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Managing Fine Hardwoods after a Half Century of Research

Proceedings of the Seventh Walnut Council Research Symposium

Abstract

This report presents information from the Seventh Walnut Council Research Symposium, held August 1-3, 2001. This report includes 14 papers and abstracts relating to economics and utilization, pest management, nursery production, plantation establishment, tree improvement, stand management, agroforestry, and nut production of black walnut, related *Juglans* species, and other high value hardwoods. This report is being published in electronic format only: Web and CD.

Cover Photos

Clockwise from top left: portable band saw (photo by Jerry Van Sambeek, U.S. Forest Service); mature walnut in the Rule Forest fertilization study (photo by Jerry Van Sambeek, U.S. Forest Service); tractor-mounted CDA herbicide applicator (photo by Brian B. Beheler, Purdue University, used with permission); and mixed walnut, chestnut, and oak planting (photo by Lenny D. Farlee, Purdue University, used with permission).

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Managing Fine Hardwoods after a Half Century of Research

Proceedings of the Seventh Walnut Council Research Symposium
Madison, Wisconsin
August 1-3, 2011

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PREFACE

This publication is the result of the Seventh Walnut Council Research Symposium cosponsored by the Walnut Council and the U.S. Forest Service. The objectives of this and previous symposia were to bring together researchers, other professionals, and land managers interested in management of walnut and other hardwoods on their lands and to compile a proceedings reviewing the research findings from the last 7 to 15 years for distribution to forest managers who could not attend. The Seventh Walnut Council Research Symposium marks a half century long effort by the Walnut Council and the U.S. Forest Service to transfer new research information to forest managers. The first symposium, sponsored by the U.S. Forest Service, the American Walnut Manufacturers' Association, and Southern Illinois University, was held in 1966 in Carbondale, IL, partly in response to the rapidly dwindling supply of quality walnut. Subsequent walnut research symposia were held at Southern Illinois University in 1973; at Purdue University in 1981; at Southern Illinois University in 1989; in Springfield, Missouri in 1996; and at Purdue University in 2004. The proceedings titles as well as the titles of the state-of-the-art review articles within each proceeding provide an interesting historical perspective on how research findings have changed the recommendations on management and utilization of walnut, especially black walnut. A listing and their availability on the Web follows:

U.S. Forest Service, North Central Forest Experiment Station. 1966. Black Walnut Culture. 94 p.

USDA Forest Service. 1973. Black Walnut as a Crop. Gen. Tech. Rep. NC-4. 114 p. 30 papers. Available at http://www.treesearch.fs.fed.us/pubs/10069

U.S. Department of Agriculture, Forest Service. 1982. Black Walnut for the Future. Gen. Tech. Rep. NC-74. 151 p. 33 papers. Available at http://www.treesearch.fs.fed.us/pubs/10138

Phelps, John E., ed. 1989. The Continuing Quest for Quality. Walnut Council. 310 p. Out of print.

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Michler, C.H. and others, eds. 2004. Black Walnut in a New Century. Gen. Tech. Rep. NC-243. Available at http://www.treesearch.fs.fed.us/pubs/11988

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ECONOMICS AND UTILIZATION

CHANGES IN WALNUT AND OTHER HARDWOOD MARKETS: 1990 TO 2010

William G. Luppold and Scott Bowe[1]

Abstract.—After a decade of record demand in the 1990s, production and price of hardwood lumber declined moderately between 1999 and 2005 and then plummeted between 2005 and 2009. The decline in hardwood lumber price affected all species. However, walnut was the last species to decline in price, starting in 2007, and has had the largest price increase since hitting its low point in early 2010. The most obvious factor affecting walnut lumber price is the export market. As exports of walnut lumber declined in the 1990s, walnut lumber price was surpassed by that of black cherry and hard maple. As export and domestic demand for these species began to decline in the 2000s, walnut re-emerged as the highest priced U.S. species. While lumber exports have a considerable impact on lumber price, walnut log exports appear to have even a greater impact on saw log and veneer log prices. Walnut products exported to China increased in the late 1990s, rising from less than $0.2 million in 1996 to more than $10.5 million in 2000. By 2007, China had become the largest export market for walnut logs and Canada had become the largest international market for walnut lumber and veneer. Exports will remain an important aspect of the walnut market if the value of the dollar continues to decrease and demand by China and other countries continues to increase.

After a decade of record demand in the 1990s, demand for hardwood lumber declined by 49 percent between 1999 and 2009 (Fig. 1). The primary causes of this reduced demand were a large increase in furniture imports from Asia that caused a reduction in domestic furniture production, a decline in housing construction that began late in 2006, and the 2009 recession (Luppold and Bumgardner 2011a,b; Luppold et al. 2012). The decline in hardwood lumber demand has been greater in appearance applications (furniture, cabinets, flooring, etc.) than in industrial applications (pallets, crossties, etc.). As a result, the proportion of lumber being consumed in appearance uses has declined from 60 percent in 2000 to 40 percent (HMR 2009, Johnson 2011). This shift in hardwood lumber use has put extreme downward pressure on mid-grade (No. 1 common) hardwood lumber price and hardwood lumber production. As a result of these declines, hundreds of hardwood sawmills have either become idle or gone out of business (Luppold and Bumgardner 2009). Most of the decline in hardwood lumber price and production occurred after the decline in the housing market, which began in 2006 (Woodall et al. 2012).

The decline in hardwood lumber price and production since 2005 has affected all species including walnut. Changes in real (inflation adjusted) prices of No. 1 common lumber for various Appalachian species show a shared decline from their near historic highs in the mid-2000s to their lows in 2009 and 2010 (Table 1). This decline in the real price of mid-grade lumber occurred across all species and was unprecedented in the post WWII period. The declines ranged from 36 percent for hickory to 66 percent for black cherry; the decline in walnut price was in the lower third of this

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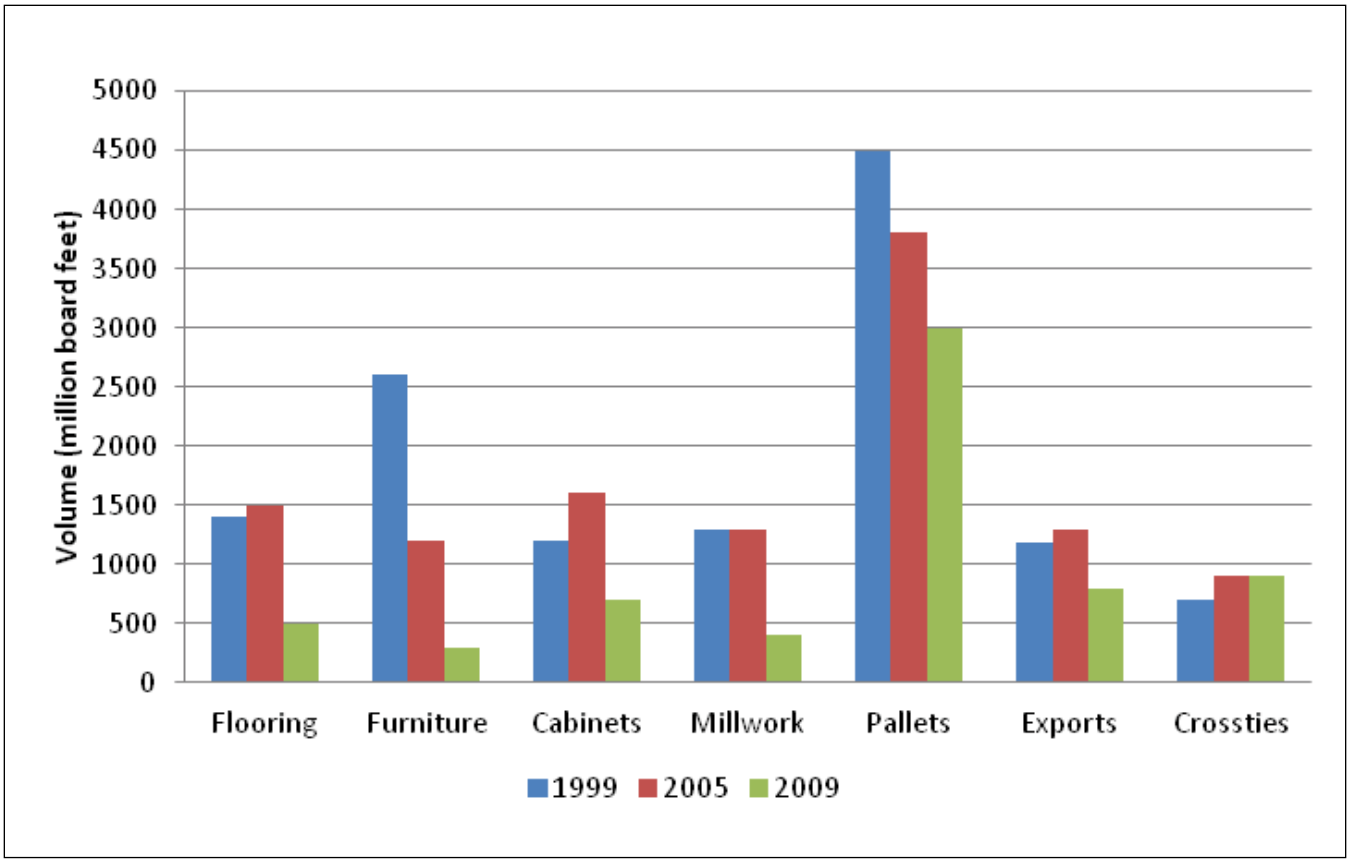

Figure 1.— Hardwood lumber consumption by major appearance grade users, industrial users, and exports in 1999, 2005, and 2009 (HMR 2009, Johnson 2011).

Table 1.—Percentage declines and subsequent recoveries in inflation-adjusted hardwood lumber prices following peak prices in 2003 to 2007 to the second quarter of 2011 for black walnut and eight other hardwoods (Luppold and Bumgardner 2010).

Species	Quarter when price peaked	Quarter with lowest price	Percent decline	Percent recovery
Ash	Fourth 2004	Third 2009	-43.3	+28.3
Black cherry	Third 2004	First 2010	-66.3	+0.7
Hickory	Third 2003	Second 2010	-37.6	+3.3
Hard maple	Third 2005	First 2010	-55.0	+5.6
Soft maple	Third 2005	Third 2009	-46.8	+4.8
Red oak	Second 2004	Third 2009	-50.6	+10.0
White oak	Second 2004	Third 2009	-47.3	+21.2
Y-poplar	Third 2003	Third 2009	-32.5	-2.3
Walnut	Fourth 2007	First 2010	-43.8	+45.2

range. What sets walnut apart from the other species is that it was the last species to descend in price and declined for only 8 quarters compared to at least 15 quarters for the other species listed in Table 1. Walnut lumber prices also have rebounded more than any other species since its low point in early 2010.

The data provided in Table 1 seem to indicate that the market factors driving the walnut lumber market may be different from the factors driving the market for other species. The most obvious of factors is that the export market for walnut has been especially strong relative to domestic production (Luppold and Bumgardner 2011a.b). The objectives of this paper are to examine the price, production, and export demand trends for walnut lumber compared to trends for black cherry and hard maple and to examine if these factors also have influenced the price of walnut logs.

DATA

Price trends for black walnut, black cherry, and hard maple lumber during the last two decades were developed from the annual Hardwood Market Reports (HMR 1990 to 2011). Price trends for walnut veneer and saw logs are based on data supplied by Hoover (2011). Relative production of walnut, cherry, and maple was developed from annual reports by the U.S. Department of Commerce (USDC 1991 to 2011). All export statistics came from a report prepared by the U.S. Department of Agriculture, Foreign Agricultural Service (USDA FAS 2011).

CHANGES IN LUMBER MARKETS 1990 TO 2011

Walnut lumber has traditionally been the highest priced U.S. hardwood species that is traded at any significant volume excluding limited sales of Hawaiian koa, lignum vitae, and American chestnut. The place of walnut in the U.S. hardwood lumber market began to decline in the early 1990s as the nominal (reported market price) remained constant while inflation caused the real price to decrease (Fig. 2). Meanwhile, the real price of black cherry and hard maple began to increase in 1992. In 1995, walnut lumber prices began to decrease in nominal terms as did the price of hard maple. The decline in walnut price was especially acute in the higher (FAS) grade. The price of black cherry continued to increase, surpassing walnut lumber price in 1993. Unlike walnut, the price of hard maple lumber began to rebound in 1996 and exceeded walnut price in 1997.

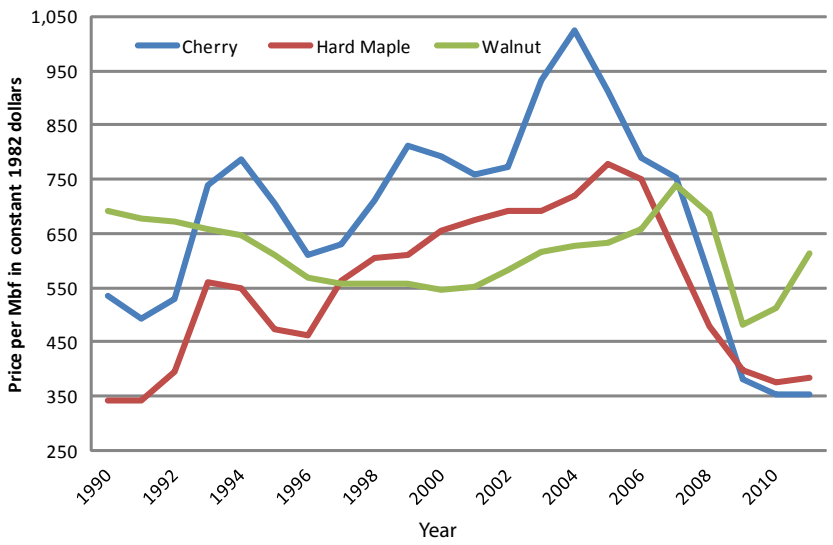

Figure 2.—Price for No. 1 common lumber for walnut, cherry, and hard maple in constant 1982 dollars per thousand board feet, 1990 to first half of 2011 (HMR 1990 to 2011, USDL 2011).

Once walnut lumber price declined, so did walnut lumber production. Because of differences in the scale of walnut, cherry, and hard maple production, it is easier to see changes in production as indexes (based on 1990 production levels) rather than raw quantities (Fig. 3). As indicated in Figure 3, walnut lumber production trended downward between 1993 and 1998 as real price declined (Fig. 2). This decline coincided with decreased walnut lumber exports. The increased walnut lumber production after 1998 coincided with an increase in lumber exports. It is impossible to determine all the factors influencing the upward trend in lumber prices in 1999, but some of the factors appear to be increased export demand, relatively low log costs, and a stable price of walnut lumber. As exports of walnut lumber continued to increase between 1998 and 2007, so did walnut lumber price and production. The USDA Foreign Agricultural Service (2011) reports a 43-percent decline in walnut lumber export between 2007 and 2009, matched by a 45-percent decline in price and a 41-percent decrease in production (Figs. 2 and 3). Although production estimates for 2010 and onward have yet to be released, the 45-percent increase in walnut exports between the first two months of 2010 and 2011 was the primary cause of the 45-percent increase in walnut price during this period.

Black cherry lumber exports increased by 300 percent between 1990 and the peak year of 2005 while total hardwood lumber exports increased by 62 percent. Cherry exports began to rapidly decline in the mid-2000s and had dropped by 61 percent by 2009 as European demand for this species all but stopped. The rapid drop in European cherry demand followed rapid and large increases in cherry lumber prices, indications that black cherry may have priced itself out of the European market. Cherry also was the premier species for the production of high-end kitchen cabinets in the early 2000s, but this demand dropped sharply after the decline in the housing market in 2005. Although much of the domestic furniture manufacturing has moved to Asia, black cherry is still an important component of the furniture industry. According to the Appalachian

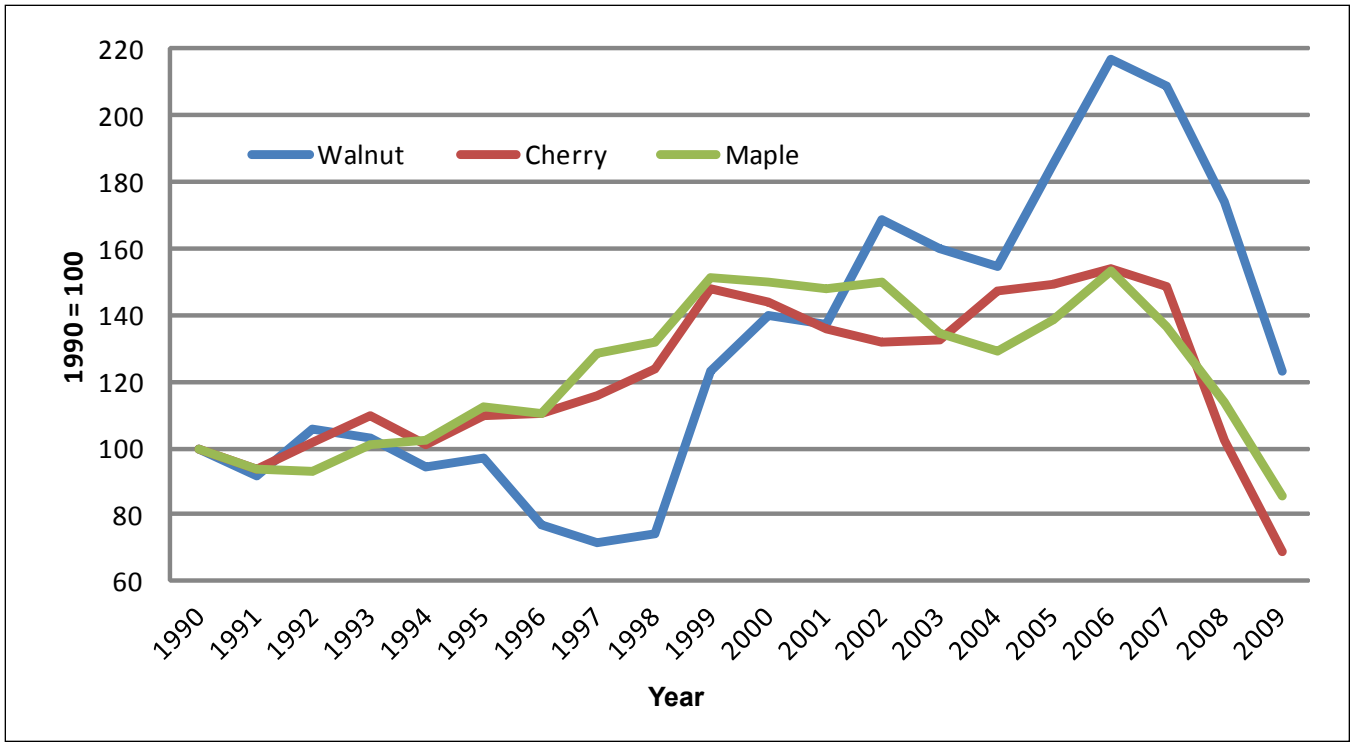

Figure 3.—Index for lumber production of walnut, black cherry, and hard maple when 1990 production equals 100 (USDC 1991 to 2010).

Hardwood Manufacturers (AHMI), cherry in recent years has ranked as the number one species featured at the High Point furniture market (AHMI 2010), although furniture sales have yet to reach levels experienced before the 2009 recession. Because of cherry's large declines in demand in domestic kitchen cabinet, domestic furniture, and export markets since 2005, it is of little wonder that cherry declined more in price than any other species listed in Table 1.

Hard maple also had a large increase in lumber exports in the late 1990s, but exports have declined since then. Between 1900 and 2000, maple (hard and soft) exports increased by more than 360 percent compared to a 53-percent increase in total lumber exports. As export demand for this species declined after 2000, domestic demand increased as this species became the most common lumber used by the kitchen cabinet industry. In recent decades, hard maple also has been reintroduced as a furniture species and was the third most featured species at the 2009 High Point furniture market. The second most featured species at this market was rubberwood, which comes from latex trees that had been taken out of production. As in the case of cherry, the decline in hard maple lumber price and subsequent declines in production are the result of declines in multiple markets.

INTERNATIONAL DEMAND FOR PRIMARY WALNUT PRODUCTS

As the previous discussion of the lumber market indicates, the production and price of walnut are heavily influenced by exports of this species. To what extent walnut lumber price and production are currently influenced by export is difficult to determine because of the ambiguities in estimates of hardwood lumber production by the U.S. Department of Commerce. In 1994, the USDC changed procedures to estimate hardwood lumber production, which included a new interpretation of data from surveyed mills and the estimated production from smaller non-surveyed mills. As a result of these changes, estimated total hardwood lumber production in 1993 increased by 47 percent and the "eastern hardwood not specified by kind" portion of estimated production increased from 16 percent to 31 percent. Then, in 2009, the USDC stopped including estimates of "eastern hardwood not specified by kind" production. The proportion of walnut lumber production that was exported ranged from 39 to 67 percent in 2007, declined to a range of 30 to 52 percent in 2008, and rebounded to an estimated range of 38 to 64 percent in 2009. To arrive at the lower portions of these ranges, 30 percent of the walnut lumber would have to be manufactured in smaller non-surveyed mills. Because these smaller mills tend to produce ungraded lumber and industrial products, it is most likely that at least 50 percent of the walnut lumber currently produced is exported.

While walnut lumber exports have increased in recent years, the U.S. also exports significant volumes of walnut logs and veneer (Fig. 4). In most years since 1990, the value of log exports was equal to or greater than the value of lumber exports. An examination of veneer and saw log price indexes reveals a familiar pattern of price movement relative to the value of exports (Fig. 5). It appears that veneer log prices are even more sensitive to export levels than saw log prices, but a true econometric test of this hypothesis requires much more data than available. Given that walnut logs are either transformed into lumber and veneer or are exported, the information presented in Figure 4 indicates that most walnut logs currently harvested in the U.S. are exported in some form. Because of these facts, it would be useful to examine the specific regions and countries that receive exports of walnut logs, lumber, and veneer.

