each fall after a killing frost to reduce risk of wildfires; this treatment also effectively mulched most plots with sufficient dead vegetation to partially suppress resident vegetation the following spring.

Although hairy vetch, a cool-season annual vine, produced one of the most dense covers during establishment of the walnut seedlings (Van Sambeek and Rietveld 1982), only isolated dense patches of hairy vetch were present each spring during the fifth, sixth, and seventh growing season. These dense patches of hairy vetch usually died before producing mature seed while relatively thin stands produced sufficient seed to initiate isolated dense stands the following year. Unlike other ground cover treatments, cheat (*Bromus secalinus* L.) dominated the resident vegetation in plots originally seeded with hairy vetch. This grass germinated in the fall, flowered in late spring, and mulched these plots through the growing season.

The desired vegetative cover for crimson clover, Korean lespedeza, and resident vegetation averaged approximately 20 percent primarily because of the mulch of dead resident vegetation produced by fall mowing (table 1). In year 5 to year 7, resident vegetation was predominately a mix of broomsedge (*Andropogon virginicum* L.) and composites that consisted mostly of *Solidago*, *Aster*, and *Erigeron* species. Crimson clover, an upright cool-season annual, had produced a dense stand the spring of year 1;

Table 1.—*Desired fourth-year ground cover (sum of exposed soil, dead vegetation, and seeded legume) and annual growth increment for height, basal diameter, trunk cross-sectional area, and stem volume for walnut saplings 5 to 7 years after planting with six ground covers*

Ground cover	Desired vegetative cover	Year 4 Height	Year 4 Basal diameter	Year 5 to 7 annual growth increment: Height	Basal diameter	Trunk area	Stem volume
	— % —	— cm —	— cm —	—cm—	—cm—	—cm^2—	—cm^3—
Crownvetch	91 a	157 b	3.5 b	70 b	1.34 a	13.5 b	6120 b
S. lespedeza	64 b	169 b	3.0 bcd	53 c	1.02 b	8.9 c	3680 c
Hairy vetch	27 c	219 a	4.6 a	85 a	1.61 a	18.2 a	9650 a
Crimson clover	19 c	157 b	3.4 bc	50 c	0.92 b	8.5 c	3430 c
K. lespedeza	25 c	123 c	2.6 d	45 c	0.75 b	6.0 c	2280 c
R. vegetation	18 c	147 bc	2.8 cd	45 c	0.80 b	6.8 c	2650 c

Means followed by the same letter within columns are not significantly different at the 0.05 level according to Duncan's new multiple range test.

however, either the new seed failed to germinate or seedlings failed to overwinter the second year. Korean lespedeza, a low-growing warm-season annual, did not effectively suppress resident vegetation in year 1 and was no longer found in year 5. In general, the desired vegetative cover and species remained relatively stable until the walnut crown competition factor reached 80 to 100 and resident vegetation gradually changed to the annual cheat grass that first dominated areas seeded to hairy vetch.

LEGUMES AND WALNUT GROWTH

After four growing seasons, walnut seedlings established with a hairy vetch ground cover were taller than walnut saplings with the other five ground covers (table 1). There was a trend for walnut saplings established with Korean lespedeza and resident vegetation to be shorter than for saplings established with ground covers of crownvetch, crimson clover, and sericea lespedeza. Stem basal diameter confirmed this trend, where walnut saplings established with hairy vetch, crownvetch, crimson clover, and sericea lespedeza were larger in diameter than walnut saplings established with a ground cover of Korean lespedeza or resident vegetation.

During the fifth through seventh growing season, walnut saplings established with a ground cover of hairy vetch continued to have the largest annual height and diameter growth increments although hairy vetch was a minor component of the ground cover (table 1). Saplings growing in dense ground covers of crownvetch also had larger annual height and diameter increments than did saplings growing in a relatively dense ground cover of sericea lespedeza. When averaged across the fifth through seventh growing season, walnut saplings in the dense ground covers of sericea lespedeza had annual height and diameter growth increments similar to those established with crimson clover, Korean lespedeza, or resident vegetation. There was a trend for annual increment of walnut established with crimson clover to gradually decline from the fifth to the seventh growing season (9.0, 7.6, and 10.7 mm, respectively) and annual increment for walnut established with sericea lespedeza to gradually increase (7.9, 8.8, and 13.3 mm, respectively) while annual growth increments remained relatively constant for walnut established with Korean lespedeza or resident vegetation (7.1, 6.2, and 9.7 mm, respectively).