In 1990, 63 percent of the value of walnut products (lumber, logs, and veneer) was shipped to Germany, Korea, Japan, and Italy, but each of these countries imported a different mix of walnut products (Table 2). Italy was the most important market for walnut logs, Japan was the largest market for walnut lumber, and Germany was the largest market for walnut veneer. Germany also was the most important single market for walnut products in 1990 with an 18-percent market share.

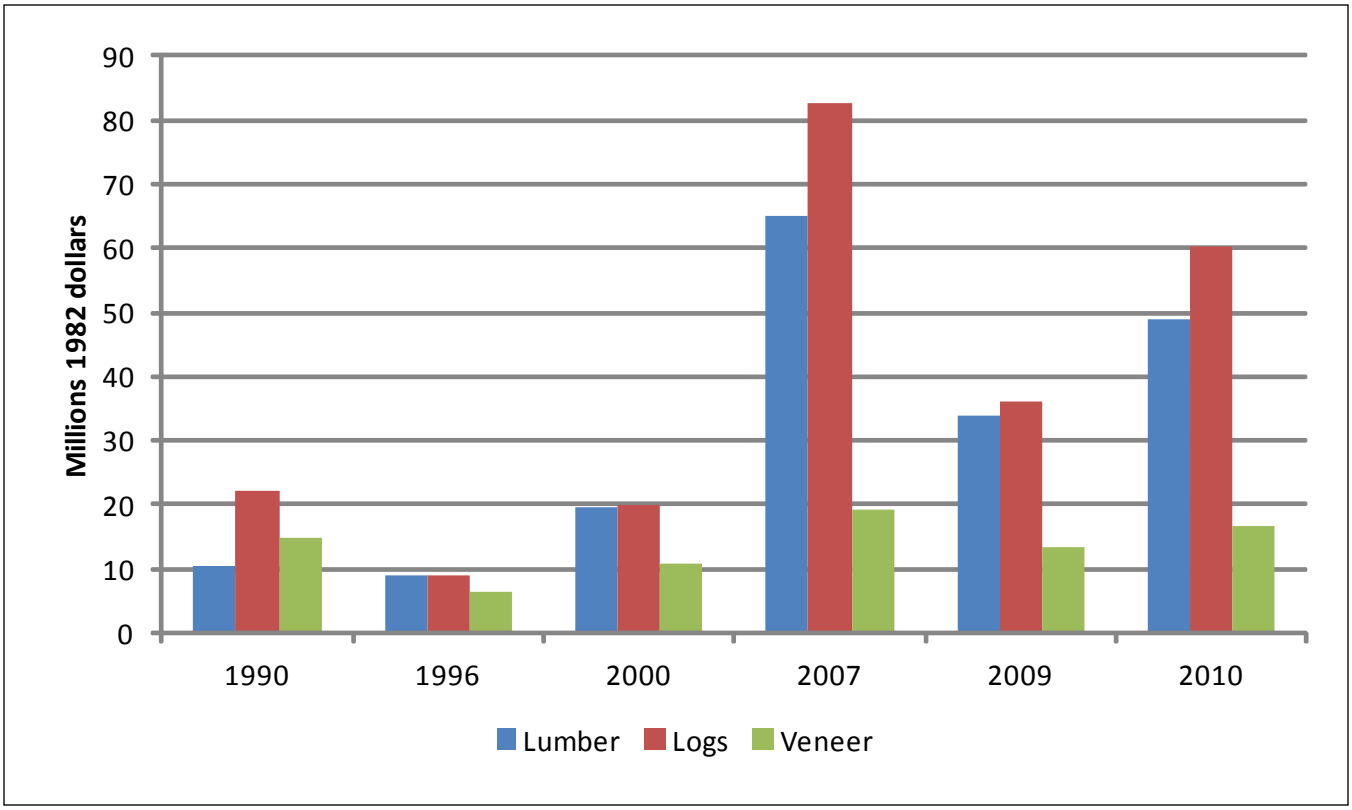

Figure 4.—Value of walnut exports for lumber, log, and veneer in constant 1982 dollars in 1990, 1996, 2000, 2007, 2009, and 2010 (USDA FAS 2011, USDL 2011).

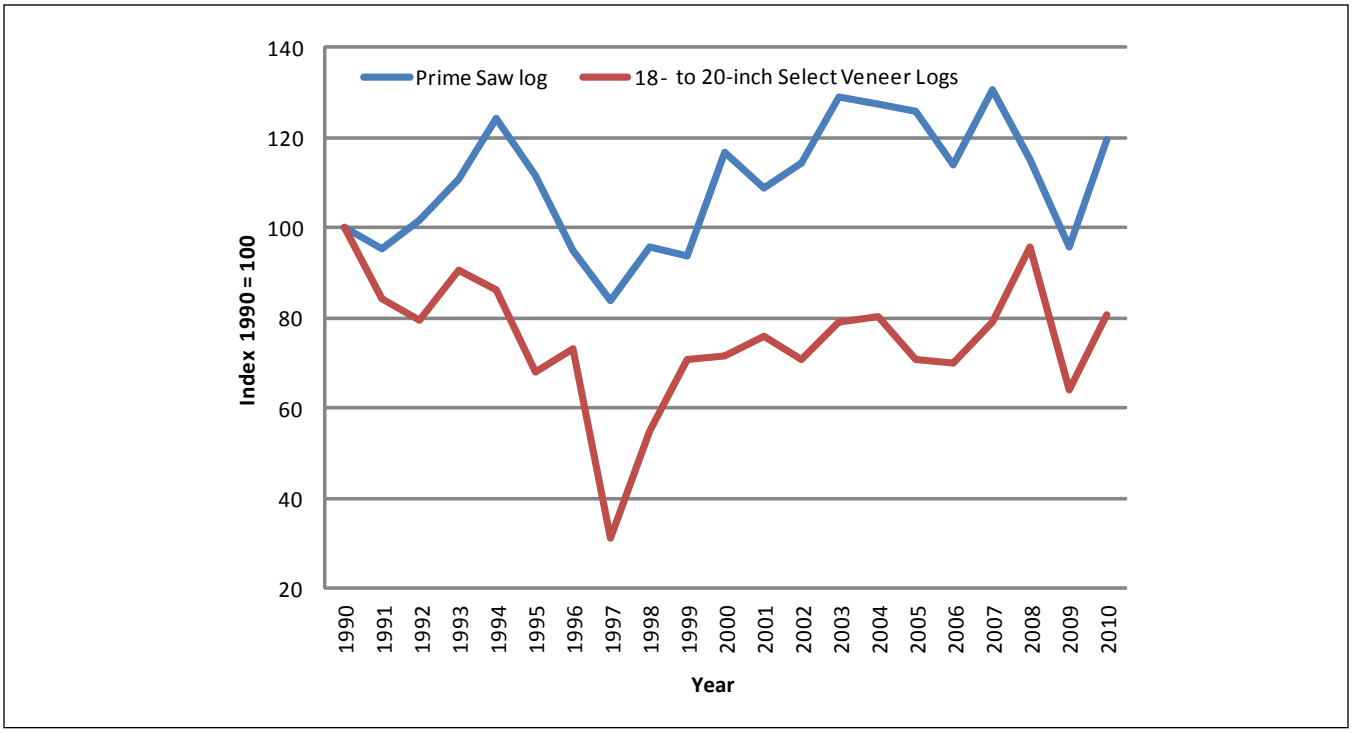

Figure 5.—Index of price for Indiana prime walnut saw logs, and 18- to 20-inch select grade walnut veneer logs, 1990 to 2010 (Hoover 2011, USDL 2011).

Table 2.—Top export markets and percent of market for walnut logs, lumber, and veneer for 1990, 1995, 2000, 2007, and 2010 by value in constant 1982 dollars (USDA FAS 2011, USDL 2011).

		Log		Lumber		Veneer	
Year	Rank	Country	Percent	Country	Percent	Country	Percent
1990	1	Italy	21.6	Japan	25.7	Germany	23.6
	2	Germany	20.6	Canada	17.1	Canada	17.0
	3	Korea	17.4	Korea	16.5	Korea	16.7
	4	Japan	12.4	Italy	14.6	U.K.	12.9
	5	Spain	8.1	Germany	5.6	Japan	9.9
1995	1	Italy	34.8	Italy	31.7	Germany	21.6
	2	U.K.	14.9	Canada	16.0	Canada	18.1
	3	Switzerland	12.6	Japan	15.7	Korea	18.0
	4	Korea	9.1	Spain	7.0	Italy	9.7
	5	Canada	9.0	Taiwan	6.9	Egypt	9.1
2000	1	Italy	21.9	Canada	24.5	Germany	31.2
	2	China/HK	20.0	China/HK	14.3	Canada	26.8
	3	Spain	15.9	Japan	11.4	Spain	6.2
	4	Switzerland	9.0	Italy	10.4	China/HK	5.9
	5	Canada	6.9	Taiwan	10.4	Italy	4.3
2007	1	China/HK	44.8	Canada	35.7	Canada	35.4
	2	Italy	10.8	China/HK	10.3	Germany	18.3
	3	Germany	10.8	Japan	9.0	China/HK	16.3
	4	Canada	6.7	Germany	5.0	Spain	5.5
	5	Japan	5.2	U.K.	4.7	Italy	4.9
2010	1	China/HK	46.7	Canada	28.7	Canada	32.8
	2	Germany	11.9	China/HK	18.6	Germany	16.9
	3	Italy	8.1	Germany	9.9	Spain	8.4
	4	Japan	5.6	Japan	8.6	China/HK	5.8
	5	U.K.	4.3	U.K.	5.6	Italy	3.7

In the middle and late 1990s, exports of logs and veneer declined by 59 and 57 percent, respectively (Fig. 4). The decline in log exports was largely due to declines in German and Korean demand while the decline in veneer exports was caused by declines in German, Korean, and Italian demand. These declines in European and Asian demand for logs and veneer caused walnut saw log prices to decline moderately and walnut veneer log prices to decline by more than 50 percent (Fig. 5).

The value of walnut product exports rebounded slightly by 2000, exceeding 1990 levels but with one new element: exports to China and Hong Kong. Exports of walnut products to China increased in the late 1990s, rising from less than $0.2 million in 1996 to more than $10.5 million in 2000. As a result, China became second only to Canada as the most important market for combined walnut products in 2000. China's share of the walnut export market may even be greater than what is shown in Table 2. The transshipment of hardwood products through Canada has been documented (Luppold 1992) and a significant amount of lumber and veneer exported to Canada may be reshipped to China. By 2007, China had become the largest market for walnut logs and Canada had become the largest market for walnut lumber and veneer. Overall, China accounted for more than 28 percent of the walnut product exports by value in 2007 and Canada counted for an additional 21 percent. Both these markets declined during the 2009 worldwide recession but re-emerged in 2010 and are continuing to grow in 2011. Germany also has increased imports of hardwood logs and veneer in the current century and by 2010 was the second overall market for U.S. walnut products after China.

CONCLUSIONS

Walnut lumber has traditionally been the highest priced U.S. hardwood species; however, the real price of walnut declined in the middle to late 1990s while the price of black cherry and hard maple surpassed that of walnut. The decline in walnut lumber prices was associated with a decline in exports. Between the 1ate 1990s and 2008, exports of walnut surged while exports and domestic consumption of black cherry and maple declined. A 43-percent decline in walnut lumber exports between 2007 and 2009 was matched by a 45-percent decline in price and a 41-percent decrease in production. In contrast, the 45-percent increase in walnut exports between the first two months of 2010 and 2011 was the primary cause of the 45-percent increase in walnut price during this period.

The influence of exports on walnut lumber price and production during the last decade is undeniable. The proportion of domestic walnut lumber production could have been as high as 64 percent in 2009. Although lumber exports have a considerable impact on price and production, walnut log exports appear to have an even greater impact on saw log and veneer log prices. It appears that the majority of currently harvested walnut logs are either exported as logs or processed into lumber and veneer and then exported. Exports of walnut products to China increased exponentially in the 1990s, reaching more than $10.5 million by 2000, making China second only to Canada as the most important market for combined walnut products. By 2007, China had become the largest market for walnut logs while Canada remained the largest market for walnut lumber and veneer. In the 2000s, Germany also increased imports of hardwood logs and veneer and by 2010 was the second overall market for U.S. walnut products after China. Exports will remain an important aspect of the walnut market if the value of the dollar continues to decrease and demand by China and other countries continues to increase.

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SAWMILLING PRACTICES FOR HARDWOODS

John "Rusty" Dramm[1]

Abstract.—The Sawmill Improvement Program (SIP) provides guidance to improve the bottom line of a sawmill both by recovering more lumber from a log and by using simplified procedures to produce more grade lumber. Lessons learned from SIP have led to improved yields of grade lumber through improved log manufacturing, reducing sawing variation by using thinner kerf saws and better decisionmaking from debarking of logs to edging of grade lumber, and better product sizing by reducing dimensional oversizing and excessive planning allowances. Developing higher grades of lumber requires a skillful edger and trim saw operator as well as a skillful sawyer.

State and Private Forestry of the U.S. Forest Service began the Sawmill Improvement Program (SIP) in the 1970s to extend the Nation's timber resources by identifying practices both to increase lumber recovery and to mill hardwood logs more efficiently. Lessons learned from SIP have led to improved yields of grade lumber through improved log manufacturing, reducing sawing variation by using thinner kerf saws and better decisionmaking from debarking of logs to edging of grade lumber, and better product sizing by reducing dimensional oversizing and excessive planning allowances. Lumber lost was estimated to be 15 percent from oversizing, 12 percent from excessive sawing variation, 20 percent from heavy slabbing, 20 percent from overedging, and 6 percent from excessive saw kerf. Losses in log volume were estimated to be as high as 10 to 15 percent from poor debarking and 2 to 8 percent from poor processing decisionmaking.

Figures 1, 2, and 3 illustrate a portion of the simplified procedure for developing grade lumber from hardwood logs (Malcolm 2000). A working knowledge of the hardwood grade rules of the National Hardwood Lumber Association is essential for processing grade lumber (American Hardwood Export Council 2002). Of first importance in sawing for grade is recognizing external indicators of internal defects. The position of the other three sawing faces is fixed as soon as the first face is sawn. Defects should be located at the edges or corner of sawn lumber where they can be edged off. The poorest face should be sawn first to provide a firm bearing from which to saw the better faces for grade. Walnut should be opened to a 5.5-inch face and other hardwoods should be opened to a 6.5-inch face. Wide boards should be ripped into two boards when more than half the original surface can be raised one grade and the remaining board does not drop more than one grade.

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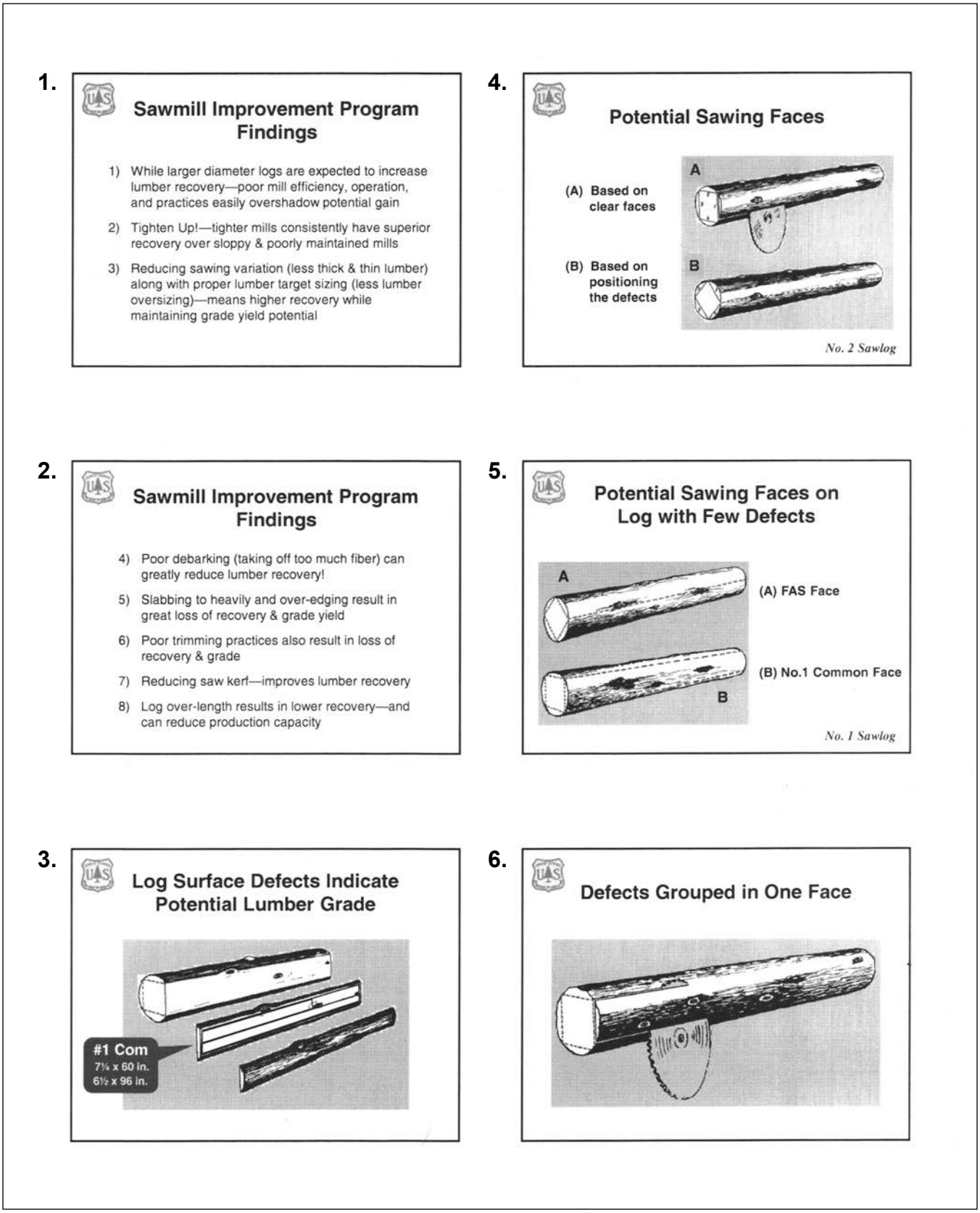

Figure 1.—Series of slides listing the findings of the Sawmill Improvement Program and illustrating the importance of identifying defects before opening a log to produce grade lumber (illustrations from Malcolm 2000).

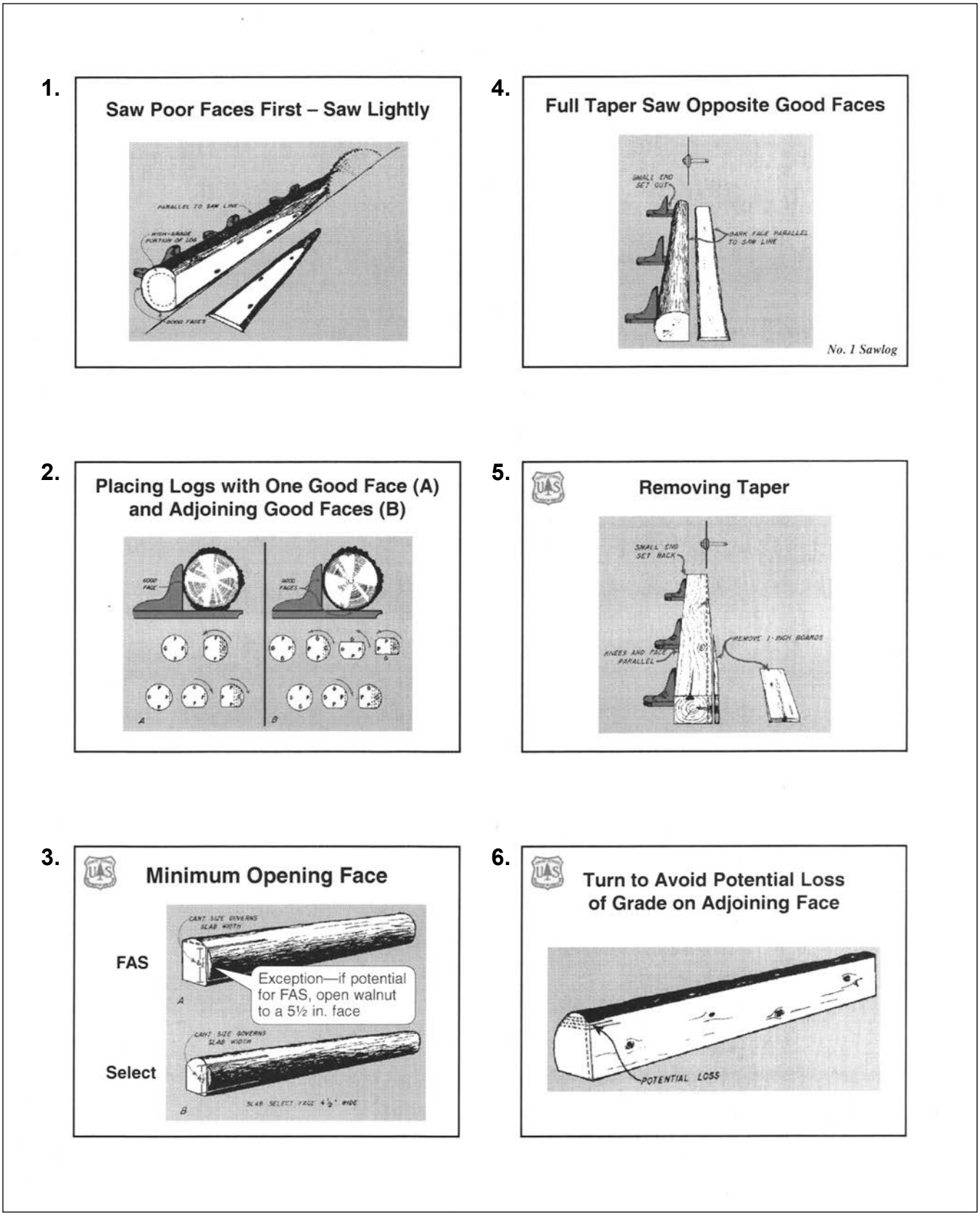

Figure 2.—Series of slides illustrating how to open a log and when to rotate to maximize production of grade lumber (illustrations from Malcolm 2000).

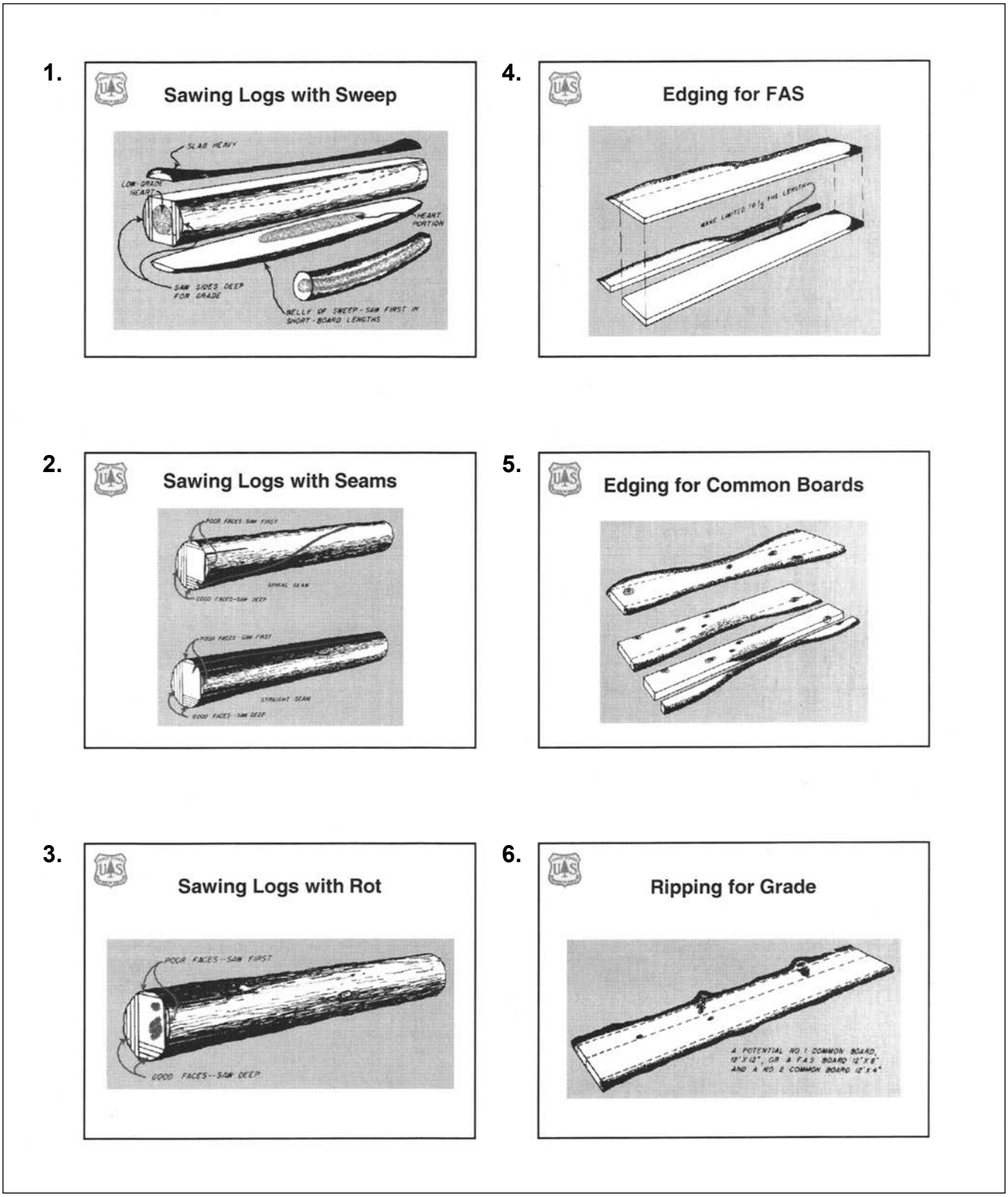

Figure 3.—Series of slides illustrating how to open logs with sweep, seams, and rot, and how to edge and rip for production of grade lumber (illustrations from Malcolm 2000).

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BIOREFINERY OPPORTUNITIES FOR FOREST PRODUCTS INDUSTRIES

Alan W. Rudie[1]

ABSTRACT

Wood residues offer biorefinery opportunities for new products in our industries including fuel and chemicals. But industry must have two capabilities to succeed with biorefineries. Most forest products companies already have the first capability: knowing where the resource is, how to get it, and how much it will cost. They will need to integrate the acquisition of woody residues for making new products while minimizing competition for valuable timber suitable for dimension lumber and other traditional products. The second capability needed requires companies to look at the overall biorefinery effort and acquire the expertise to move thermal and biochemical conversion of biomass into chemicals with a higher value than ethanol (Rudie 2009). Sugar platform chemicals, those that have glucose as a common intermediate, include ethanol for fuel, ethylene, butadiene, lactic acid used to produce polylactic acids for producing biodegradable plastic to replace polystyrene, and diols used in synthesis of polyesters and other specialty products. The thermo-chemical process first gasifies biomass to produce hydrogen and carbon monoxide and then reforms it into products including diesel or aviation fuel and methanol. The literature on the chemical and biochemical processes for these new products and the likelihood of success was recently reviewed (Rudie 2011). Forest products, including wood-based chemicals and polymers, are well positioned to be carbon neutral, sustainable, and green solutions to global problems (Winandy et al. 2008). Some of these wood-based products do not have large markets and will reward only the first companies willing to invest in their production. Most of these processes cannot be implemented without further research and without risk.

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PEST MANAGEMENT

INHIBITION OF *OPHIOGNOMONIA CLAVIGIGNENTI-JUGLANDACEARUM* BY *JUGLANS* SPECIES BARK EXTRACTS

M.E. Ostry and M. Moore[1]

Abstract.—A rapid and reliable screening technique is needed for selecting trees with resistance to butternut canker. In a laboratory assay, reagent grade naphthoquinones and crude bark extracts of *Juglans* species variously inhibited spore germination and growth of *Ophiognomonia clavigignenti-juglandacearum*, the causal fungus of butternut canker. The in vitro disc assay revealed that the level of inhibition varied by naphthoquinones and by extracts from different species of *Juglans* and selections of butternut. Ranking the trees by the level of inhibition approximated their level of resistance observed in past assays based on challenging the trees with the fungus through wounds and their response to natural infection in the field. Butternut is known to produce naphthoquinone compounds with antimicrobial activity. These compounds, if produced at different concentrations, may account for the observed range of inhibition levels in the assay and variation in canker resistance among selections of butternut in the field. This assay may have potential use for selecting butternut with disease resistance for conservation and restoration purposes.

Concern over the rapid loss of butternut (*Juglans cinerea*) to butternut canker caused by *Ophiognomonia clavigignenti-juglandacearum* (OCJ) (=*Sirococcus clavigignenti-juglandacearum*) (Broders and Boland 2011) has increased since the disease was first reported in 1967. Investigators in the United States and Canada are examining the potential conservation of individual trees that may have resistance to the disease (Schlarbaum et al. 2004). Occasionally, one to several healthy butternut trees are found growing among groups of similarly aged diseased and dying butternut, and it has been speculated that these trees may have resistance to the disease and value for breeding and restoration of the species (Ostry and Woeste 2004).

Differences in susceptibility to OCJ among *Juglans* species and selected butternuts have been demonstrated using artificial wound inoculation tests (Orchard et al. 1982; Ostry and Moore 2007, 2008). Among the species tested, heartnut (*Juglans ailantifolia* var. *cordiformis*) and black walnut (*J. nigra*) were among the least susceptible and Persian walnut (*Juglans regia*) was the most susceptible. Inoculations of putative resistant butternuts found significant differences between accession, month of inoculation, and fungal isolate (Ostry and Moore 2008). Resistance mechanisms among different *Juglans* species have been only minimally explored. It has widely been observed that butternut x heartnut hybrids, often referred to as "buarts," are more resistant to canker than pure butternuts (Hoban et al. 2009). One hypothesis is that the thicker periderm of heartnut provides resistance against the fungus, and the high phenolic production of black walnut confers disease resistance to that species (Nair 1999).

The capability of plants to produce chemical substances involved in resistance to pathogens has been extensively studied. Phenolics such as salicylic acid are well known as signal molecules for both the hypersensitive response and systemic acquired

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resistance (Klessig and Malamy 1994). Disease resistance may be correlated with an increase in these and other substances, and chemical assays for detecting disease resistance have been developed. Baiocchi et al. (1994) found varying levels of phenolics among poplars displaying different levels of resistance to *Discosporium populeum*. Bucciarelli et al. (1999) found that aspen phenotypes resistant to *Entoleuca mammata* (=*Hypoxylon mammatum*) produced wound callus rich in phenolics that was absent in the susceptible phenotypes. Reservatrol production has been investigated as a possible indicator of resistance in grapevines to *Plasmopara viticola* and *Botrytis cinerea* (Barlass et al. 1987, Jeandet et al. 1992). Gao and Shain (1995) found that different levels of a polygalacturonase inhibitor in American and Chinese chestnut explained the difference in levels of resistance of these species to *Cryphonectria parasitica*, the cause of chestnut blight.

Evidence indicates that there are substances in butternut bark that have substantial fungicidal and antimicrobial properties. Butternut bark extracts were the most antagonistic and had the broadest spectrum of activity of the tree species tested against several human pathogenic bacteria (Omar et al. 2000) and fungi (Ficker et al. 2003).

It is generally established that *Juglans* species contain a number of structurally related, double-ring compounds called naphthoquinones. Many naphthoquinones have been found to inhibit the growth of plant pathogens. Several naphthoquinones known to be present in walnut husks including 1,4-naphthoquinone, juglone, menadione, and plumbagin were found effective against *Aspergillis flavius* (Mahoney et al. 2000). Naphthoquinones also inhibited the growth of several human pathogenic bacteria (Park et al. 2005, 2006).

The most predominant and most thoroughly studied naphthoquinone is juglone. It has long been observed that walnut trees are detrimental to the growth of certain plants such as alfalfa, apples, and tomatoes grown in close proximity. Root exudates were implicated and the substance was found to be juglone (Davis 1928, Massey 1925). It is responsible for the allelopathic effect of black walnut and butternut, and is present in the roots, leaves, fruit hulls, and bark of both species (Heimann and Stevenson 1997). Pure juglone and crude extract from green walnut hulls have been found inhibitory against a wide range of microorganisms including bacteria, filamentous bacteria, algae, and dermaphytes (Krajci and Lynch 1978). Juglone was an effective inhibitor of *Botrytis cinerea*, *Cladosporium herbarum*, and *Fusarium avenaceum* (Hadacek and Greger 2000). Inhibition of the growth of the wood-rotting fungus *Pleurotis sajor-caju* (Curreli et al. 2001) and the pecan scab fungus, *Fusicladium effusum* (Windham and Graves 1981) has also been demonstrated. It has been suggested that, compared to pecan, black walnut's high levels of juglone may be responsible for its greater resistance to scab (Hedin et al. 1979).

In a study comparing both leaf pathogens and non-pathogens of black walnut, juglone was more effective against the non-pathogens (*Gnomonia quercina*, *G. platani*, and *Sclerotinia sclerotiorum*) and one pathogen (*Cristulariella moricola*) than against the other two pathogens, *Cylindrosporium juglandis* and *Gnomonia leptostyla* (Cline and Neely 1984). This finding may indicate tolerance to juglone among some *Juglans* pathogens and higher concentrations of juglone are required to inhibit their growth. In that study the juglone concentration in leaves was dependent on leaf age; young leaves had a higher juglone concentration and were more resistant to anthracnose fungi than older leaves.

The objective of this study was to test reagent grade naphthoquinones and crude bark extracts of *Juglans* species and a *Juglans* hybrid for their effects against OCJ using a disc diffusion assay. Bark variables examined included month of collection and tissue age. We tested the hypothesis that *Juglans* species and selections contain various concentrations of juglone and/or related naphthoquinones, and that these

compounds influence resistance to OCJ. The purpose of this work was to examine the potential use of this assay to select butternut with resistance to butternut canker.

MATERIALS AND METHODS

Disc Diffusion Assay with Reagent Grade Naphthoquinones

A preliminary disc assay was conducted using several related naphthoquinones including juglone, 1,4-naphthoquinone, plumbagin, menadione, and lawsone obtained from Sigma-Aldrich (St. Louis, MO). The naphthoquinones were dissolved in 95 percent ethanol and applied to sterile 6.5-mm-diameter cellulose discs at a rate of 0, 5, 10, 20, 50, and 100 µg per disc. The assay procedure used was similar to the standard antibiotic sensitivity test (Barry 1964). To each petri plate containing malt agar, a spore suspension equivalent to 4 x 10^5 OCJ spores per plate was added and spread over the surface evenly using a sterile, bent plastic rod. Eight discs of naphthoquinone were tested for each treatment level. Plates were placed in the dark and incubated at 20 °C. After incubation for 72 hours, the fungal growth was clearly visible on the plates as a solid lawn, except for a clear inhibition zone around the discs. The diameter of each of these inhibition zones (including the disc) was measured, and samples with no inhibition were recorded as 6.5 mm, the diameter of the disc. The experiment was repeated once.

Plant Material

All bark samples were collected from a plantation near Rosemount, MN, consisting of 10- to 12-year-old trees. Species included *J. cinerea*, *J. nigra*, *J. ailantifolia* var. *cordiformis*, and the hybrid *J. cinerea* x *J. ailantifolia*. These trees included both non-selected, seed-propagated butternut of unknown origin and grafted trees selected for possible disease resistance (Table 1). Bark samples were collected monthly from April through October. A minimum of three 30-cm lengths (0.5 to 2.5 cm diameter) of 4- to 6-year-old branches per tree were collected each month.

Bark Extraction

In 2006, branches were divided by bark age: current year, 1- to 2-year-old, and 3- to 4-year-old bark. Outer (green layer) bark was discarded and only the inner, fibrous bark was used. Current year bark was collected starting in June. The following extraction procedure according to Omar et al. (2000) was used. Bark was air dried and ground in a Wiley mill to a fineness of a 20 mesh screen (0.8 mm). For the extraction, the bark powder was soaked in 95 percent ethanol at a rate of 3 g per 15 ml for 48 hours, and the resultant extractives were filtered and air dried. A total of 190 extract samples from 10 trees (Table 1) were prepared and stored at -20 °C. Extracts were prepared once and two experiments were performed on samples of the same extract.

In 2010, the inner bark of 1- to 6-year-old branches was used. The extraction procedure was modified somewhat to reduce heating and oxidative processes during grinding and to increase yield of extractives. Bark was ground with dry ice and stored at -70 °C. The extraction process was begun by mixing 1 g of bark powder in 10 ml of cold (-20 °C) 95 percent ethanol and soaking the mixture overnight. Mixtures

Table 1.—Source trees for bark extracts, Rosemount, MN.

Accession	Species/Selection	Year tested 2006	Year tested 2010
NB03	Non-selected *J. cinerea*[a]	X	X
NB04	Non-selected *J. cinerea*	X	X
NB10	Non-selected *J. cinerea*	X	X
NB11	Non-selected *J. cinerea*	X	X
NB16	Non-selected *J. cinerea*	X	X
SB01	Selected *J. cinerea*[b]		X
SB20	Selected *J. cinerea*		X
SB22	Selected *J. cinerea*	X	X
SB54	Selected *J. cinerea*		X
SB60	Selected *J. cinerea*		X
SB67	Selected *J. cinerea*		X
SB148	Selected *J. cinerea*	X	X
XX128	*J cinerea* x *J. ailantifolia*[b]	X	X
HN133	*J. ailantifolia* var *cordiformis*[b]	X	X
WA01	*J. nigra*[a]	X	X

[a]Open-pollinated seed origin.
[a]Grafted orchard trees, source tree selected for potential resistance to *Ophiognomonia clavigignenti-juglandacearum*.

were then agitated at room temperature for 24 hours, centrifuged, and the supernatant removed. Two successive extractions of 10 ml of 95 percent ethanol each were performed on the same bark powder and added to the original aliquot for a total of 30 ml of combined extract. Extracts were dried under vacuum until near dryness, and then air-dried to a tarry consistency. A total of 105 samples from 15 trees (Table 1) were prepared once and stored at -70 °C. Three experiments were performed with each extract sample.

Fungal Cultures

Cultures of OCJ isolated from butternut cankers collected in Wisconsin and Minnesota (Table 2) were grown on malt agar petri plates at 20 °C in the dark until sporulation occurred (30 days). Sporulating cultures were flooded with sterile water and rubbed lightly with a sterile, bent plastic rod to dislodge spores. Spore concentration was adjusted using a hemacytometer. Spores from two separate isolates were used in 2006 and mixed spores from four isolates were used in the 2010 experiments.

Bark Extract Disc Diffusion Assay

Bark extracts were resuspended in 95 percent ethanol and applied to sterile 6.5 mm cellulose discs at a rate of 2 mg per disc, then air dried. Ethanol controls were also prepared. To each malt agar petri plate, a spore suspension equivalent to 4 x 10^5 OCJ spores per plate was added and spread over the surface evenly using a sterile, bent plastic rod. Four discs of each extract were placed equidistant on each malt agar plate, two plates for each combination of month, tree accession and isolate. Plates were incubated at 20 °C in the dark. After 72 hours, the diameter of inhibition zones was measured. The experiment was repeated once in 2006 and twice in 2010.

Table 2.—*Ophiognomonia clavigignenti-juglandacearum* isolates used in assays.

Isolate	Origin	Year used 2006[a]	Year used 2010[b]
1344	Forest Co., WI	X	
1347	Kanabec Co., MN	X	
1384	Goodhue Co., MN		X
1385	Ramsey Co., MN		X
1387	Langlade Co., WI		X
1388	Forest Co., WI		X

[a]Isolates were used separately.
[b]Isolates were mixed.

Statistical Analyses

The 3-day inhibition zone measurements were subjected to analysis by means and standard errors, one-way ANOVA and via PROC MIXED (Enterprise Guide 4.2, SAS Institute, Cary, NC). Tree accession was included as the fixed effect and month of bark harvest, experiment, and isolate (for the 2006 data) were included as random effects; least square means separation tests were conducted using a Tukey-Kramer procedure with a significance level of 0.05.

RESULTS

Disc Diffusion Assay with Reagent Grade Naphthoquinones

The assay revealed that OCJ spore germination and growth was inhibited to varying degrees by the reagent grade naphthoquinones (Fig. 1). Menadione, 1, 4-naphthoquinone, and plumbagin were highly effective against OCJ. Juglone was also inhibitory, but to a lesser extent. Lawsone was minimally inhibitory and the ethanol controls exhibited no inhibition of spore germination or fungal growth.

Bark Extract Disc Diffusion Assay

In 2006 bark extracts from the current year branch growth had a significantly ($p < 0.0001$) weaker inhibitory effect than older bark, with the inhibitory effect of extracts from 1- to 2-year-old bark nearly identical to extracts of the 3- to 4-year-old bark (Fig. 2). The level of inhibition in the first experiment was greater than in the second experiment ($p < 0.0001$), presumably because of degradation of the compounds in storage. However, the difference had no effect on the ranking of the accessions in the experiments. The level of inhibition varied by OCJ isolate with isolate 1347 being inhibited less than isolate 1344 ($p < 0.0001$) (Fig. 2). Isolate, however, had no effect on the ranking of the accessions (data not shown).