LEGUMES AND WALNUT DEFOLIATION

Leaflet abscission on tagged leaves occurred later during the growing season in year 5 than it did in year 6 (table 2). In year 5, 25 percent of the tagged leaflets had abscised in mid-August and premature defoliation gradually increased to near 50 percent by mid-September. Visual examination of the tagged leaflets in year 5 revealed most leaflets had few brown lesions characteristic of anthracnose. Records from the National Oceanographic and Atmospheric Sciences for two nearby weather stations indicate in year 5 the planting probably had above normal precipitation in April (29.5 cm), May (23.7 cm), and June (16.7 cm) followed by below normal precipitation in July (2.5 cm), August (3.2 cm), and September (2.4 cm). In addition, there were more than 40 days with precipitation in the spring followed by only 11 days with precipitation during the summer. The below normal late summer precipitation, the few periods of 12 or more hours of leaf wetness, lack of secondary anthracnose infections, and delayed leaflet abscission indicate premature defoliation was in response to moisture stress induced by the summer drought.

Table 2.—*Mean number of leaflets per leaf and percentage defoliation of tagged leaflets on walnut saplings grown in six different ground covers*

		YEAR 5 DEFOLIATION		YEAR 6 DEFOLIATION		
Ground cover	**Leaflets per leaf**	**Early August**	**Middle Sept.**	**Middle July**	**Middle August**	**Middle Sept.**
	—no.—	— % —	— % —	— % —	—%—	—%—
Crownvetch	17.1 ab	14 a	47 a	17 a	38 a	84 a
S. lespedeza	16.4 b	19 b	62 b	16 a	37 a	82 a
Hairy vetch	17.8 a	14 a	44 a	14 a	43 a	86 ab
Crimson clover	17.1 ab	14 a	43 a	15 a	38 a	92 c
K. lespedeza	16.3 b	14 a	50 a	16 a	38 a	91 bc
R. vegetation	16.2 b	15 a	47 a	17 a	43 a	93 c

Means followed by the same letter within columns are not significantly different at the 0.05 level according to Duncan's new multiple range test.

In contrast to year 5, almost 40 percent of the tagged leaflets had abscised before mid-August and rapidly increased to more than 80 percent by mid-September of year 6 (table 2). Many of the tagged leaflets had large brown lesions characteristic of secondary anthracnose infections. Climatological data for year 6 suggest slightly below normal precipitation during April (9.3 cm), May (11.6 cm), and June (4.6 cm) followed by near normal precipitation during July (7.4 cm), August (8.4 cm), and September (15.7 cm). Of greater significance may be the number of days with precipitation because spore germination and hyphen infection require extended periods of leaf wetness. In year 6, there were 35 days with precipitation in the spring followed by more than 25 days with precipitation during the summer supporting the observation that premature defoliation found in year 6 was in response to secondary anthracnose infections.

In early August of the fifth growing season, defoliation of tagged leaflets of walnut trees with a ground cover of sericea lespedeza was greater than that of walnut with any of the other ground covers (table 2). Accelerated defoliation of walnut growing with sericea lespedeza during a summer drought was even more pronounced by mid-September compared to walnut saplings growing in a nearly dormant cover of crown vetch and mostly non-existent cover of hairy vetch, crimson clover, and Korean lespedeza. Sericea lespedeza is a deep-rooted perennial legume with rapid vegetative growth during the summer and may have depleted available soil moisture more rapidly than resident vegetation or the cool-season legume ground covers.