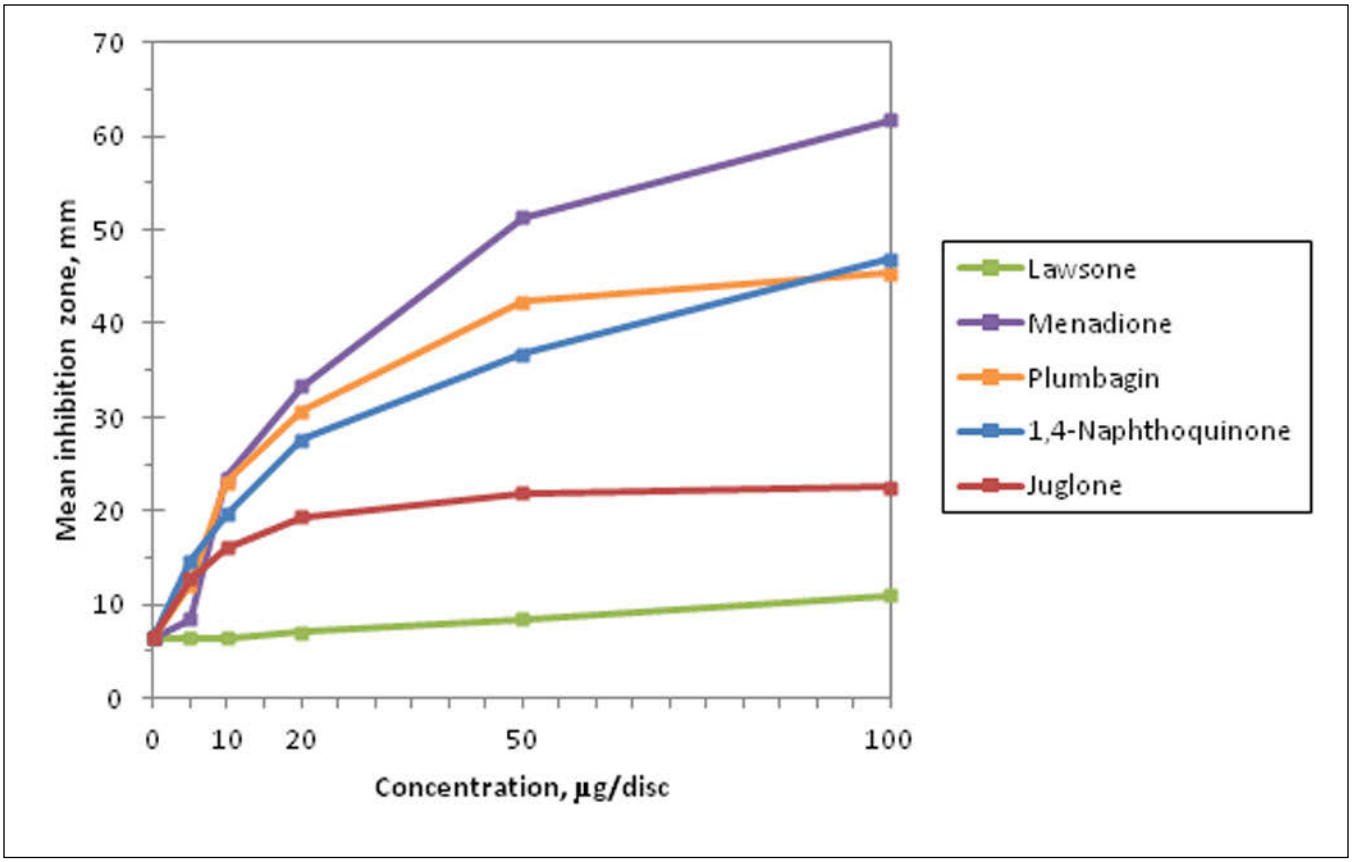

Figure 1.—Inhibition of *Ophiognomonia clavigignenti-juglandacearum* by reagent grade naphthoquinones. Data points are means of two experiments, n=16, SE=0.725.

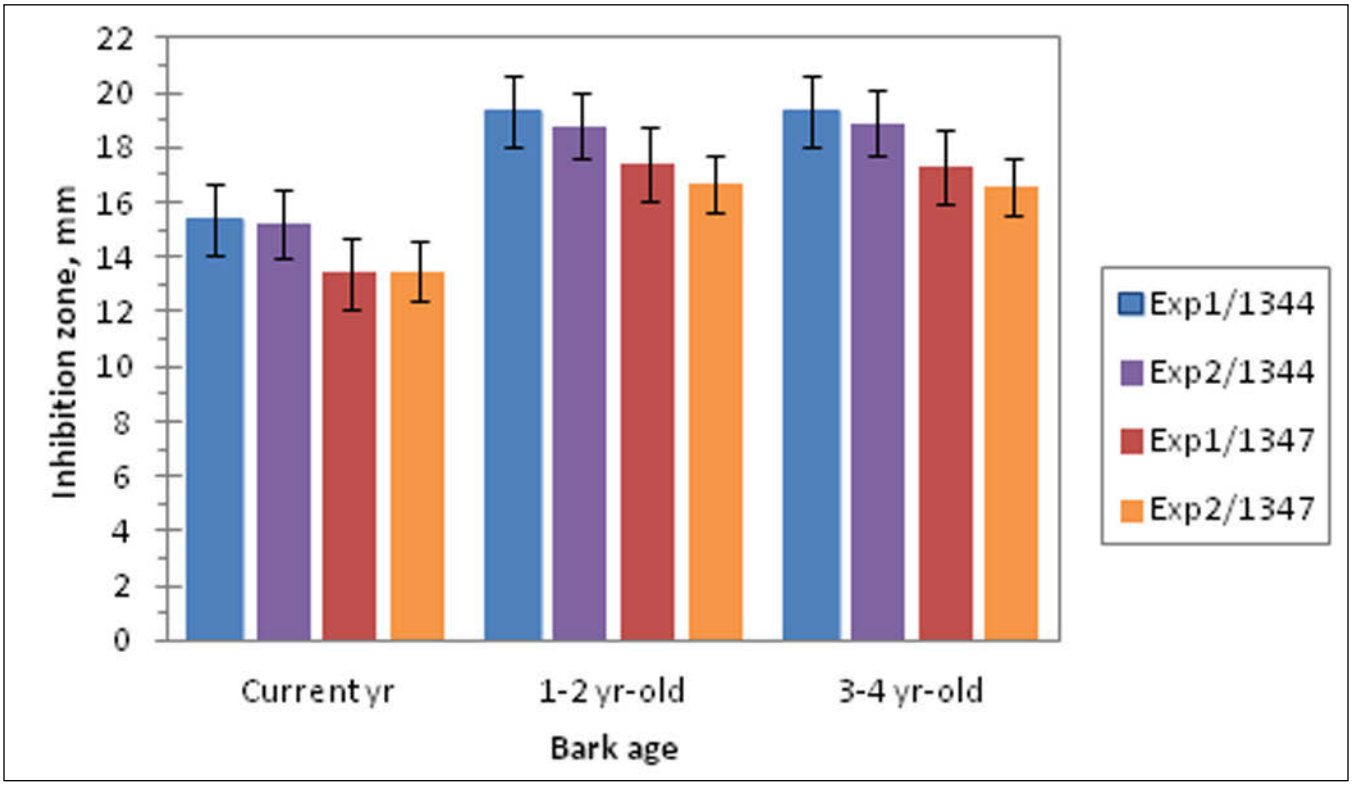

Figure 2.—Bark extract inhibition of *Ophiognomonia clavigignenti-juglandacearum* comparing bark age and isolate, April-October, 2006. Data from all collection months and accessions combined.

There was a difference ($p < 0.0001$) in inhibition by month of bark collection (Fig. 3). In 2006 inhibition by extracts peaked in May. Inhibition reached another peak in August and September. The level of inhibition using extracts from bark collections in August and September were not significantly different from each other. In 2010 there was no peak in inhibition in May, however the later trend was similar to 2006, with the inhibitory activity peaking with late summer and early fall bark collections (Fig. 3). Although there was a difference ($p < 0.0001$) between the three experiments in 2010, the ranking of the accessions in terms of the size of the inhibition zone in each experiment was similar (Fig. 4).

The inhibitory effect of bark extracts varied by *Juglans* species and accession (Table 3, Fig. 5). Most of the nonselected butternut lines (NB) ranked lower than the selected, putative resistant lines (SB). For example, inhibition by extracts of NB16 and NB03 consistently ranked among the lowest in both years, while inhibition of bark extract from SB22 was greater than all other accessions in 2006 and continued to rank among the highest in 2010. Extracts from the hybrid consistently ranked high in inhibition, and the walnut and the heartnut were somewhat variable, ranking moderate to low.

In 2010 the differences in rankings of the accessions, species and the hybrid was most clearly evident using the extracts from the August bark collection (Fig. 5). While bark extracts from all accessions yielded peak inhibition in late summer or early fall, the inhibition of extracts from the selected butternuts peaked earlier than the non-selected butternuts.

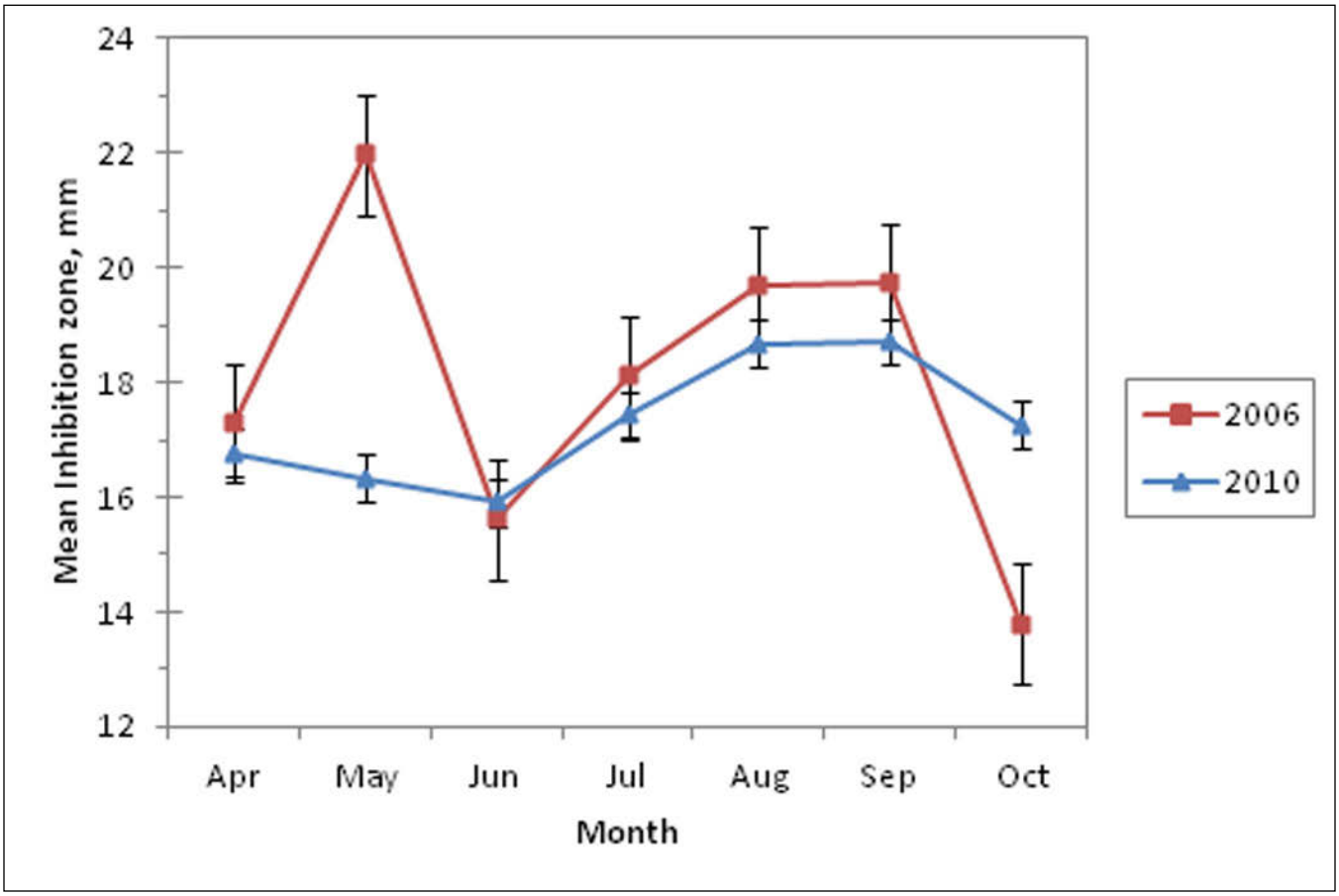

Figure 3.—Inhibition of *Ophiognomonia clavigignenti-juglandacearum* comparing experiment year and month of bark collection. Data from all accessions combined. The experiment was repeated once in 2006 and twice in 2010.

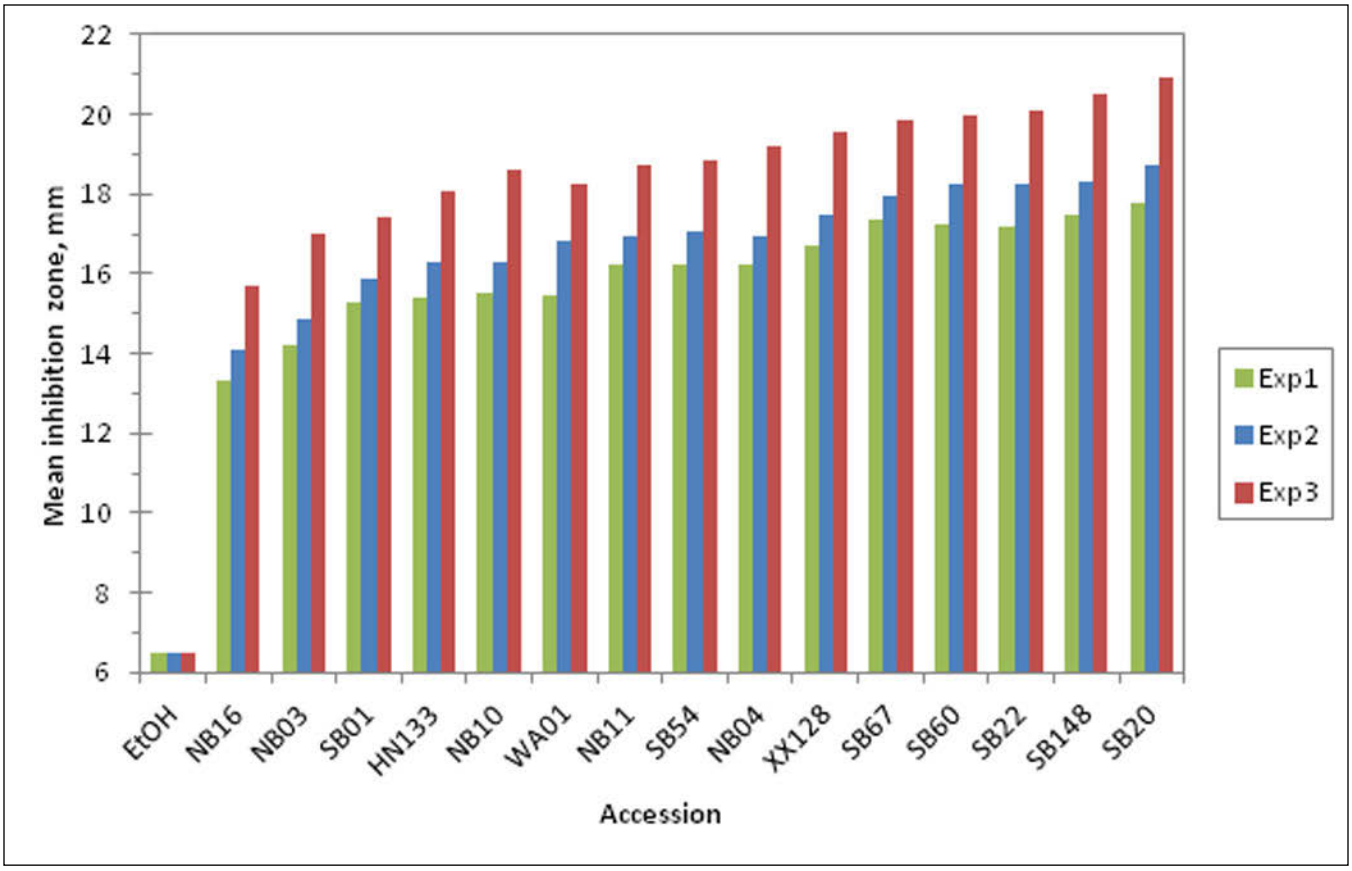

Figure 4.—Inhibition of *Ophiognomonia clavigignenti-juglandacearum* comparing tree accession and experiments in 2010. NB=Nonselected butternut, HN=heartnut, WA=walnut, XX=hybrid, SB=selected butternut, EtOH=ethanol control.

Table 3.—Bark extract inhibition of *Ophiognomonia clavigignenti-juglandacearum*.

2006[a]				2010[b]			
	Inhibition zone, mm				Inhibition zone, mm		
Accession	Mean[c]	Range	SE	Accession	Mean[c]	Range	SE
NB16	14 a	10.5-18	0.208	NB16	16 a	13-19	0.223
WA01	18 b	13.5-22	0.209	NB03	16 a	14-20	0.221
NB03	18 b	13.5-23	0.217	NB10	17 ab	13-20	0.250
NB04	20 c	15-26	0.233	HN133	18 bc	15-21	0.199
HN133	20 c	16-26	0.201	NB04	18 c	13-22	0.389
SB148	21 c	16-25	0.215	SB01	18 c	14-23	0.311
NB10	21 cd	15-28	0.287	NB11	18 c	14.5-21	0.288
NB11	21 de	16.5-28	0.237	WA01	19 cd	16-22	0.239
XX128	21 e	17-29	0.252	SB54	19 cd	16-22	0.212
SB22	23 f	18-29	0.247	SB148	20 de	17-23	0.234
				SB22	20 ef	17-23	0.202
				XX128	20 ef	17-23	0.211
				SB60	20 ef	16.5-25	0.364
				SB67	21 ef	17-26	0.334
				SB20	21 f	17-24	0.241

[a]Data for August/September collection, 1- to 4-year-old bark, 2 isolates and 2 experiments combined, n (number of discs) = 128/accession.
[b]Data from August/September collection, 3 experiments combined, n (number of discs) = 48/accession.
[c]Values with the same letter do not differ significantly according to Tukey-Kramer's least squares means test ($p<0.05$).

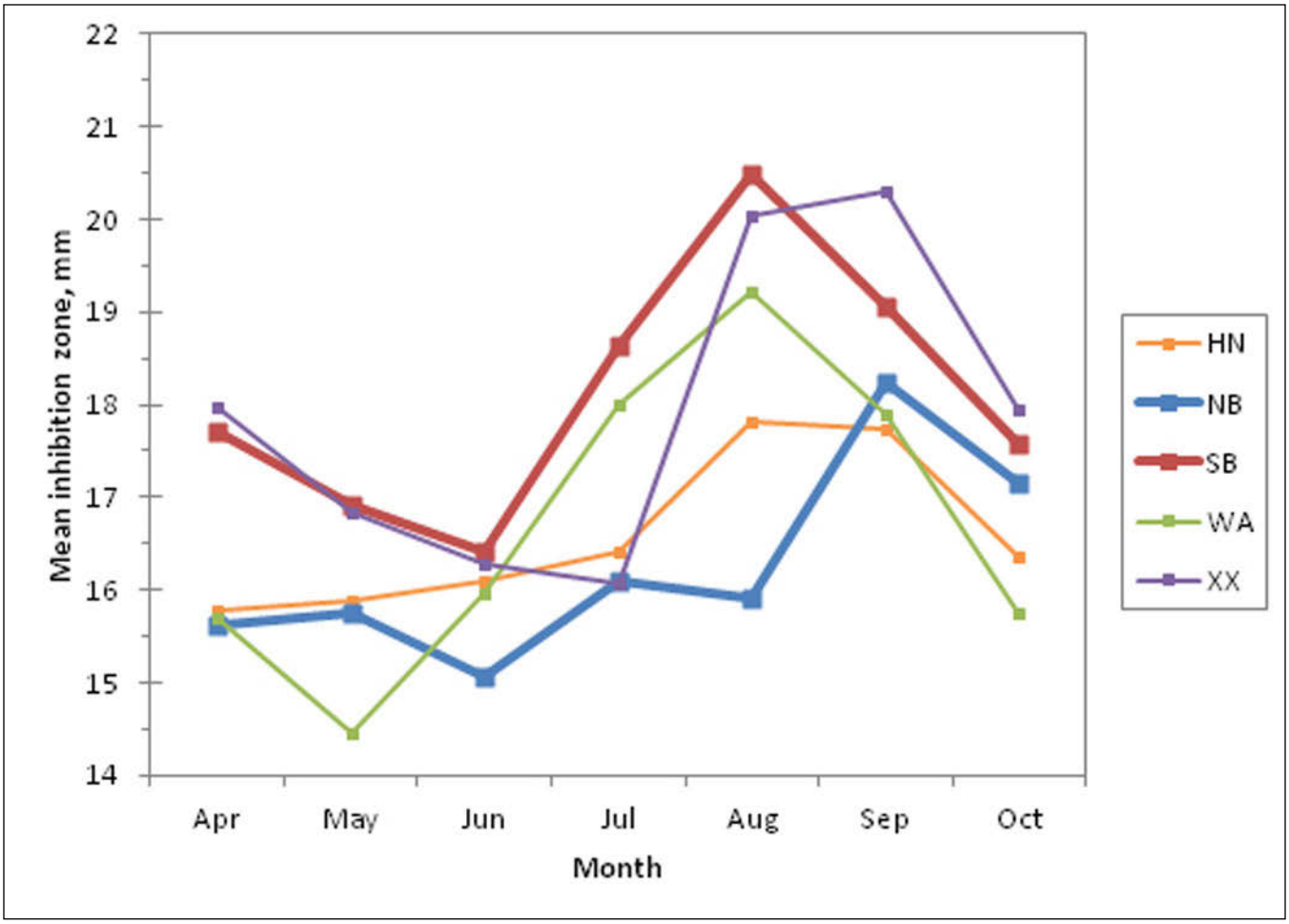

Figure 5.—Mean inhibition of *Ophiognomonia clavigignenti-juglandacearum* comparing month of bark collection and species, 2010. HN=heartnut, NB=Nonselected butternut, SB=selected butternut, WA=walnut, XX=hybrid.

DISCUSSION

Restoration of butternut will require a reliable procedure to select trees that have resistance to butternut canker. Some success has been reported by investigators challenging trees directly with the pathogen in common garden orchards. However, propagating candidate trees, establishing orchards and testing trees in this manner is time and cost prohibitive in most cases. A rapid, repeatable test that distinguishes highly disease resistant trees from susceptible trees is needed.

The preliminary work reported in this paper offers an encouraging approach to screen butternut for canker resistance using crude bark extracts against the pathogen employing a rapid in vitro assay. We demonstrated that naphthoquinone compounds known to be produced in *Juglans* species are inhibitory to spore germination and growth of OCJ.

A range in the size of the inhibitory zones resulting from bark extracts of different *Juglans* species and butternut selections suggests that different inhibitory compounds or quantities of these compounds produced by individual trees may be responsible for the level of fungal growth inhibition. It remains to be determined whether these compounds play a role in resistance to the fungus in nature that could explain the observed variation in disease severity among butternut.

The highest level of inhibition was obtained using extracts from bark collected in late summer and fall. Fall was also the period of greatest separation of susceptible and resistant butternut selections based on artificial inoculations of trees with the fungus (Ostry and Moore 2008). This suggests that this may be a key period for butternut trees to produce active defense compounds. We are investigating the temporal changes in the level of inhibition of bark extracts among the known resistant and susceptible butternut selections to determine if a late summer-fall assay of bark extracts could be used to differentiate levels of compounds among trees in order to select trees that may be resistant to the canker disease.

Results of the disc assay produced results similar to screening 7- to 11-year-old trees in the field by introducing the fungus into wounds (Ostry and Moore 2008). We obtained a range of reactions among unknown butternut selections and those selected for putative resistance to OCJ. Butternut selections known to be disease-free or nearly so in the field (SB accessions) generally ranked higher than nonselected (NB) accessions based on the size of the inhibition zones in the laboratory assay.

We are currently working with Dr. Adrian Hegeman in the Department of Horticultural Science at the University of Minnesota using metabolomics (analytical measurement of secondary metabolites) to identify the active compounds in the crude extracts used in the assay reported in this paper. Juglone and plumbagin have been positively identified in the extracts. Bark extracts from additional trees in our butternut archive collection will be used in future assays and results compared to previous canker resistance screening tests of these trees and to the original source tree health in the field to validate the utility of this assay.

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NURSERY PRODUCTION AND PLANTATION ESTABLISHMENT

ADVANCES IN FERTILIZATION FOR HARDWOOD REGENERATION

Douglass F. Jacobs[1]

ABSTRACT

Optimizing fertilization programs in the nursery and field may help improve regeneration and restoration of temperate deciduous hardwoods. Our research program has demonstrated the applicability of nutrient loading in fine hardwood systems to promote seedling uptake and storage of nutrients during the nursery phase (Birge et al. 2006, Salifu and Jacobs 2006, Salifu et al. 2006, Schmal et al. 2011). We also have shown the benefits of nutrient loading for subsequent seedling establishment under a wide range of transplant conditions (Salifu et al. 2008; Salifu et al. 2009a, b).

We have reported on how controlled-release fertilizer technologies can stimulate growth of afforestation hardwoods (Jacobs et al. 2005) and are currently investigating how these advanced fertilizers affect nutrient uptake and leaching in mid-rotation black walnut (*Juglans nigra* L.) plantations.

Finally, some of our recent research with intensively managed black walnut plantation systems in Spain has documented very high optimal foliar nitrogen concentrations, as well as limitations in fertilizer use efficiencies at upper fertilizer rates (Goodman et al., in press). Collectively, these current research results have important implications for managing black walnut and other fine hardwoods in the nursery and field.

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DIRECT SEEDING OF FINE HARDWOOD TREE SPECIES

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Abstract.—Direct seeding of fine hardwood trees has been practiced in the Central Hardwoods Region for decades, but results have been inconsistent. Direct seeding has been used for reforestation and afforestation based on perceived advantages over seedling planting, including cost and operational efficiencies, opportunities for rapid seedling establishment and early domination of planting sites by desirable trees, improved tree form through increased competition, and ability to select the parentage of planting stock. Some barriers to successful direct seeding have included poor seed quality, improper handling or planting of seed, seed predation by rodents and other seed predators, and difficulty in establishing germinants due to competing vegetation. The literature and current field practice indicate direct seeding of black walnut, butternut, black cherry, American chestnut, and chestnut hybrids can be a viable regeneration technique, but success is dependent on proper seed collection, handling and sowing procedures, protection of seed from predation, and effective weed control maintained until seedlings are established.

Direct seeding of fine hardwood tree species has been used for afforestation and reforestation efforts for many years with mixed results. Direct seeding has several advantages over planted seedlings. For example, direct seeding has a lower initial cost than planting seedlings. Direct seeding results in undisturbed root system development, thus avoiding the root damage and transplanting shock associated with planting bare-root seedlings. Direct seeding may be more flexible in the timing of the planting, depending on the species being planted and seed treatments. Direct seeding may also correspond better with the equipment and labor available to private landowners. The desire to create high density tree plantations to quickly occupy the planting site and encourage development of straight boles and small side limbs, and subsequent natural pruning, has also created interest in using direct seeding. Seed for direct seeding can be collected from parent trees with desirable characteristics such as disease resistance, rapid growth rate, superior wood quality, or selected provenance (Rasmussen et al. 2003, Van Sambeek 1988).

Practitioners using direct seeding can experience challenges in application, resulting in poorly stocked plantings or outright regeneration failures in several cases. The following sources of failure were reported: planting seed that is not viable, incorrectly handling and sowing seed resulting in reduced viability, seed predation (primarily by rodents), lack of site preparation or site preparation that does not adequately control competing vegetation, failure to maintain control of competing vegetation until germinants or seedlings are established, poor sowing technique or soil conditions resulting in failure of seed to germinate or mortality of new seedlings, and failure to match the tree species to appropriate growing sites.

Several studies and reforestation projects have demonstrated that direct seeding of fine hardwood species such as black walnut (*Juglans nigra* L.), butternut (*Juglans cinerea* L.), northern red oak

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(*Quercus rubra* L.) and white oak (*Quercus alba* L.), black cherry (*Prunus serotina* Ehrh.), American chestnut (*Castanea dentata* (Marshall) Borkh.), and chestnut hybrids can be successfully established. This paper examines the literature and field practices related to direct seeding of black walnut, butternut, black cherry, and chestnuts planted for reforestation and afforestation in eastern North America, with the objective of outlining recommended practices to increase success. Direct seeding of oak species was reviewed in detail by Dey et al. (2008).

SPECIES REVIEWS

Black Walnut

Black walnut is one of the most promising species to regenerate by direct seeding; however, results with direct seeding of black walnut have been inconsistent (Rasmussen et al. 2003).

Black walnut seed may be collected locally or purchased through commercial outlets. Some sources have recommended using local seed or seed collected from areas within 100 to 200 miles south of the planting location to take advantage of superior growth demonstrated by seed from areas south of the planting area. Deneke et al. (1981) and Bey (1980) noted that using seed from 100 to 200 miles south of the area to be planted resulted in better growth except in the far northern part of the black walnut range.

Seed can be sown cleaned or in the husk. Nielsen (1973) suggested that walnuts thoroughly cleaned of all husk material may not be pilfered by rodents to the extent that walnuts planted in the husk may be. There are several examples of heavy pilferage of husked walnut after planting, but these seeds may not have been cleaned to the degree in the previous instance (Phares et al. 1974). If collectors want to clean the seed, it should be done before the husk dries. Seeds still in the husk need to be stored carefully to avoid heating due to decay of the husk, resulting in possible death of the seed. Storage in cool conditions or in small lots allowing for good air circulation is recommended to keep from overheating the seed (Willliams 1982). Immersing freshly husked walnut seed in water and removing floating seed are recommended to increase the number of sound or viable nuts that may be planted. Seeds may be planted in the fall at or shortly after collection, or they may be stratified and planted the following spring. The stratification period for optimum seed germination is 90 to 120 days at 1 to 5 °C (Bonner and Karrfalt 2008), but some seed sources may yield varied results. Some seed may not germinate until the second season after planting (Van Sambeek et al. 1990).

Dierauf and Garner (1984) examined the influence of nut size and planting depth on seedling performance over 5 years. Nuts were sorted into three size classes: small (1 to 1.25 inches), medium (1.25 to 1.5 inches), and large (greater than 1.5 inches). Nuts smaller than 1 inch were discarded. Size-sorted, stratified nuts were sown in March at depths of 3, 5, and 7 inches. Nuts in the medium class produced the most seedlings after one growing season followed closely by the large class. Small walnuts lagged far behind. The 3-inch sowing depth resulted in the most seedlings after one growing season. At five growing seasons, there was no strong relationship between seedling height and nut size or depth of planting.

Studies evaluating season of planting have produced variable results, but the operational advantage seems to go to fall planting, which eliminates additional seed handling, results in natural stratification, and may provide for improved germination and earlier seed emergence in the spring (von Althen 1969). Some studies indicated that spring planting resulted in higher stocking, possibly due to decreased time of exposure to seed predators. In either case, the potential for seed predation should be carefully evaluated. Planting seed near woodlands or other habitat that harbors rodents can result in massive loss of seed to predation (Wendel 1979, Williams and Van Sambeek 1984). Direct seeding areas within 300 feet of woodlands or other favorable habitats for squirrels and other seed predators may result in heavy seed losses. Seed protection may provide improved germination and establishment when seed predation is likely.

In a study of several reproduction methods for black walnut in Ontario, Canada, the depth of planting was examined as a possible deterrent to seed predation (von Althen 1969). Black walnut seed was planted in open fields and small openings in hardwood woodlots at depths of 2, 6, and 10 inches. Deep seeding delayed germination and reduced total germination in the open field plantings with third year survival of 93, 85, and 72 percent for fall seeded black walnut planted at 2, 6, and 10 inches deep, respectively. Survival of spring seeded germinants was only slightly lower for each depth. Nuts planted in the woodland openings experienced heavy predation by squirrels with 78 to 86 percent of planted nuts eaten; 60 percent of planting spots were disturbed in the first 4 weeks. In another experiment, seeds planted in woodland openings yielded 80 percent of seed spots stocked for seed protected with 24-inch-tall and 30-inch-wide wire screens versus 16 percent stocked with no seed predator protection. Nursery seedlings (1-0) planted in the same experiment yielded 94 percent stocked after two growing seasons and were recommended as superior to direct seeding for reliability of regeneration and growth of black walnut.

Fall and spring direct seeded walnut and spring planted walnut seedlings were compared over a 7- year period on four nonforested sites in western Virginia (Dierauf and Garner 1984). Nine seeds were planted at spots on a 6.6-foot grid. Seedlings were planted on the same spacing. Simazine and paraquat dichloride was sprayed around but not over each seeding and planting spot at planting and for 3 years after planting. March seeding resulted in 90 percent of the seeded spots with at least one seedling compared to 76 percent for November seeding. Planted seedlings averaged 98 percent survival over the four tracts. By the end of the seventh year, approximately 14 percent of the seeded seedlings had died. The tallest seedlings in each direct seeded spot grew faster than the planted seedlings for the first 3 years and at about the same rate thereafter. Planted seedlings grew slowly in the first two seasons, but growth improved in the third and fourth seasons. The average height of all trees 7 years after planting equaled: planted seedlings (10.0 feet), March sown seed (9.5 feet), November sown seed (9.4 feet).

Stratified and sprouted seed can be used to increase the potential for desirable stocking and better control tree spacing (Fig. 1). Black walnut progeny tests using sprouted seed have demonstrated high survival rates and height growth equivalent to seedling plantings of the same genetic families (data on file with the Hardwood Tree Improvement and Regeneration Center, West Lafayette, IN). Jacobs and Severeid (2004) reported black walnut survival over 95 percent 5 years after sowing sprouted seed in Wisconsin. Davis et al. (2004) recommend using pre-germinated seed in direct seeding operations to improve density control and to replace failed seedlings early in plantation establishment.

Figure 1.—Stratified black walnut seeds that are beginning to sprout. (Photo by James R. McKenna, U.S. Forest Service)

Careful site selection is as crucial to direct seeding of walnut as it is for planting walnut seedlings. Soil surveys should be consulted to assist in evaluating the site suitability for black walnut plantings along with the recently developed Black Walnut Suitability Index available in participating states on their USDA Natural Resources Conservation Service Web Soil Survey sites (Wallace and Young 2008). SoilWeb is a new tool available to smart phone users that provides on-site soil information based on GPS-determined location (Beaudette and O'Green 2009). Combining the real-time soils information from SoilWeb with the more detailed information in the Web Soil Survey, Black Walnut Suitability Index, and references such as Ponder (2004) provides convenient tools for resource professionals and landowners to evaluate sites for planting black walnut and other tree species. Soil testing for pH and nutrients can help determine appropriate sites and suggest soil amendments that may improve establishment and long-term performance.

Site preparation is a key practice for seedling survival and establishment. Black walnut is a species that can pioneer in established grass and weeds, but growth is often slow and survival reduced. Glyphosate is the most commonly listed herbicide for pre-planting control of perennial weeds and grasses and should be applied in the summer or fall before sowing. Some practitioners apply post-emergent herbicides over the planting area in the spring before seedling emergence, stating that the killed vegetation provides natural mulch for the emerging seedlings (Edge 2004). Some post-emergent herbicides used for direct seeding include glyphosate, clethodim, clopyralid, sulfometuron methyl, imizaquin, and fluazifop-p-butyl.

A study on graded surface-mine land demonstrated black walnut seeded into perennial grasses yielded 38 to 50 percent establishment and 42 to 48 cm average stem height after two seasons when glyphosate and simazine applications were used to control grass and forb growth (Philo et al. 1983). They found that black walnut direct seeded in May of 1980 on soil banks of Illinois land surface mined in the 1960s benefited from 2 years of weed control. Seeds planted in established perennial grasses germinated and grew at a much lower rate than seeds provided with 2 years of weed control using glyphosate or glyphosate and simazine. Reduced germination in plots sprayed with simazine and glyphosate compared to glyphosate only indicated a possible negative effect on germination by simazine. The authors suggested that simazine might have less negative effects at a lower rate of application than was used in the experiment (5 lb/acre). Some sources recommend delaying pre-emergent herbicide application until after the first year of seeding to avoid possible damage to seed germination. Several successful plantings mentioned in research literature or extension publications indicated pre-emergent herbicides were successfully applied shortly after direct seeding. Some pre-emergent herbicides used for direct seeding include simazine, oryzalin, pendimethalin, oxyfluorfen, and metolachlor.

Van Sambeek (1988) listed some steps to follow to improve success when direct seeding black walnut. Prepare the site before planting by killing competing vegetation. Place collected seed in water and remove floaters. Break open a sample (10 to 20) of seed to determine the percentage of sound seed. Viable seed has white, firm kernels. Non-viable seed has shriveled, beige or brown kernels that are watery or give off a rancid odor. The percentage of sound seed should guide planting density. If seed is spot-planted, 80 to 100 percent sound seed should be planted at two seeds per spot, 60 to 80 percent sound at three seeds per spot, 40 to 60 percent sound at four seeds per spot, and less than 40 percent viable seeds at five or more seeds per planting spot. Seed should be planted 2 to 3 inches deep and can be oriented in strips, triangles, or squares, depending on whether rows or spots are to be sprayed for weed control. Seeds should be protected from squirrels and other seed predators with mechanical barriers or chemical repellents. An inexpensive repellent application entails placing a generous amount of fresh cow manure over each

planting spot (Williams and Funk 1979). Thin to the best seedling in each planting spot following the first or second growing season. Planting seed about 8 inches apart in each spot will make it easier to drive a spade through the top of the taproot to kill unwanted seedlings or to lift and transplant extra seedlings in the fall or the following spring.

Robison et al. (1997) make several recommendations based on experience with nursery seedling production and experimental and field experience with direct seeding. Intensive site preparation is required for successful seedling establishment, and weed control for at least three growing seasons can increase the ability of seedlings to occupy the site. Screening for suitable walnut sites, soil testing, and nutrient management in conjunction with effective weed control can also enhance seedling growth and establishment and provide a better opportunity for long-term productivity. Choose seed sources for best long-term results by using local or southern sources. Rodents pose a significant threat to direct seeding success rate. Late spring planting of stratified or pre-germinated seed may provide for quick emergence of seedlings in a season when other food sources are available for predators. Providing alternate food sources or cull seed between rodent habitat and direct seeded areas may help reduce predation, especially if lightly disked in so seed begins the stratification and germination process. Circumstantial evidence indicates that squirrels ignore sound air-dried seed with dead embryos or that squirrels detect volatiles produced during stratification, which can be masked by fermenting grain in fresh cow manure.

A long-term study applied to planted walnut seedlings, but with application for direct seeding as well, indicated that seedlings protected from wind for the first 4 years after planting developed and retained a large advantage in height and diameter growth compared to those without wind protection (Heiligmann et al. 2006). Black walnut seedlings grown in an open field location but protected from wind by a barrier made of lathe snow fence during their first 4 years of growth demonstrated increased growth after the first growing season and maintained a significant growth advantage after 11 growing seasons compared to unprotected seedlings. After 11 years the protected seedlings showed 21 percent improved survival, 60 percent more diameter growth, and 70 percent more height growth versus unprotected seedlings. Unprotected seedlings showed discolored leaves in late August; protected seedlings did not display discolored leaflets until at least mid-September. This difference disappeared after the wind barriers were removed after the fourth year. Protected walnut also developed larger crowns and leaf areas. After 2 years the leaf area of protected seedlings was 1.75 times that of unprotected seedlings.

Butternut

Butternut has been the subject of much less experimentation in direct seeding than black walnut. Butternut has become rare in most of its former range due to disease, particularly butternut canker (*Ophiognomonia clavigignenti-juglandacearum* ((Nair, Kostichka, & Kuntz) Broders & Boland), and land use patterns that may not favor regeneration of this relatively short-lived tree. Direct seeding butternut has many points in common with direct seeding black walnut. Butternut seed collection and handling procedures as well as planting procedures are similar to those of black walnut. Due to the rarity of butternut and the attractiveness of the seed to squirrels and other seed predators, seed should be protected from predation by barriers or other physical or cultural methods. Stratifying seed and planting sprouted seeds with protection from seed predators is an intensive direct seeding technique, but it also provides the best chances for establishing seedlings.

The butternut canker disease can be carried on the seed and infect newly sprouted seedlings (Andre et al. 2001), so collection of seeds from uninfected or apparently healthy and vigorous trees is preferred. Andre et al. tested several methods to decontaminate butternut seed before planting. They found that soaking the seed in boiling water for 1 minute was

effective in eliminating butternut canker infection and did not negatively impact seed germination. Seed collectors should be aware that butternut hybrids, generally with Japanese walnut (*Juglans ailanthifolia* Carr.), are commonly encountered and are often prolific nut producers (Woeste et al. 2009). The Identification of Butternuts and Butternut Hybrids guide can assist seed collectors in recognizing butternut hybrids from butternut for seed collection (Farlee et al. 2010a). Efforts are under way to identify disease resistant butternut. But until disease resistant seed sources are available, pure butternut plantings or plantings with a high proportion of butternut are not recommended, because of a high probability of early mortality. Scattering butternut through a planting has the advantages of maintaining some butternut in the area, limiting the amount of butternut canker inoculum and hosts, and providing adequate diversity of trees for a well-stocked planting (Farlee et al. 2010b).

Experiments with direct seeding butternut have shown that the seedlings require full sunlight and may have difficulty competing with associated fast growing shrub and tree sprouts, so weeding or crop tree release may be required to establish the butternut in a direct seeded planting (Ostry et al. 2003). Sprouted butternut seeds have been used for progeny tests by the Hardwood Tree Improvement and Regeneration Center and have performed similarly to seedling plantings; however, sprouted seedlings were reported to be more labor intensive to establish than dormant 1-0 seedlings due to cumbersome procedures to sprout, store, and transport the seed, and effort and supplies needed to protect the seed from predation (McKenna et al. 2011).

American Chestnut and Chestnut Hybrids

American chestnut and the back-crossed hybrid chestnuts being bred for resistance to chestnut blight are trees of great interest to landowners, agencies, and the surface mining industry in the eastern United States for reforestation and land reclamation. As disease resistant chestnuts are made available, the re-introduction efforts may include direct seeding. Sprouted American chestnut seed was spot planted in mixed plantings with sprouted northern red oak and black walnut seed near Rockland, WI, in the spring of 1995 and 1996. Seed and resulting seedlings were protected with 24-inch-tall tree tubes through the following spring. By November 2002, American chestnut and black walnut survival was more than 95 percent, and red oak survival was about 85 percent. The reduced oak survival was primarily the result of seed predation. American chestnut was significantly larger in d.b.h. and height compared to both black walnut and northern red oak (Jacobs and Severeid 2004). Fields-Johnson et al. (2010) reported direct seeded American chestnut survival after one growing season was 76 percent compared to 83 percent for bare-root seedlings. French et al. (2008) reported American chestnut direct seeded on the Cumberland Plateau had greater first-year survival (61.8 percent) than containerized transplants (51.2 percent), but height and diameter growth were greater for the containerized transplants.

American chestnut, Chinese chestnut (*Castanea mollissima* Blume), and three back-crossed hybrids of these two species were direct seeded in May 2008 on loosely graded surface-mine soils in West Virginia. Some seeds were protected with 18-inch-tall tree shelters, while others were unsheltered. Combined survival for all seed types 4 months after planting was 72 percent. Seed protected with tree shelters had 81 percent survival, while unprotected seed had 63 percent survival (Skousen et al. 2009). Predation did not pose a problem at the study location. Chinese chestnut had the highest survival (82 percent) and American chestnut had the lowest survival (67 percent) of all seed types, while the hybrids were intermediate in survival. Direct seeding was found to be the most cost effective and efficient method for establishment; however, planting of seedlings was found to ensure greater survival, better control over tree spacing, and enhanced ability to compete with other vegetation. Direct seeded trees did not compete adequately with resprouting vegetation that had been cleared (Phelps et al. 2005).

Chestnuts may be planted in the fall shortly after collection or stored for spring planting. Seed should be floated in water, and unfilled or immature seed removed. Seed collected in extremely dry conditions should be left in water overnight to restore normal seed moisture. Fall planted seed should be protected from predators. Nuts to be stored for spring planting should be allowed to surface dry after floating and then be stored in unsealed bags at 1 to 3 °C for 1 to 3 months. Nuts should be sown 0.75 to 1.5 inches deep (Bonner and Karrfalt 2008). American chestnut can grow rapidly on ideal sites, so consideration should be given to interspecific competition when designing the planting. The sprouted seed planting of Larry Severeid in northwestern Wisconsin, composed of a mixture of American chestnut, black walnut, and northern red oak (Fig. 2), is an example of a well-stocked direct seeded planting where American chestnut growth has outstripped neighboring oaks and black walnut (Jacobs and Severeid 2004).