In mid-July and mid-August of the sixth growing season, defoliation of tagged leaflets averaged 15 and 40 percent, respectively, with no statistical differences for walnut trees growing with any of the six ground covers (table 2). Near the end of the growing season, walnuts growing in ground cover treatments dominated by resident vegetation had abscised more than 90 percent of the tagged leaflets compared to only 84 percent of the tagged leaflets on walnut saplings growing with hairy vetch, crownvetch, or sericea lespedeza. The latter three ground cover treatments had the highest percentage of legume ground cover during the growing season. Hypothetically, these ground covers made more soil nitrate nitrogen available to the walnut saplings reducing intensity of anthracnose infections.

DEFOLIATION AND WALNUT GROWTH

Several studies have shown that most of the annual height growth for walnut saplings is complete by late-July in southern Illinois or Missouri (Bey and others 1971, Lucier and Hinckley 1982, Van Sambeek and others 1989). These studies also show that diameter growth occurs over a slightly longer time interval and is frequently terminated by late August. Theoretically, premature defoliation occurring in August or September should minimally affect growth during the same year.

Todhunter and Beineke (1984) found that mid-September defoliation in response to anthracnose was not correlated with height growth of walnut saplings during the same year but was negatively correlated with diameter growth. Evidence from other fungal diseases suggests infections increase tissue respiration and reallocation of photosynthates before lesions are visible (Daly and others 1961, Verleur 1968). Presumably, secondary infections caused reallocation of photosynthates to infection sites after completion of height growth but before completion of diameter growth. In addition, anthracnose infections would also reduce stored starch normally used for growth the following spring.

The mean defoliation rates in mid-September of year 5 and mid-August of year 6 indicate that approximately half the tagged leaflets had abscised; however, analysis of individual tree responses show that defoliation ranged from 2 to 98 percent with normal distributions in both years. Defoliation percentages in mid-September of year 5 were not correlated with defoliation percentages for mid-August in year 6 for plot means ($r = 0.120$, 71 df), but were correlated using individual tree values ($r = 0.187$, 547 df). Funk and others (1981) also found relatively weak tree-to-tree correlations between years with low incidence of anthracnose with the best correlations occurring between years when there was a high incidence of anthracnose. The weak correlation found between year 5 and year 6 defoliation could also suggest defoliation in year 5 was in response to either the summer drought and/or the low incidence of anthranose found late in the growing season.

Correlation analyses between defoliation percentage and growth increment of the same and following year using either plot means or individual walnut sapling values were generally stronger for growth increment the following year (table 3). This pattern was strongest for mid-August defoliation of year 6 in response to a high incidence of anthracnose when using individual tree values. Mid-September defoliation in year 5 was highly correlated for growth increment the same year and the following year using either plot means or individual tree values. Height growth in year 6 (38 cm) was approximately 30 percent less than in year 5 (49 cm) suggesting the factors leading to defoliation in year 5, i.e., moisture stress rather than a low incidence of anthracnose, affected growth both years because year 6 had nearly normal precipitation and temperatures.

The relatively weak correlations between defoliation and annual growth increments are in sharp contrast to the strong correlations between tree size and subsequent annual growth increments (table 4). This suggests that the site and environmental factors responsible for accelerated tree growth during the establishment phase, i.e., legume ground covers, continued to strongly affect growth increment and may have masked defoliation response to either anthracnose and/or drought.

To more fully evaluate the effects of premature defoliation, tree size, and their interaction on growth increment, these variables were fitted to a full first and second-order polynomial using regression analysis to generate response surfaces predicting the following year's growth for height, basal diameter, trunk cross-sectional area, and stem volume. Tree size and premature defoliation (mid-September for year 5 and mid-August for year 6) predicted only 37 and 50 percent of the variation for height growth and diameter growth, respectively; however, it predicted nearly 70 percent of the growth in trunk cross-sectional area or stem volume (table 4). Westwood (1978) and Smith and others (1989) indicated that trunk cross-sectional area is a more sensitive measure of tree volume or biomass than are height, stem diameter, or crown area.