The American Chestnut Foundation provides the following guidelines for planting American chestnut and chestnut hybrids. The ideal pH range is 4.5 to 6.5, and ideal planting sites should be well drained with sandy to loamy soils. Avoid sites with heavy clay soils or poor drainage. Early spring planting is recommended. Seed may be sprouted by this time, and if so, the seed should be planted with the radicle facing down and covered with 0.5 to 1 inch of soil. Long

Figure 2.—Fifteen-year-old planting of American chestnut (right foreground), black walnut (middle), and red oak (left foreground) established by directing seeding using sprouted seed in 1995 and 1996. (Photo by Lenny D. Farlee, Purdue University)

radicles may be clipped before planting. Protection from seed predators is required even after seedling emergence, because squirrels will dig up the seedling to access the remainder of the nut. Protection can be provided by placing partially buried tree tubes, wire cones, or cages over planted nuts (Fitzsimmons 2006). Another economical technique to protect seed of chestnuts or other hardwoods from rodents uses a number 2 (20 oz) can. One end of the can is removed, and an X or cross pattern is cut in the center of the other end. Pliers or a similar tool are used to curl back the four corners of the cut to allow a space for the seedling to emerge (Fig. 3). The can is pushed into the soil over a planted seed until the cut end is flush with the surface. Non-aluminum cans generally rust away before they present a barrier to growth of the seedling. Burning the can before use will accelerate corrosion (Diller 1946).

Black Cherry

Black cherry use in direct seeding has been less successful compared to the other species covered in this paper. Huntzinger (1972) reported that seed treatment and storage, depth of seed sowing, and protection from deer browsing are important contributors to direct seeding success for black cherry in the Allegheny Plateau. Planting in areas with established grass or weeds may lead to long establishment periods or failure unless intensive vegetation control measures are employed. Direct seeding black cherry was recommended for cutover mixed hardwood areas where advance regeneration is lacking.

Figure 3.—A can prepared for placement over a planted seed. (Photo by Mel Baughman, University of Minnesota)

Fresh seed collected in September should be cleaned of pulp, allowed to surface dry, and then sown immediately if fall sowing is desired. For spring sowing, the dried seed is stored in sealed polyethylene bags at room temperature for 2 to 4 weeks and then stratified for sowing in March or early April. The recommended stratification period is 120 days at 2.8 to 5 °C.

A sowing depth of 1.5 inches combined with early sowing, either fall or spring, gave the best results. This finding stands in contrast to the general recommendation of sowing seed at a depth of one to two times seed diameter. Two potential sowing patterns were recommended. Plant a minimum of four seeds per 1-foot-diameter spot, with spots spaced 4 by 4 feet apart. This spacing should result in closed canopy within about 4 years, and the dominant seedling at each spot could average more than 8 feet tall at 4 years. The other recommended method involves planting 9 to 12 seeds in a 2-foot-diameter spot and spacing spots at about 15 by 15 foot spacing.

Protection from deer browsing is required for establishment, with fencing as the recommended method. A study comparing the performance of 1-0 bare-root seedlings, direct seeding, and containerized seedlings of red oak, tuliptree (*Liriodendron tulipifera* L.), and black cherry planted on cutover forest land on the Fernow Experimental Forest in West Virginia reported that mice and chipmunks destroyed most of the direct seeded red oak and black cherry. As a result, few seedlings and few trees were in dominant or codominant positions after 7 years, compared to 1-0 seedlings (Wendel 1979).

In direct seeding in reclamation projects, Davidson (1980) noted that black cherry has performed poorly. For direct seeding for reclamation, he recommended early spring planting of stratified seed, but fall seeding

is acceptable as long as seed will not be washed away or covered too deeply by siltation. Broadcast seeding is easiest but requires large amounts of seed and may not perform well if seed is not incorporated in the soil. Spot seeding or drilling uses less seed and allows for control of spacing and soil coverage of seed.

Direct seeding of many hardwood species has been done successfully for years on the southeastern Iowa property of Larry Krotz (pers. commun. 2011). Black cherry does not have a good success rate with direct seeding. Krotz now leaves selected black cherry as seed trees or erects perches to encourage birds to plant cherry in regeneration areas. He prefers having the black cherry seeded in by birds several years after oaks and walnuts so it does not outcompete these species in the plantings. This approach may also lead to better stem form on the cherry due to increased competition for sunlight.

Mixed Species

Direct seeding is often applied with a mix of species to produce a diverse planting. Recommendations for successful direct seeding operations can apply to a broad range of hardwood species, as illustrated by the literature and experience recounted thus far. Several extension publications, based on both scientific research and repeated practical experiences, provide some general principles for improving the success of direct seeded plantings.

Rasmussen et al. (2003) consider direct seeding a proven, effective method of establishing conservation plantings in Nebraska. Several advantages of direct seeding include replication of natural forest establishment processes, potential for high density plantings, less critical moisture conditions for dormant seed than planted seedlings, and development of undisturbed root systems with no transplant shock. Establishment costs are typically cheaper than for seedling plantings. Potential disadvantages include difficulty in controlling competing vegetation, lack of familiarity with the direct seeding method, uncertainty about seed viability, and seed predation. Recommendations include floating fresh seed for 1 hour and discarding floaters. To avoid heating, do not store large quantities of seed together. Plant seed within 1 month of collection or stratify seed for spring planting, according to species requirements.

Mixed species plantings are recommended. Planting can be done in rows or by broadcasting seed with seeding rates of 4,000 to 8,000 seeds per acre to achieve at least 400 living stems per acre in 5 years. Row planted seed is placed 6 to 12 inches apart with rows spaced no more than 16 feet apart, depending on the equipment to be used for maintenance. Black walnut is mentioned as a species that should be included in the seed mix due to high germination rate, early growth performance, and potential timber value. Site preparation is critical to successful planting. Perennial grass and weeds should be killed the fall before planting using post-emergent herbicide. The site should be disked as if to prepare for a corn or bean crop a few weeks before sowing to allow the soil to settle. Scatter seed with a fertilizer spreader, manure wagon, or by hand, and disk seed in to a depth of 2 to 4 inches. Disking in two directions yields the best results. After seeding, roll the site with a soil packer to get firm seed to soil contact. Row-seeding by machine (Fig. 4) involves calibrating the machine to the desired spacing and a sowing depth of 2 to 4 inches. Once seeds are planted, pack the row by running a tractor, truck, or ATV tire over the row to seal in the seed. Chemical or mechanical weed control will be needed for the next several years to control competing vegetation. If animal feeding pressure is anticipated, protect the 50 to 100 best seedlings per acre with animal control devices such as tree shelters.

Edge (2004) surveyed 31 direct seeded plantations in southwestern Wisconsin ranging from 1 to 7 acres and 1 to 6 years old using 0.01-acre plots for weed competition level, species composition, stand density, and seedling height. Tree species included black walnut, northern red oak, white oak, bur oak (*Quercus macrocarpa* Michx.), swamp white oak (*Quercus bicolor* Willd.), sugar maple (*Acer*

Figure 4.—Mechanical direct-seeder for row-sowing hardwood seed. (Photo by Lenny D. Farlee, Purdue University)

saccharum Marshall.), and shagbark hickory (*Carya ovata* (Miller.) K. Koch.). Plantings were all high density sowings on former agricultural fields with stand density goals between 3,000 and 8,000 stems per acre. One site was broadcast seeded by hand and the rest were planted with a seeder or drill, with some occasional hand planting of light seeded species such as sugar maple. Twenty-nine sites were fall planted and two were spring planted. The average stocking for the machine planted sites was 3,359 stems per acre, including an average of about 400 volunteer elm and box elder stems per acre. In general, black walnut had the most consistent stocking with most sites supporting more than 500 stems per acre or an assumed field germination rate of 60 to 70 percent. Red oak was more variable and had an assumed rate of 30 to 40 percent. White oaks were the most variable, with two total germination failures. Black walnut also had the best annual height growth, averaging 14.8 inches per year, compared to 4.3 inches for red oak. In mixed plantings, this resulted in quick dominance by black walnut and suppression of the oak seedlings. In one 6- year-old plantation, the black walnut was 22 feet tall and formed a canopy, with red oak 5 feet tall in the understory. Mechanical or spot seeding is a more efficient use of seed than broadcasting, allowing better control over stand density and the convenience of rows for access.

Many foresters in this survey were drilling seed into untreated grass or other cover and then treating the vegetation with glyphosate before tree seed germination in the spring. Weeds were treated in subsequent years with pre-emergent herbicides

such as simazine or sulfometuron methyl. Be aware of differential growth rates when doing mixed species plantings. Exercise caution with pre-emergent herbicides during the first growing season. Pendimethalin has been commonly used over broadleaf seeds and simazine has been used over oak and walnut, but little research has been done to determine impact on germination and growth of the hardwood seedlings.

The Illinois Direct Seeding Handbook (Herman et al. 2001) listed recommendations and resources for improving direct seeded plantings. Important points to increase success include collection and proper handling of high quality seed, preparing the planting site, properly planting the seed, maintaining weed control until seedlings are established, and protecting planted seed from seed predators. Recommendations on seed collection and handling include testing seed lots by floating and cutting to be sure good seed is being collected. Handle seed so that excessive heating or drying does not occur before the seed is planted. Fall planting simplifies handling and reduces viability losses that can occur in storage or from improper stratification procedures. Eliminate competing vegetation before planting using herbicides, tillage, or both. If seed is to be spot or row planted, a cover crop may be left between planting spots or rows. Weed control begins with site preparation before planting and extends until the seedlings are established and competitive with other vegetation on the site. Higher seedling numbers per acre can speed the process of shading out the competing vegetation. Several herbicides, previously listed in the black walnut section, are available for site preparation before planting and weed control after seedling emergence.

Seed predation is listed as the most common cause of failure for direct seeded plantings in Illinois (Herman et al. 2001). Plantings planned for small forest openings, or within 100 yards of rodent habitat may best be accomplished by using seedlings. Sample trapping can be used to estimate the number of rodents in the planting area. Plowing, mowing, disking, and burning can be used to reduce or eliminate rodent habitat. Creating raptor perches may help control small mammals through increased predation.

GENERAL RECOMMENDATIONS

Direct seeding is a viable option for regeneration of fine hardwood trees. As with seedling planting, a direct seeding operation must be properly planned and executed to have any chance of successful establishment. Planning begins well in advance of planting with an evaluation of the planting site for suitability to the species of interest, preparation of the site for the control of competing vegetation and seeding, and collection and storage of viable seed in adequate numbers to fully stock the planting area. The site potential for seed predation by rodents or other seed predators should also be evaluated. The site will require modification that includes protective measures for seed to prevent pilfering (Figs. 3 and 5), or consideration of switching to bare-root or other seedling stock for regeneration. Squirrels and other seed predators are able to rapidly depopulate a direct seeding in areas such as forest openings or fields within 300 feet of suitable habitat. Direct seeded plantings using hardware cloth sheets or cones, partially buried tree tubes, and the previously described cans for seed protection have resulted in well-stocked plantings. Placing fresh cow manure over the top of seed or providing sacrificial areas of planted seed between seed predator habitat and the planting site are additional options for reducing losses to seed predators.

To evaluate site suitability for the selected tree species, landowners should consult the appropriate soil surveys and soil tests, reference information such as the Black Walnut Suitability Index in the Web Soil Survey, and talk with local experts on soils and reforestation.

Site preparation begins the summer or fall before direct seeding in the case of cropland or pasture and grassland. Perennial grasses and weeds should be controlled with tillage or herbicides to provide a planting site free of established competitors. The method of planting will determine the soil preparation

Figure 5.—Use of tube and wire screen to protect sprouted seed from seed predators. (Photo by James R. McKenna, U.S. Forest Service)

required before planting. Broadcast seeding generally requires a site tilled similar to a field to be sown to grain crops. Strip or spot planting may be best accomplished on untilled ground depending on the equipment used.

Seed collection involves determining where suitable seed can be obtained, collecting, and testing the seed for viability through floating and cutting open a sample of seed from each lot to inspect the seed quality. Low quality will require sorting out bad seed if possible, and collecting enough viable seed. In the period between collection and planting, keep the seed cool and at acceptable moisture levels for the species. The Woody Plant Seed Manual is an excellent information source for seed collection and handling (Bonner and Karrfalt 2008).

Fall planting of seed is the simplest approach to direct seeding, avoiding the need to store or otherwise treat the seed. Fall planting may result in higher germination rates and earlier seedling emergence than spring plantings. Fall planting may expose seed to a full fall and winter of seed predation pressure as well, so an evaluation of potential predation and protection measures may be needed to retain enough viable seed for a well-stocked planting.

Spring planting will require proper storage and, for most species, meeting the requirements for breaking seed dormancy. This usually involves stratification for 90 to 120 days. During storage and stratification, protect the seed from seed predators. Seed can be held until it sprouts to gauge the viability of the seed. Sprouted seed should be handled carefully to protect the base of the extending radicle and prevent excessive drying. Long radicles can be clipped back but should not be cut or broken at the juncture with the cotyledons. Sprouted seed may not be compatible with planting methods where the seed is churned or otherwise handled roughly. As a general rule, plant seed in the soil at a depth one or two times the seed diameter.

Ideal planting density is dependent on the planting method, seed quality, seed predator pressure, and seed treatment used. Sprouted seed can be treated like a seedling in terms of spacing, because the viability of the seed has been confirmed. Row or spot direct-seeded plantings can use several thousand seeds per acre and provide space for access to control weeds after planting. Broadcast sowing can use thousands to tens of thousands of seeds per acre and access after seedling emergence is limited. Sites expected to have seed predator pressure may be sown with high numbers of seed to overwhelm predators, provide protection to seed to prevent pilfering, or create conditions at the site that deter entry by seed predators.

Weed control treatments for the first 2 to 3 years will help seedlings retain a competitive advantage over other vegetation invading the site. Pre-emergent herbicides have been used successfully to control emerging weed competition. Rate of application is crucial to get good weed control but not harm emerging tree seeds. Consult the herbicide label and local experts for proper application rates. Some sources recommend delaying the application of pre-emergent herbicides until the second growing season, when the seedlings have emerged and established a root system. Some post-emergent herbicides, like clopyralid, may control weeds such as Canada thistle (*Cirsium arvense* (L.) Scop.) and ragweeds (*Ambrosia* sp.) in areas containing tree seedlings during the growing season. Follow label directions carefully to avoid damage to tree seedlings.

The literature and practical experience indicate the most common causes of direct seeding failure are ineffective weed control and seed predation, so careful attention to these management practices should help increase success rates. These sources also indicate there are several possible paths to success with direct seeding. Sprouted seed plantings managed like a bare-root seedling planting (Fig. 6), row or spot plantings (Fig. 7), and broadcast plantings have all produced successfully established tree plantings.

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Figure 6.—Fifteen-year-old black walnut planting established by direct seeding sprouted seed. (Photo by Lenny D. Farlee, Purdue University)

Figure 7.—Mixed oak and black walnut planting in Iowa established by direct seeding in the fall using a homemade row seeder. (Photo by Lenny D. Farlee, Purdue University)

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The content of this paper reflects the views of the author(s), who are responsible for the facts and accuracy of the information presented herein.

DESIGNING AND ESTABLISHING A FINE HARDWOOD TIMBER PLANTATION

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Abstract.—Today, new tools and lessons learned from established plantations of black walnut and other fine hardwoods can provide landowners with guidelines to design and establish successful plantations to produce quality timber for the future. From earlier plantations now maturing, we can recognize design features critical during establishment. Current production practices combined with improved tools, ongoing genetic improvement, and lessons learned from various spacing and species mixes make it possible to establish higher quality timber plantations today than previously possible. We summarize new tools for assessing the suitability of soils to grow good walnut and present plantation design strategies to enhance the quality of walnut mixed with other hardwoods to minimize risk if walnut does not grow well. We also include design details that can enhance the aesthetic quality of the land and expand wildlife habitat.

As world population increases and available forest lands diminish, timber plantations hold the promise to produce a greater quantity of wood per acre than natural forests (Sedjo 1999, Sedjo and Botkin 1997). Walnut timber plantations on the scale of hundreds to thousands of acres have been established in the last decade in the United States and Europe. Plantation forestry has become a common practice for many pulp and softwood timber species throughout the world, and plantations can be more profitable than natural forest management (Frederick et al. 2007). Current production practices, improved tools, and ongoing genetic improvements make it possible to establish high quality timber plantations more successfully than in the past. We summarized research on black walnut and information from growers during the last decade. These updated data can help landowners who have established walnut plantations. In addition, new growers will find the background information, planning considerations, and descriptions of techniques needed to establish a successful plantation.

MANAGEMENT OBJECTIVES

State your objectives clearly and concisely and see how they fit into your over all land management plan. Make a detailed sketch that includes the location of the plantation and current features as well as those you might add in the future. Evaluate the suitability of the land in growing black walnut. Recognize that a walnut plantation is a long-term endeavor. The average rotation age for walnut in the native range varies from 70 to 80 years (Limstrom 1963). A well-managed walnut plantation on good soil can mature sooner than this but will still require 40 to 60 years to reach the point of having merchantable timber to harvest. If income is needed before the walnut trees mature, consider including other trees, other crops, and other endeavors on your land to generate income. Agroforestry (growing crops and trees together), forest farming (growing or collecting marketable plants or fungi in a forest), or silvopasture (raising livestock and trees) are approaches that can be used to generate income while trees are maturing (Idassi

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2012, Klopfenstein et al. 1997). Consult your local state resource professionals or local private consulting forester to see what types of tax advantages and cost-share programs your plantation may qualify for and to help you design your plantation (Farlee 2007).

Walnut is grown for both timber and nuts, but we will focus on establishing timber plantations, primarily of walnut, in the Central Hardwoods Region (CHR) of the United States. Timber production requires trees with clean, straight trunks, which occur in high density plantations where trees must grow tall to compete for light and where lower limbs are shaded and naturally die out. In contrast, nut production requires open-grown trees with large spreading crowns that are fully sunlit to produce many flowers and nuts. A walnut tree producing large crops of nuts needs strong lower limbs to minimize breakage under heavy crop loads. Hence both objectives are difficult to satisfy in the same plantation, each conflicting with the other from a light management and tree architectural standpoint. Some nut production can be an outcome of a timber plantation, but if nut production is the primary goal, trees will require wider spacings, different pruning strategies, and a more intensive operation, similar to orchard production of other fruit and nut crops. For detailed information on walnut nut culture and orchard establishment, consult Ramos (1997), Jones et al. (1998), and Reid et al. (2009).

Your objectives may be to maximize income, to improve the aesthetic quality of your land, to provide a source of recreation, to relax and enjoy growing trees, or to leave a legacy for your children and grandchildren. Consider all your objectives from the standpoint of what the plantation will look like once it is established at 10 to 20 years of age. Once trees are planted, changes are difficult and expensive to make. Spacing decisions, row orientation, species mixes, border trees, and windbreaks are difficult, costly, or simply not practical. Figure 1 shows the dramatic changes that occur as a plantation grows from 8 to 75 years of age.

Several topics should be incorporated into your plans. Multiple objectives can be accomplished as long as you avoid incompatible or mutually exclusive plans such as intensive timber production and intensive nut production. We will try to highlight the pros and cons of different choices as they occur. Remember that there are many ways to establish, plant, and manage a forest plantation. Personal preferences, topography, intensity, and scale will lead to different techniques, but as long as you use sound practices, the outcome can still be an excellent plantation of walnut and other high value hardwoods.

Site Selection

Black walnut is site specific in its growth requirements. It grows well only on moist, well drained, deep, and fairly rich soils (Beineke 1994, Ponder and Pope 2003). Wallace and Young (2008) have developed an excellent new resource for the Web Soil Survey called the Black Walnut Suitability Index (BWSI) (USDA NRCS 2012). They describe a well-suited walnut site as: "… very deep, moderately well drained or well drained, medium textured, slightly acid to slightly alkaline, have a high available water capacity, no rock fragments in the upper 24 inches, and … subject to brief or very brief flooding duration." Conversely, "Soils that are unsuited [for walnut] have a shallow effective rooting depth, a high water table (poor drainage), a low available water capacity, or are subject to flooding of very long duration." The BWSI is now an online tool that landowners in participating states can access through the Web Soil Survey. Figure 2 shows the BWSI for a potential walnut plantation site in Missouri. If your plan is to establish a 100-acre high quality walnut plantation, note that only half of the site is moderately to well suited for walnut and one-third is unsuited for walnut. Knowing this, you can avoid the mistake of planting walnut on an unsuitable site and the disappointment of a failed plantation. Instead, use this information to match walnut to the areas where it will grow well. Include other fine hardwood species that are suited to your soil, such as oaks, where the soil is not suited for walnut.

Figure 1.—Walnut plantations over time showing that the choice of vegetation management can create different aesthetics in an 8- and a 10-year-old plantation, a 39-year-old plantation reduced from 1,000 to 80/acre, and a 75-year-old plantation that resembles a natural forest. (Photos by James R. McKenna, U.S. Forest Service)

Unfortunately, the BWSI is available only in in some states at this time. Most of Indiana, Illinois, Iowa, and Missouri have the BWSI on the Web Soil Survey. In time, we hope to see the survey expanded throughout Ohio, Michigan, Wisconsin, and other states. Even without this excellent online tool, the fundamental soil and hydrological principles can be applied to your property to determine which portions of your site will grow walnut well and which areas to avoid or limit walnut in your mix of species.

New research has shown that soil electrical conductivity (EC) maps created before a plantation is established may help direct site-specific planting of walnut and help avoid areas unsuitable for walnut (Palm et al. 2008). Soil EC is correlated with soil texture, which reflects the size of soil particles and is commonly defined by the relative percentage of the three soil particles: sand, silt, and clay. Sand has the largest particle size, silt is medium, and clay is smallest. EC values show a range with sand having

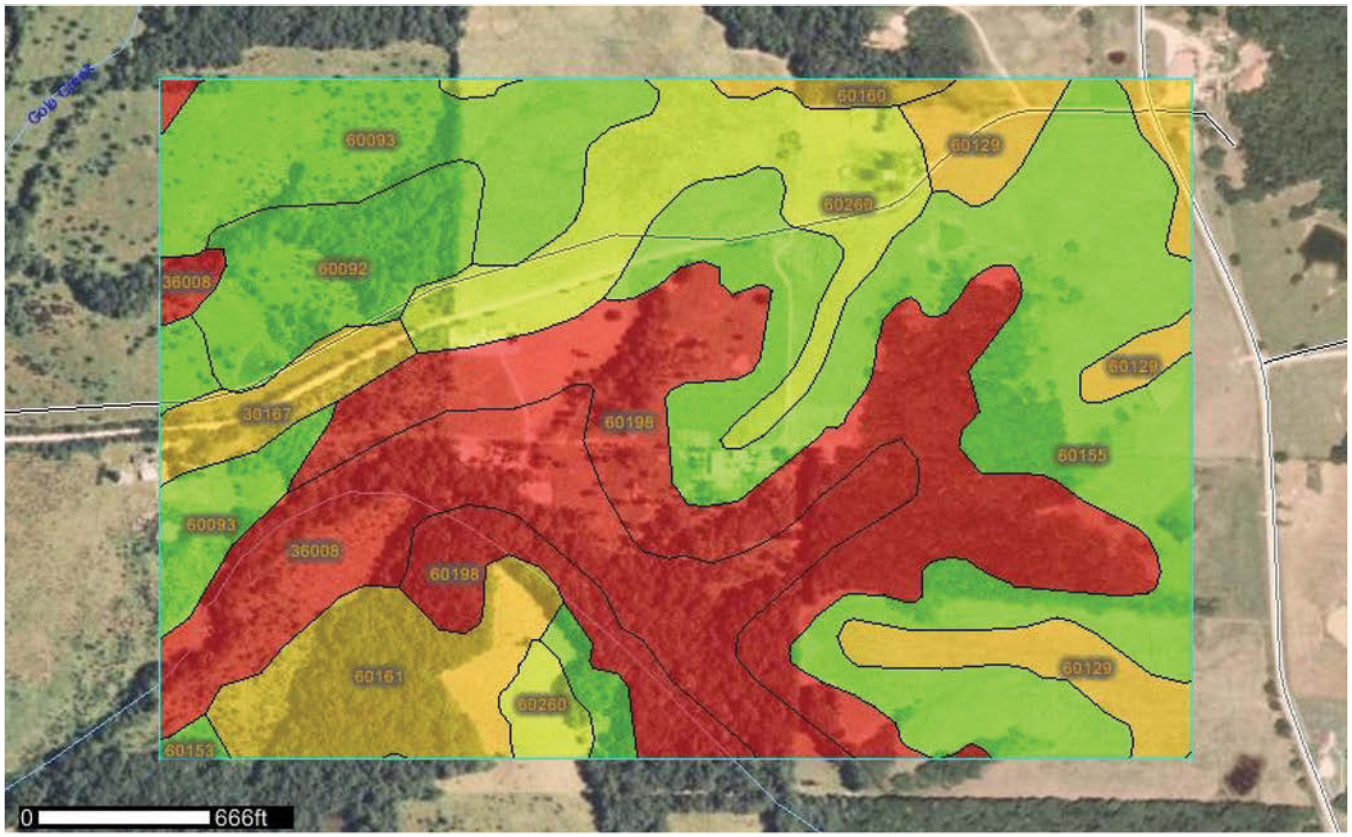

Figure 2.—Computer screen image from the NRCS Web Soil Survey illustrating walnut suitability ratings across a 235 acre area of interest (AOI) that included acreage proposed for a 100 acre hardwood planting in Howard County, Missouri.

	Summary by rating value	
Rating – Color code	Acres in AOI	Percent of AOI
Well suited – Dark green	95.9	40.8
Unsuited – Red	79.4	33.8
Somewhat suited – Light green	36.5	15.5
Moderately suited – Yellow	23.2	9.9
Totals for Area of Interest	235.0	100.0

the lowest values and clay the highest values. A strong correlation of good walnut growth with moderate EC values has been determined and mapped on two walnut plantations in Missouri, which indicates that silt soils are much better for walnut than clay soils. Measuring the EC values of your field at present can be accomplished by agronomic consultants with specialized equipment (Veris Technologies, Salinas, KS). This is a new tool you can also use to investigate variation in walnut growth across an existing plantation, and it may aid those in areas where the BWSI has not yet been developed. The strong correlation of walnut growth with EC value underscores the importance of planting walnut on the right soils. EC should not be used as the sole criterion for evaluating planting sites, but it is one of several variables to consider when evaluating the suitability of sites for growing black walnut.

Initial Planning

Before you draw a detailed plantation map, first consider the level of intensity you wish to employ. Fundamental questions are: What will the plantation look like once it is established? How intensively are you prepared to manage the plantation? How much labor and money will you spend? Is this a one-time

planting or will you add to it over time? And lastly, how will this timber plantation impact your other land use practices or plans such as farming, wetlands, grasslands, and recreation? The answers are important in the design and formation of your plantation.

One of the most critical decisions to make is where you want the plantation. Tree plantings can be grouped into two broad categories: (1) afforestation or planting trees onto current or former crop land, and (2) reforestation, or planting trees onto currently forested land that has been cleared due to harvest, fire, or some other recent disturbance. We will focus on afforestation because most new walnut plantations promote afforestation activities.

Plantation Designs

Numerous plantation designs can be developed based on careful consideration of your overall land management objectives, plantation layout, and level of intensity. The most important components of your design are the spacing of trees, orientation of rows, mixing of other species, inclusion of improved genetic sources, and determination of your thinning strategy. Fine hardwood plantations should have an initial density of at least 500 trees per acre or more because timber trees need to be closely spaced to force them to grow straight and tall and to limit sunlight on lateral branches. A goal for producing a valuable timber tree is to have at least a 9-foot limb-free, clear log. Pruning can help in this process, but is labor intensive. Closely spaced plantings quickly and more completely shade out lower side limbs, suppressing their growth and making pruning simpler and less necessary. Previous recommendations to plant grafted black walnut at spacings of 20 feet by 15 feet (Beineke 1994, Roberts and Beineke 1995) have proven difficult to maintain and are not advisable. Research has shown that in such wide spaced plantations, lateral branches that are half-inch in diameter at the start of the season can become 2 inches in diameter by the season's end (C. Michler, pers. commun.). Such large lateral branches can make pruning an annual requirement, which can still lead to large branch scars (cat faces) on the butt log for many years. If your initial survival is less than 85 percent, consider replanting extra trees to fill empty spaces in the second or third year. Rather than replanting walnut, consider replanting a more vigorous species such as sweetgum or river birch that can catch up to your established walnut and help close the canopy faster.

Recommended spacings and the number of trees per acre for each to grow fine hardwood plantations are presented in Table 1. The reduction in trees over time is graphically represented in Figure 3. The fundamental goal of most timber plantations is to

Table 1.—General guide for planting and thinning walnut timber plantations at various spacings where precommercial thinning twice remove most of the trees initially planted in the first and second decade, leaving only the crop trees with the best potential to make a valuable log. The first commercial harvest of trees 16 to 18 inches in diameter can begin from 35 to 45 years of age when larger trees may be harvested for the sake of better formed smaller diameter trees and the second harvest on trees approaching 22 inches in accordance with the landowner's management plan.

		Reasonable number of trees remaining per acre after thinning and harvesting			
Initial spacing row x tree (ft)	Initial number planted	1st thin 8-12 years	2nd thin 15-25 years	1st harvest and thin 35-45 years	2nd harvest 50-75 years
8 x 6	908	500	160	60	20
9 x 6	807	500	160	60	20
10 x 6	726	450	160	60	20
8 x 8	680	425	160	60	20
9 x 8	605	400	160	60	20
12 x 6	605	400	160	60	20
10 x 8	545	400	160	60	20
Percent reduction		~35	~60	~60	~30
Number of trees harvested		–	–	50-60	30-40

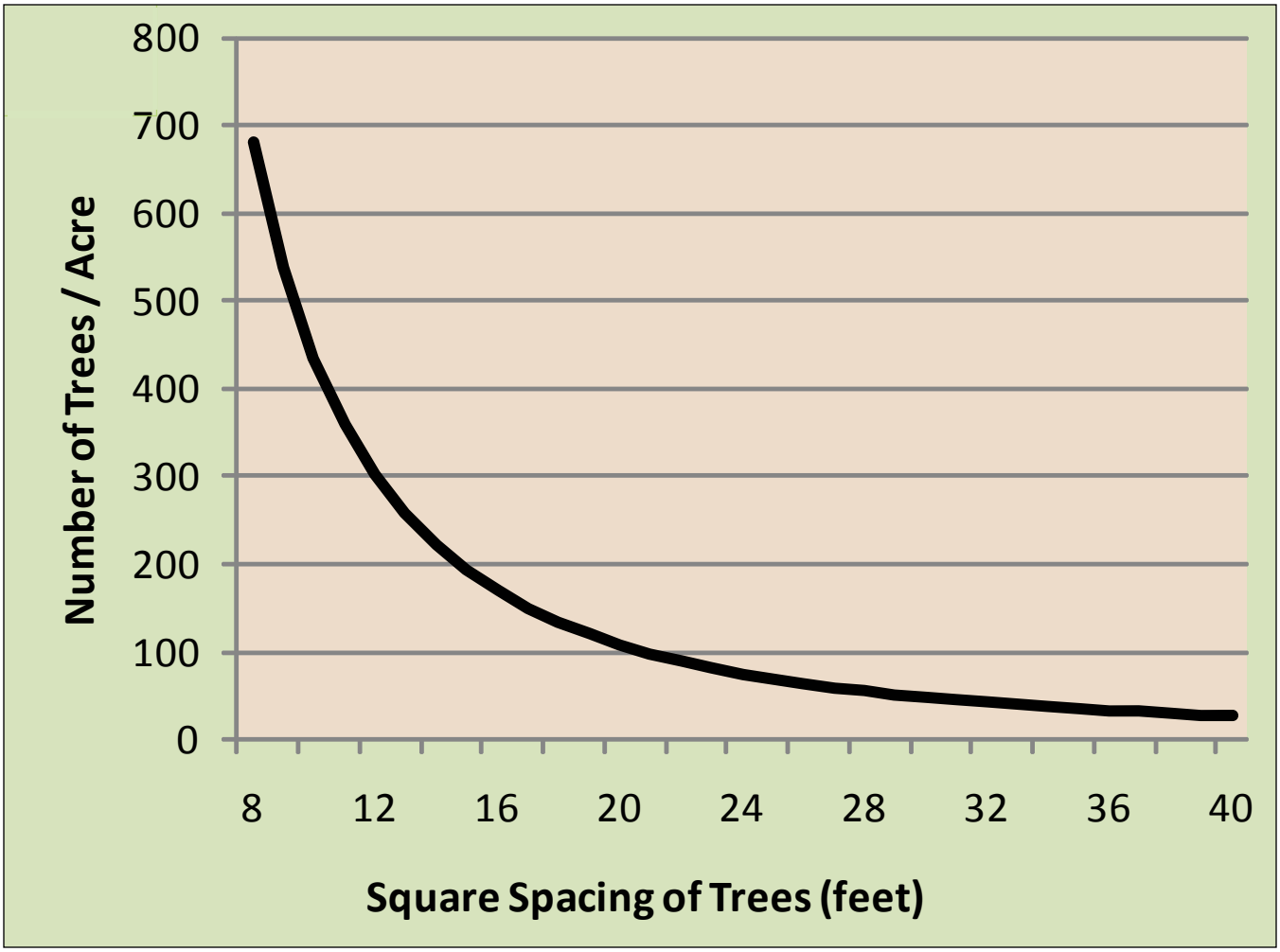

Figure 3.— Exponential relationship of trees per acre and spacing over time that show the spacing of trees increases and the number of trees per acre decreases from an initial density of 680 trees/acre at an 8-foot by 8-foot spacing with a maximum of 40 timber trees/acre at maturity.

maximize value by growing trees with straight, clear log lengths as quickly as practicable. To achieve this goal, the loss of lower limbs early is critical. The plantation will grow each year to the point where the canopy closes, or where the crown of each tree touches other trees, at which time the stand is said to have "closed canopy." Trees are now competing for light and space and begin to slow in growth. Over time, trees that require full sun, such as walnut, that fall behind in height growth and end up under the sunlit canopy, will decline and die. As competition builds through the years, fewer and fewer large trees will persist (Fig. 1). Thinning will occur naturally in plantations, but the growth rate and value of the trees that remain can be greatly improved and controlled by managing this process through thinning. Your plantation design should include a thinning strategy from its inception.

By the first time a commercial harvest is possible, more than half of the original planted trees should be gone (Table 1). Recognizing this when designing your plantation, you can include a mixture of species in your plantation and space genetically improved sources to target your thinning to remove other species and retain your best walnut. We remarked at the 2010 Walnut Council meeting in Grand Rapids, MI, that to plant half of a plantation to black walnut is to be

fully stocked with walnut once sawtimber harvesting begins. As the thinning and stocking charts show, this is mathematically true. Failure to thin trees is a major cause of reduced growth and decline in many past walnut plantations.

Establishing a high quality timber plantation with walnut as the prominent species is an excellent and achievable goal. However, it is much more prudent to design your plantation from the start with other species and to have a comprehensive thinning strategy to make sure your initial density is high enough to maximize natural side limb pruning and to produce good timber quality. Mixed species will hedge the risk of failure in parts of the plantation and provide options for dealing with future unforeseen problems. One survey of hardwood afforestation plantations in Indiana found that only 65 percent of trees overall survived 5 years after planting and that walnut survival was only 40 percent (Jacobs et al. 2004). The strong site sensitivity of walnut makes it prone to variable growth across a given site. Most foresters in the Midwest encourage mixed species plantings over monocultures because they hedge risk of one species failing and because most cost sharing programs typically require mixed species plantings (Farlee 2007, Limstrom 1963). A mix of species leads to trees with different canopies that can cast more shade than solid walnut will and that mimics natural conditions to reduce the need for pruning and to shade competing vegetation in the understory.

Spacing of Trees

Row spacings are important to consider based on how you plan to manage the plantation. If routine mowing and spraying will occur for the first few years or more, make sure you have enough room to accommodate your equipment. Keep in mind the average square-foot value of your design. For example, if you want to plant 8 feet by 8 feet (64 square feet per tree) but have a 7-foot-wide tractor, increase your between-row spacing to 9 feet and decrease your in-row spacing to 7 feet (63 square feet).

Although a planting with a grid of 8 feet by 8 feet (680 trees/acre) is simple and sound, you have a great deal of latitude in how rows are spaced and how trees are arranged in the plantation. The more closely the trees are planted, the quicker the canopy of leaves closes and the faster thinning needs to be done. Keep in mind your objectives—a geometrically square grid plantation, a more natural forest look, or contoured rows to follow the natural curve of a valley or hillside. If you plant by hand, it is easy to arrange trees in any pattern you want, but if you plant by machine, controlling in-row spacing is more difficult.

Row Orientation, Feathered Edges, and Windbreaks

If you want your plantation to look more like a natural forest and you machine plant, plan how your rows should be orientated for your main view. For example, if the main view of your plantation is along a county road, running rows parallel to the road, with variable in-row spacing, will appear much more natural than orienting the rows perpendicular to the road. If your plantation is rectangular and narrow, and it is impractical to do this for the whole planting, consider planting three to five “border rows” parallel to the road and the remainder of the plantation perpendicular. Such long-term and potentially important aesthetic considerations are best figured out by making a crude sketch before planting the trees. Consider border rows and end trees to function as windbreaks and forest edges to protect interior trees and foster wildlife. Edge trees in a plantation typically grow larger than the average trees within the plantation and have larger lower limbs, resulting in lower quality logs. A vigorous border row can serve as a wind break and encourage better apical growth of interior crop trees. Windbreaks can also result in improved early growth of black walnut plantation trees (Heiligmann et al. 2006). Choices should be vigorous species well adapted to your location. Depending on your preference and location, consider white pine, river birch, sweet gum, soft maple, or tulip trees.

Many foresters scatter a few conifers individually or in small patches throughout a hardwood plantation to provide some green color in the winter. One way to improve habitat for song birds and other small mammals is to plant several rows of shrubs or several shrubs at the end of rows to create a "feathered edge" (USDA NRCS 2008). Consider such feathered edges on the south side of the plantation so that the shrubs will persist and not become shaded out. You may also feather the east and west sides, but realize that only taller trees or shade-tolerant shrubs will persist on the north side. For more options and species choices for edge feathering and other considerations for creating good wildlife habitat, see MacGowan (2003).

Mixing Species

Within the plantation and among the walnut trees, northern red oak is complementary in growth to black walnut. Planting a 50:50 mixture of walnut and red oak can be effective because soil that is not well suited for walnut will often grow good red oak. Other species with timber value to include that can thrive where walnut may fail are white oak, bur oak, chinkapin oak, swamp white oak, and black cherry. Where the soil is good for walnut, the oak can be thinned. In areas where walnut grows poorly, you can select oak or cherry as a crop tree. Various species mixtures and arrangements can be devised to fit your objectives and preferences, and we will discuss a few general approaches to consider as models of the process. Consult with local forestry professionals and experienced landowners in your area to consider the best complementary and valuable species to include. The following examples and diagrams are aimed to show you general examples that we hope will emphasize the importance of a well thought out design and a good sketch before you plant.

Two general methods of mixing two or more species are the planting of alternate rows or a "checkerboard" mix where every other tree down each row alternates each species. Consider a plantation on a soil that is mostly suitable for walnut that is planted primarily with a 50:50 mix of northern red oak and walnut in a checkerboard fashion. Walnut begins the first row, red oak begins the second row, and the pattern repeats with walnut beginning each odd row and red oak beginning each even row (Fig. 4). This example is based on an 8 by 8 foot grid to demonstrate the approach but can be applied to other spacings. In Figure 4, you will see that every fourth row changes to a mix of black cherry and tulip poplar. These species are both more vigorous than walnut, and the tulip poplar helps train the cherry making it a good idea to keep them together in their own row. Cherry or tulip poplar, due to faster growth rates, can be harvested sooner than walnut and can shorten the time to receive income from harvest. Once removed, they create access lanes to manage and harvest walnut.

Including Genetically Improved Stock

Genetically improved walnut stock is becoming more available from a variety of state and private nurseries. Realize that such material is not a "silver bullet" and will not overcome a poor site choice. In fact, improved sources will show gains in growth and quality only on good sites; on sites moderately suited to poor walnut, genetically improved stock will grow as poorly as run-of-the-mill genetic sources! However, if both your level of intensity and your site quality for walnut are high, adding genetically improved sources may provide more predictable tree quality and growth characteristics.

If you intend to plant new genetically improved stock, seedlings or grafted black walnut cultivars, carefully consider how to place them. The hypothetical plantation sketched in Figure 4 shows that select walnut seedlings and grafted black walnut cultivars are planted every fourth row. In each of those rows, select seedlings alternate with grafts leaving them each at 32 by 32 feet, which amounts to 42 or 43 grafted walnuts per acre and 42 or 43 select seedlings, nestled within the initial 680 trees per acre. If the grafted walnut trees grow well, they should become the final mature crop trees. If some grafts break or perform poorly, you have the select seedlings to choose for crop trees. Unless your resources are vast, it makes little sense to plant

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Figure 4.—Hypothetical plantation design mixing black walnut and red oak in a checkerboard fashion (75%) with black cherry and tulip poplar (25%) that includes select genetic sources of black walnut (bold) in even rows including a grafted elite cultivar as every fourth walnut (boxed). The plantation is bordered by white pine on the west and east and a double row of white pines and two rows shrubs to create a feathered edge along the south side. Species code: BW = black walnut; NRO = northern red oak; BC = black cherry; TP = tulip polar; wp = white pine; w = flowering dogwood; x = American plum; y = red bud; and z = hazelnut.

an entire plantation of genetically improved walnut, purchased at a premium, only to thin out half of those trees in a decade or two.

Thinning Trees

Once the trees have closed canopy and are beginning to compete for sunlight among each other, typically between 8 and 12 years of age depending on your spacing and growth, thinning one-quarter to half of the trees is beneficial to provide additional growing space for the high quality trees. You can most efficiently and easily thin trees by removing entire rows. Such an outcome is sketched in Figure 5 using the previous plantation example from Figure 4. Depending on your objectives, time, resources, and scale of your plantation, a variety of actual thinning methods and variations may be employed.