Analyses of the response surface generated from the full polynomial confirm that tree size affected future growth more than premature defoliation (figs. 1A to 1D). The coefficient for interaction between tree size and defoliation was significant for both trunk cross-sectional area and stem volume (table 4). Both variables are more closely correlated to tree biomass and demand for photosynthates than are tree height or basal diameter (Westwood 1978). The interaction between tree size and defoliation occurred because small trees showed little response to increasing incidence of defoliation while expected growth on the larger trees showed a linear decrease with increasing incidence of defoliation. This may suggest that the amount of stored photosynthates are limiting tree growth

Table 3.—*Pearson's Correlation Coefficients between premature defoliation percentage and current and following year growth increment using individual tree or plot means for height, basal diameter, trunk cross-sectional area, and stem volume*

		PLOT MEAN BASIS		INDIVIDUAL TREE BASIS	
Growth Increment	**Year**	**Year 5 September defoliation**	**Year 6 August defoliation**	**Year 5 September defoliation**	**Year 6 August defoliation**
		— r —	— r –	— r —	— r —
Height	Current	-0.479***	-0.001	-0.274***	-0.044
	Following	-0.417***	-0.177	-0.258***	-0.143***
Basal diameter	Current	-0.449***	-0.113	-0.268***	-0.099*
	Following	-0.376***	-0.179	-0.233***	-0.123**
Trunk area	Current	-0.436***	-0.067	-0.253***	-0.059
	Following	-0.435***	-0.108	-0.241***	-0.078
Stem volume	Current	-0.334**	-0.018	-0.181***	-0.010
	Following	-0.387***	-0.039	-0.207***	-0.042

Correlation coefficients followed by an *, **, or *** are significant across 72 plots or 548 trees at the p = 0.05, 0.01, or 0.001 levels, respectively.

the following year on the better sites while other factors are limiting growth of the small trees usually found in plots without legumes which could be lack of available soil nitrogen on this old field site.

CONCLUSIONS

Black walnut saplings, originally established as seedlings with herbaceous legumes, continued to have more rapid height and diameter growth than walnut saplings growing with resident vegetation dominated by grasses and perennial composites. In addition, saplings with legume ground covers retained their leaflets later into the growing season than saplings with weed vegetation. Premature defoliation of walnut saplings occurred in response to anthracnose and/or drought. Dense stands of a deep-rooted perennial legume accelerated walnut defoliation in response to drought. Decreases in walnut growth were more closely correlated with premature defoliation from the previous growing season than the current growing season.

Models predicting future growth from tree size and premature defoliation indicate that site and environmental factors more strongly control future growth than premature defoliation. Premature defoliation affects the future biomass growth of the faster growing trees more than the growth of the slower-growing trees. Results indicate selection for anthracnose resistance will be an important trait to include in walnut tree improvement programs.

ACKNOWLEGMENTS

The author kindly acknowledges the contributions of William J. Rietveld for initiating the ground cover study, Ken J. Kessler in designing and implementing the anthracnose study, Valerie Roe and Linda Swanson for collecting the data, Zhanqi Cheng for assistance with the response surface modeling, and the Shawnee National Forest for providing the planting site. Electronic spreadsheet files of the tree measurements and modeling information are available upon request from the USDA Forest Service by requesting study file FS-NC-1151-83-08.

LITERATURE CITED

Berry, F.H. 1960. Etiology and control of walnut anthracnose. Bull. A-113. University of Maryland Agriculture Experiment Station. 22 p.

Bey, C.F.; Toliver, J.R.; Roth, P.L. 1971. Early growth of black walnut from twenty seed sources. Res. Note NC-105. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 4 p.

Black, W.M.; Neely, D. 1978. Effects of temperature, free moisture, and relative humidity on the occurrence of walnut anthracnose. Phytopathology. 68: 1054-1056.

Black, W.M.; Neely, D.; Matteoni, J.A. 1977. How to identify and control leaf spot disease of black walnut. HT Leaflet. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 5 p.

Daly, J.M.; Bell, A.A.; Krupka, L.R. 1961. Respiration changes during development of rust diseases. Phytopathology. 51: 461-471.

Table 4.—*Coefficient, significance, and range of values for variables fitted for response surfaces using a full first and second order polynomial to predict following year's growth from tree size and mid-season defoliation*

	COEFFICIENTS FOR RESPONSE SURFACE			
Variable	Height	Diameter	Trunk area	Stem volume
	- cm -	- cm -	- cm^2 -	- cm^3 -
Intercept	10.22394	-0.13906	-0.22082	1487.09**
Size (X)	0.31316***	0.35533***	0.66660***	1.5076***
X-squared (X2)	-0.00011*	-0.01184***	-0.00189***	-0.00001***
Defoliation (Y)	-0.15203	0.00248	0.01938	68.5541***
Y-squared (Y2)	-0.00075	-0.00003	-0.00019	-0.83045***
Interaction (XY)	-0.00049	-0.00045	-0.00125**	-0.00282***
Minimum value	25	0.6	0.4	4
Maximum value	600	12.0	110	40,000
r^2-value	0.37	0.50	0.67	0.68

Coefficients followed by an *, **, or *** are significant (n = 1096) at the p = 0.1, 0.01, or 0.001 levels, respectively.

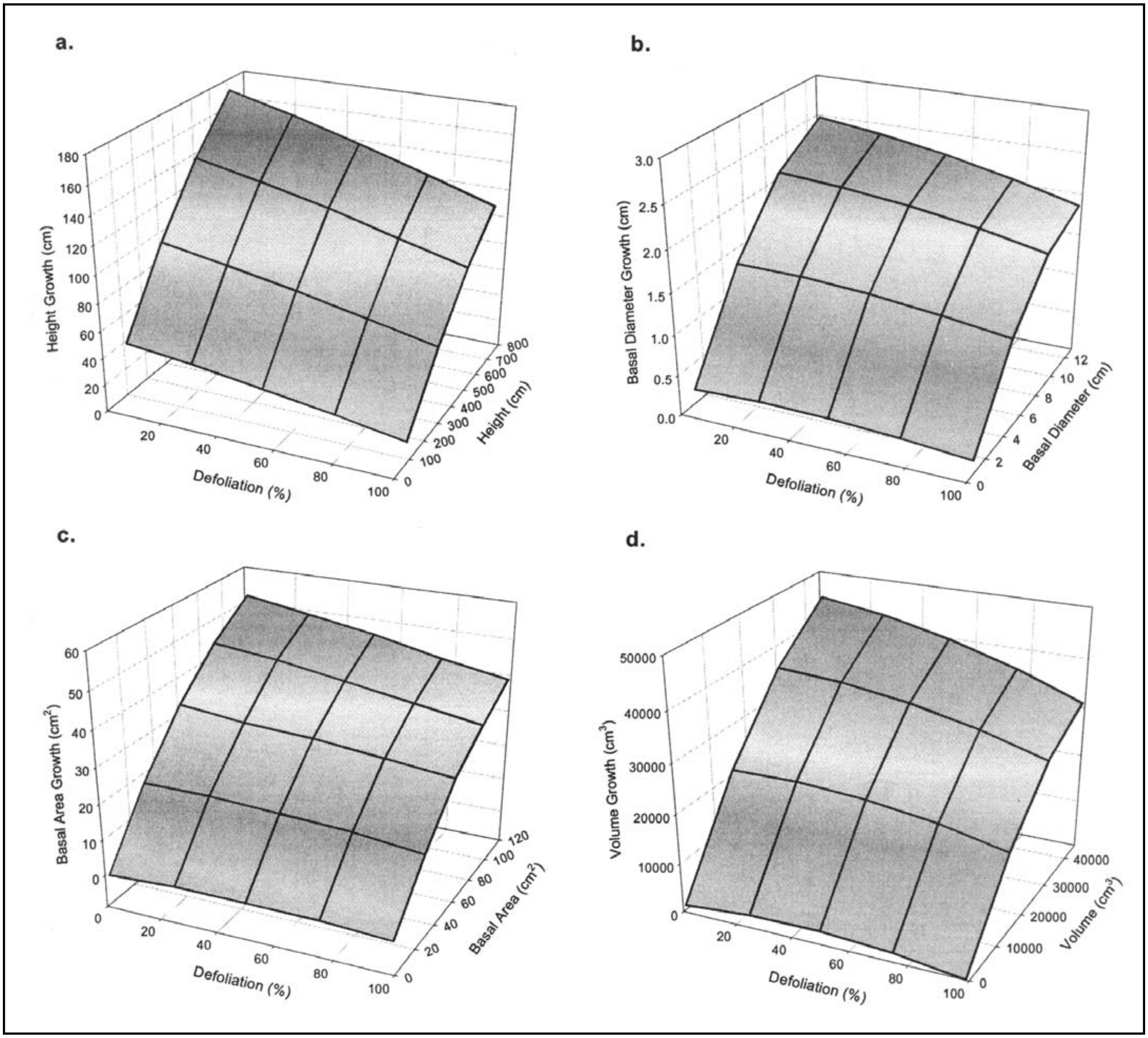

Figure 1.—R*esponse surface for (a) height, (b) basal diameter, (c) trunk cross-sectional area, and (d) stem volume predicting following year's growth as a function of tree size and amount of late summer or early fall defoliation.*

Funk, D.T.; Neely, D.; Bey, C.F. 1981. Genetic resistance to anthracnose of black walnut. Silvae Genetica. 30: 115-117.

Kessler, K.J., Jr. 1984. Similarity of annual anthracnose epidemics in young *Juglans nigra* plantations from 1978 through 1982. Plant Disease. 68: 571-573.

Kessler, K.J., Jr. 1985. Companion planting of black walnut with autumn-olive to control Mycosphaerella leaf spot of walnut. In: Dawson, J.O.; Majerus, K.A., eds. Proceedings, 5th Central Hardwood Forest conference. SAF Publ. 85-05. Champaign, IL: Society of American Foresters: 285-288.

Kessler, K.J., Jr. 1988. Walnut anthracnose. In: Burde, E.L., ed. Walnut notes. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. Walnut Notes 5.01: 2 p.

Lucier, A.A.; Hinckley, T.M. 1982. Phenology, growth and water relations of irrigated and non-irrigated black walnut. Forest Ecology and Management. 4: 127-142.

Neely, D. 1979. Etiology, epidemiology and control of black walnut anthracnose. In: Kessler, K.J., Jr.; Weber, B.C., coords. Walnut insects and diseases. Gen. Tech. Rep. NC-52. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 58-62.

Neely, D. 1981. Application of nitrogen fertilizers to control anthracnose of black walnut. Plant Disease. 65: 580-581.

Neely, D. 1986. Total leaf nitrogen correlated with walnut anthracnose resistance. Journal of Arboriculture. 12(12): 312-315.

Smith, M.W.; Taylor, G.G.; Karner, K.; Couvillon, G.A. 1989. Evaluation of pecan/peach intercropping systems. Scientia Horticulturae. 40: 133-137.

Todhunter, M.N.; Beineke, W.F. 1984. Effect of anthracnose on growth of grafted black walnut. Plant Disease. 68: 203-204.

Van Sambeek, J.W.; Ponder, F., Jr.; Rietveld, W.J. 1986. Legumes increase growth and alter foliar nutrient levels of black walnut saplings. Forest Ecology and Management. 17: 159-167.

Van Sambeek, J.W.; Rietveld, W.J. 1982. Leguminous cover crops can suppress weeds and accelerate growth of black walnut seedlings in intensively cultured plantation. In: Muller, R.N., ed. Proceedings, 4th Central Hardwood Forest conference. Lexington, KY: University of Kentucky Press: 229-243.

Van Sambeek, J.W.; Schlesinger, R.C.; Roth, P.L.; Bocoum, I. 1989. Revitalizing slow-growth black walnut plantings. In: Rink, G.; Budelsky, C.A., eds. Proceedings, 7th Central Hardwood Forest conference. Gen. Tech. Rep. NC-132. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 108-114.

Verleur, J.D. 1968. Regulation of carbohydrate and respiratory metabolism in fungal diseased plants. In: Hira, T.; Hidaka, Z.; Uritani, I., eds. Biochemical regulation in diseased plants and injury. Tokyo, Japan: Kykoritsu Printing Co. Ltd.: 275-285.

Westwood, M.N. 1978. Temperate zone pomology. W.H. Freeman: 221.