At the time of the first thinning, three general options exist: row thinning, diagonal thinning (Fig. 5), or crop tree release. If vertical row thinning is done, the plantation becomes balanced with half cherry/tulip poplar and half walnut/red oak. If you use diagonal thinning, more walnut persists. Crop tree release identifies evenly spaced high quality trees and thins to release three or four sides of the crown of each

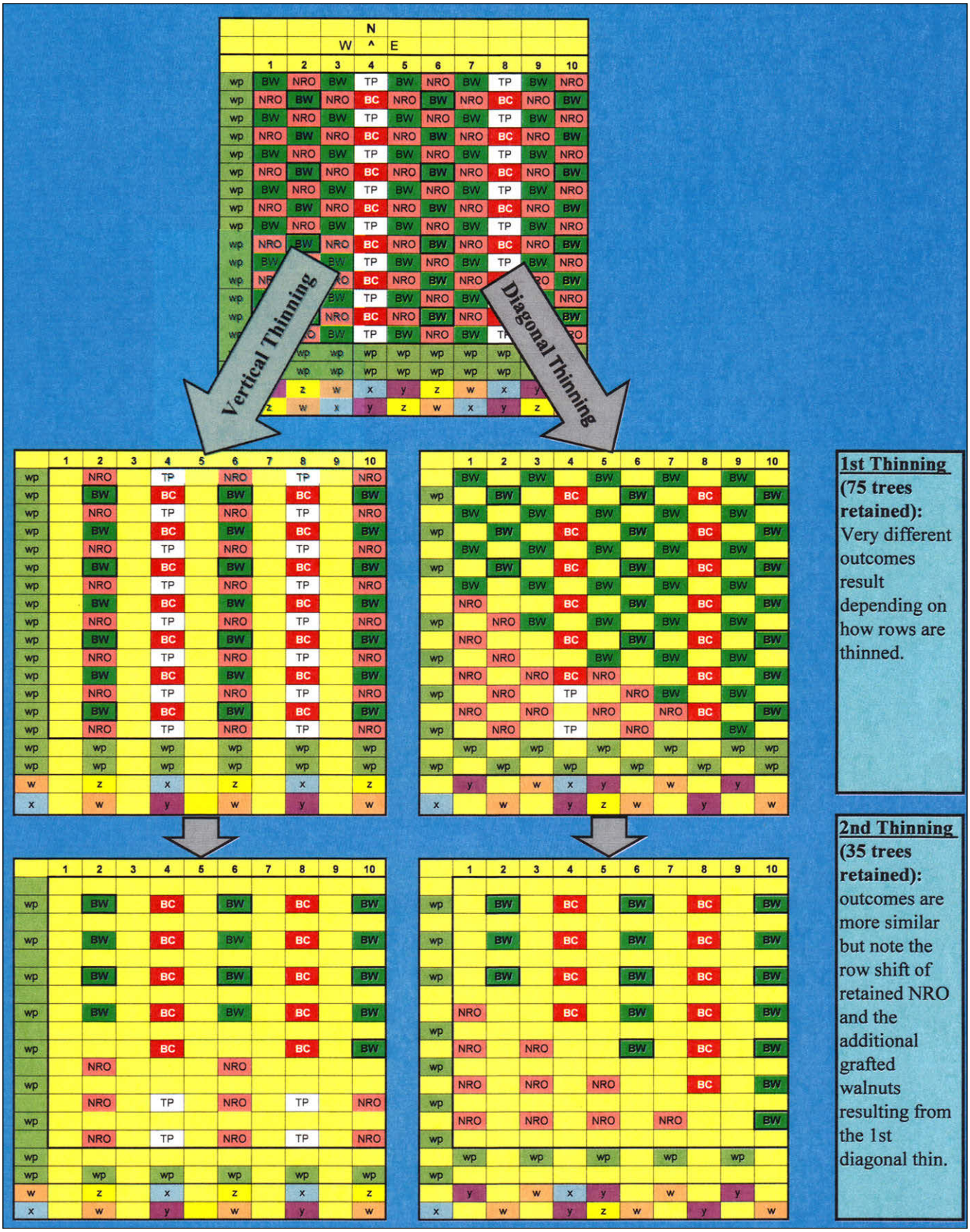

Figure 5.—Alternative thinning approaches for the Figure 4 plantation that leave 150 crop trees primarily from genetically improved sources as a pure walnut and cherry plantation or as a pure red oak plantation.

crop tree from competition. By the second thinning, diagonal thinning allows two extra walnut trees, the same number of cherry, and two extra red oak trees. The example from the first vertical thinning allows less walnut and red oak, but retains four tulip poplars.

The example in Figure 5 shows that walnut did not grow well in the southwestern portion of the plantation, as shown by the time of the first thinning, and the removal of walnuts—even a few grafted walnuts—with the diagonal thinning. The geometry of diagonal thinning, or planting trees in an "off set," diamond type, or equilateral triangle maximizes the area around each tree. Once an 8 foot by 8 foot plantation is thinned diagonally, the result is a 16 foot by 11.3 foot plantation compared to a 16 foot × 8 foot plantation after straight row thinning. The increased distance between trees in neighboring rows reduces stand density to 241 trees per acre compared to 340 because diagonal thinning leaves the same number of trees distributed more consistently across the entire acreage while row thinning leaves trees at their original spacing down the row and removes one row from the calculated area.

Even if you do not have a perfect grid and your row and tree spacing was not square, perhaps 9 feet by 6 feet, these same principles apply. You can also thin less than half of the trees in your first thinning, and you can choose a more scattered and selective thinning approach, removing a quarter of the trees in, say, year 9, another eighth in year 10, and an eighth in year 12 as you see fit. The bottom line and most important point is to plan to thin trees and know how you will approach thinning when designing the plantation; variation in growth and other circumstances may modify your original strategy.

Another option for mixing species that ensures against walnut failure is to plant multiple small blocks of various species (Fig. 6). Blocks of tree species most suited for the site will become the crop trees. The number of trees down the rows within blocks should be at least four to eight but can be the entire length of the row to make management more efficient. Like the hypothetical plantation design in Figure 4, you can add more than two species into a block design. In Figure 6, there are six fine hardwood species, including some hybrid butternut and American chestnut. Blocking of species may be a better choice for incorporating white oak, which tends to grow more slowly than red oak, walnut, and black cherry. As mentioned for the checkerboard approach, use an even number of rows of species to facilitate proportional reductions while thinning and to systematically distribute genetically improved sources in even or odd rows.

Trainer or Nurse Trees and Shrubs

Woody nurse crops or trainer trees are planted among walnut trees to aid their growth and improve their timber quality through side limb shading and forcing the walnut tree to grow taller and straighter than it would in a solid walnut planting (Geyer and Rink 1998, Ponder 1983, Van Sambeek and Garrett 2004). Checker boarding red oak and walnut is an example of using the red oak as a trainer with the additional benefit of hedging risk of walnut growing poorly in portions of the plantation.

Trainer trees can also be lower value timber species that are easy and inexpensive to establish, do not outcompete walnut, and ultimately are naturally thinned out over time. A good example of this is the case of alternating rows of white pine. Many successful plantings in northern Indiana have been designed with alternating rows of white pine with walnut. In some cases, walnut and red oak were alternated, creating 25 percent walnut, 25 percent red oak, and 50 percent white pine. For these plantings, 9-foot-wide rows and 8-foot within-row spacings have been the most successful (B. Wakeland, pers. commun.). However, this design sometimes fails because some sites will strongly favor the white pine over the hardwoods and ultimately become a pine plantation; or conversely, the site favors hardwoods and the plantation becomes mostly hardwoods spaced too far apart with a few stunted pines (Von Althen and Nolan 1988). Alternate rows of white pine have been

N

W ^ E

wp	wp	wp	wp	wp	wp	wp	wp	wp	wp	wp	wp	wp	wp	wp	wp
wp	CN	**CN**	CN	**CN**	wp	**WO**	WO	**WO**	WO	wp	**HB**	HB	**HB**	HB	wp
wp	CN	**CN**	CN	**CN**	wp	**WO**	WO	**WO**	WO	wp	**HB**	HB	**HB**	HB	wp
wp	CN	**CN**	CN	**CN**	wp	**WO**	WO	**WO**	WO	wp	**HB**	HB	**HB**	HB	wp
wp	CN	**CN**	CN	**CN**	wp	**WO**	WO	**WO**	WO	wp	**HB**	HB	**HB**	HB	wp
wp	CN	**CN**	CN	**CN**	wp	**WO**	WO	**WO**	WO	wp	**HB**	HB	**HB**	HB	wp
wp	CN	**CN**	CN	**CN**	wp	**WO**	WO	**WO**	WO	wp	**HB**	HB	**HB**	HB	wp
wp	CN	**CN**	CN	**CN**	wp	**WO**	WO	**WO**	WO	wp	**HB**	HB	**HB**	HB	wp
wp	CN	**CN**	CN	**CN**	wp	**WO**	WO	**WO**	WO	wp	**HB**	HB	**HB**	HB	wp
wp	CN	**CN**	CN	**CN**	wp	**WO**	WO	**WO**	WO	wp	**HB**	HB	**HB**	HB	wp
wp	CN	**CN**	CN	**CN**	wp	**WO**	WO	**WO**	WO	wp	**HB**	HB	**HB**	HB	wp
wp	BC	**BC**	BC	**BC**	wp	**NRO**	NRO	**NRO**	NRO	wp	**BW**	BW	**BW**	BW	wp
wp	BC	**BC**	BC	**BC**	wp	**NRO**	NRO	**NRO**	NRO	wp	**BW**	BW	**BW**	BW	wp
wp	BC	**BC**	BC	**BC**	wp	**NRO**	NRO	**NRO**	NRO	wp	**BW**	BW	**BW**	BW	wp
wp	BC	**BC**	BC	**BC**	wp	**NRO**	NRO	**NRO**	NRO	wp	**BW**	BW	**BW**	BW	wp
wp	BC	**BC**	BC	**BC**	wp	**NRO**	NRO	**NRO**	NRO	wp	**BW**	BW	**BW**	BW	wp
wp	BC	**BC**	BC	**BC**	wp	**NRO**	NRO	**NRO**	NRO	wp	**BW**	BW	**BW**	BW	wp
wp	BC	**BC**	BC	**BC**	wp	**NRO**	NRO	**NRO**	NRO	wp	**BW**	BW	**BW**	BW	wp
wp	BC	**BC**	BC	**BC**	wp	**NRO**	NRO	**NRO**	NRO	wp	**BW**	BW	**BW**	BW	wp
wp	BC	**BC**	BC	**BC**	wp	**NRO**	NRO	**NRO**	NRO	wp	**BW**	BW	**BW**	BW	wp
wp	BC	**BC**	BC	**BC**	wp	**NRO**	NRO	**NRO**	NRO	wp	**BW**	BW	**BW**	BW	wp
wp	wp	wp	wp	wp	wp	wp	wp	wp	wp	wp	wp	wp	wp	wp	wp
wp	wp	wp	wp	wp	wp	wp	wp	wp	wp	wp	wp	wp	wp	wp	wp
z	w	x	y	z	w	x	y	z	w	x	y	z	w	x	y
w	x	y	z	w	x	y	z	w	x	y	z	w	x	y	z

Figure 6.—Example of a block style mixed species planting with six different species where every other row of hardwoods is a select genetic source (bold) that includes four grafted walnuts. Species code: BW = black walnut; HB = hybrid butternut; WO = white oak; NRO = northern red oak; CN = American chestnut; BC = black cherry; wp = white pine; w = flowering dogwood; x = American plum; y = redbud; and z = hazelnut.

most successful at latitudes 41º N or higher. When a site is suitable for pine, walnut, and red oak, these plantings offer the benefit that the hardwoods will shade, overtop, and naturally thin out the white pines. River birch and sweetgum show promise although they may need to be physically thinned out.

Alternatively, trainer or nurse trees can be shrubby species or small trees planted in between walnuts down rows. A shrub or shorter statured trees will be overtopped by walnut and oak and naturally thinned out. Two of the best trainer systems developed in the past were autumn olive (*Elaeagnus umbellata*) and European black alder (*Alnus glutinosa*) (Funk et al. 1979, Geyer and Rink 1998, Ponder 1983, Schlesinger and Williams 1984). However, these systems are not recommended today because they are now known to be exotic invasives.

An alternative to the invasive nitrogen-fixing shrubs as shrubby trainer species are the native yellowwood (*Cladrastis kentukea*) and redbud (*Cercis Canadensis*). Yellowwood is a shrubby or small statured tree when mature, growing often 25 feet in height at maturity although some older trees were found to be 60 feet tall. Another species tested in Indiana and Missouri is redbud (Van Sambeek et al. 2008). Redbud, like yellowwood, is a short statured shrubby tree that grows to 20 to 30 foot tall at maturity. Both species tolerate some shade and cast fairly dense shade. The idea is to incorporate them into walnut plantations much like autumn olive had been—centered in between walnuts spaced from 8 foot to 12 foot in rows. Current difficulties that have limited testing of both species have been limited seed availability for yellowwood and low survival of transplanted dormant redbud stock.

Vigorous trainer tree species that have shown some success in past tests are black locust (*Robinia pseudoacacia* L.), a nitrogen-fixing leguminous tree and silver maple (*Acer saccharinum*) (Van Sambeek and Garrett 2004). Both need frequent pruning and/or coppicing to keep them from overtopping walnut. Black locust seemed promising in the past because it is easy to establish, could provide durable fence posts when thinned, and was hoped to provide some additional nitrogen for walnut trees. However, in most cases over time, black locust has proven too competitive with walnut and should be used with extreme caution. It requires repeated coppicing and constant control of root sprouts, which makes it invasive in and around the plantation. Silver or red maples (*Acer rubrum*) are vigorous "soft maple" species that are excellent choices for a border row and could be good trainer trees if used with caution. Silver maple is so vigorous that it must be coppiced and prevented from over topping and suppressing the walnut trees at 2 to 3 years after planting and again at 5 to 8 years (Von Althen 1989).

Pre-Plant Soil Management

Depending on the condition of your land, level of intensity, and the weather, various pre-plant soil management options are available in the late summer to fall before planting. If your land suffers from compacted layers of soil called "plow pans," which form after years of using farm equipment on the land, it should be deep ripped or sub soiled to fracture the plow pan in late summer or early fall when the soil is moderately dry 1 to 2 years before planting (Michler and Rathfon 2003). Deep rip by running shanks spaced 4 feet apart to a depth of 2 to 3 feet below the soil on a three-way pattern: length, width, and a 45-degree angle. This creates 4 foot by 4 foot triangular columns of soil where the compaction stress will "relax" into the shank marks over the winter and subsequent years. This operation should not be done if the soil is extremely wet and is most effective when the soil is dry; however, a larger tractor is needed. The goal of ripping the soil is to fracture it. If you cannot deep rip with shanks, consider hiring a local farm service to run an 18 or 16 inch deep subsoiler.

Test your soil for pH and nutrients and correct deficiencies before planting. You can locate soil testing services through your local extension service, agricultural consultants, or consulting forester. Whether you adjust the pH and nutrient content of your soil ahead of planting will be a function of your desired intensity level and available budget. Once you have ripped or subsoiled, and added any amendments such as lime, phosphorous, or potassium, smooth out the field surface with an agricultural finisher, a disk and ring roller, a tractor mounted rotovator, or a box grader.

Pre-Plant Vegetation Management

Areas with heavy perennial grass or weed cover should be broadcast sprayed with herbicide or tilled to control highly competitive weeds before planting seedlings. If your site does not need deep ripping or

subsoiling, and you have native vegetation consisting of broadleaf weeds and grasses, spray the field the fall before planting with a non-selective herbicide such as glyphosate. This control is generally best accomplished during the late summer or early fall before planting (Seifert et al. 2011, Van Sambeek and Garrett 2004).

If you are planting in March or early April, especially during a cool spring, there may be few weeds growing on your site. Planting later when temperatures have warmed and there is increasing green vegetation requires a second spring broadcast application of a post-emergent herbicide such as glyphosate. If you had sown a cover crop of perennial grasses or annual grasses such as wheat or rye, you should spray a 2- to 3-foot-wide band down each planned tree row. Alternatively, if you treated the site with herbicide in the fall, consider a light disking or rototilling a month or so before planting. If you will plant with a tractor tree planter, avoid any deep disking or tillage and note that a good rain to firm the surface before planting will be beneficial.

Cover Crops

You may want to consider adding a cover crop for your plantation if you will have relatively wide rows and are considering nut harvesting or if you wish to keep the plantation mowed regularly and looking neat from the start. Rather than allow native vegetation to grow into the middle of the tree rows, you can add a more manageable and beneficial annual or perennial crop. Look over the various options and pros and cons in Van Sambeek and Garrett (2004).

The first advice on ground covers is what not to do: do not use any form of tall fescue, which can lead to 60 to 70 percent reduction in tree growth compared to maintaining the plantation free of ground cover and understory species. In a walnut plantation where harvesting nuts is a goal, Kentucky bluegrass and white clover are good choices. These can be mowed relatively short in the fall just before nut fall without leaving a lot of debris that will interfere with nut collection. This ground cover needs to be mowed during the summer or it will be shaded out. For plantation establishment, Kura clover, which looks like red clover, has been impressive in field trials because it is more shade tolerant than most forage legumes. Kura clover is frequently used by commercial pecan growers and has persisted for almost 10 years in a Missouri study (J. Van Sambeek, pers. commun.). However, a current problem is limited seed availability. If you want to mow more than twice a year and want a neat appearance, consider sowing orchard grass or perennial rye the fall before planting. These are relatively inexpensive and inhibit walnut growth much less than fescue and other grasses.

The tighter your timber planation is spaced, and the higher your initial tree density, the less you will need to mow as the trees shade the plantation floor sooner. For such cases, a cover crop will not persist very long and may not be worth the investment. If you deep rip, and disk your field early enough in the fall, a cover of annual rye or wheat can be good to limit any erosion during the winter and to help keep other weed species in check. These annual grasses will both die naturally in June or July. In subsequent years, managing native vegetation is fine.

Marking Rows

If you are going to plant many trees with a shovel or planting bar, ripping each row with a 12-inch- to 18-inch-deep 2-inch- or 3-inch-wide shank on the back of a tractor is a good idea to mark each row and loosen the soil to make planting easier. If you will use a tractor mounted tree planter, you will want the soil firm for the coulter wheel and shoe of the tree planter to cut a slit into the soil.

To mark rows for a tractor driven tree planter, or to pre-rip and mark the rows for hand planting, run lines of flag stakes at the ends of every row, making the initial row a baseline, and then every 120 to 300 feet for the tractor to sight on (McKenna et al. 2011). Alternating colors such as pink flags on odd rows and blue flags on even rows helps the tractor driver to

sight on the correct neighboring flag stake and not get "cross-eyed" sighting on flag stakes one or two rows over. An additional check to keep the tractor spaced accurately is to hang a bar the width of two rows from the front of the tractor and to hang chains off the bar at the precise row distance. Thus, for 8-foot rows, a 16-foot bar is required. The driver can clearly see and adjust the tractor so that the chain is traveling along the trees in the center of last planted row. Combining both flag stakes to vertically sight on along with side bars and chains to horizontally cross-check leads to the straightest rows.

If you want contoured or curved rows, use the side bar and chain. The first row of trees will define the contour pattern that subsequent rows will follow. Keep in mind that tractor drawn tree planters can curve only so much. Avoid getting rows to narrow when contouring. It is better to make them too wide rather than too narrow. If your curve begins to get out of control and the between-row spacing gets off as you plant, stop and redefine a new row.

For hand planting, depending on your soil conditions, the easiest way to mark rows is to scratch a line on the surface. If your field is too rough and you have remnant live or dead vegetation, run a long rope or string taut from end-stake to end-stake and plant to one side of the rope. For the actual in-row spacing, if a tight grid is desired, mark the rope or string with paint or colored tape at the correct in-row spacings. You can use marking paint to mark a spot on the ground where each tree goes or, if your soil is tilled and soft, you can insert inexpensive wooden garden markers or plastic drinking straws to mark tree spots. If you do not want to tightly control in-row spacing, develop a system of pacing steps or cut a pole to your desired in-row spacing and use it as a quick guide to keep consistent in-row spacing.

Plant Material

A variety of stock and genetic sources can be planted, but dormant bare-root trees that are 1 year old are most common. Other stock types include containerized dormant trees (plant containerized actively growing walnut only in the late summer or early fall, not in the spring or early summer); direct seed in the fall or plant stratified or presprouted seed in the spring. You may want to include genetically improved sources such as select seedlings from state or private nurseries. You may also plant grafted trees with a cultivar known to produce trees with characteristics that may lead to better timber quality, such as 'Purdue #1.'

Whichever stock type or genetic source you choose, make sure that the material is adapted for your area (Bressan et al. 1994, Geyer and Rink 1998, Limstrom 1963). Handle your plant material carefully and keep it in good condition after you receive it and throughout planting. Bare-root trees should be kept moist in the shade and as cool as possible. If you are unsure, ask your nursery for specific methods of handling and storing your trees, or if you are planting over an extended time period, arrange to get multiple shipments out of cold storage. Sorting out and discarding the smallest seedlings and seedlings with few lateral roots can result in better seedling survival and performance across the plantation. Order more than enough seedlings to make up for those you discard.

Planting Methods

Numerous planting methods exist and the one you employ will be a function of the scale of your plantation, budget, and labor supply. Most methods will lead to satisfactory growth if performed properly. As previously discussed, the specific planting method you choose will affect aspects of your plantation design. For example, when planting with a tractor drawn tree planter, unless making some tight control over within-row spacing you will have variable numbers of trees per row and different spacings between trees (McKenna et al. 2011). The consequences of this spatial variation will be that you cannot cross mow the plantation or achieve a perfect checkerboard pattern with two species. For specific descriptions of various planting techniques and methods, see Limstrom (1963) and Pijut (2003).

Post-Plant Vegetation Control

Controlling vegetation around young trees is one of the most important management practices you can do. Regardless of the method you use, keeping a 2-foot to 3-foot circle or band around each tree free of weeds will greatly increase their growth and often increase survival (Geyer and Rink 1998, Jacobs et al. 2004, Seifert et al. 2011). Applying a combination of pre- and post-emergent herbicides for the first 3 years is typically the most effective and least expensive method to control competing vegetation. For detailed descriptions of current products, rates, and application techniques, see Seifert et al. (2011) and Pease and Geyer (2007). Cultivating around trees or applying mulch can be chemical free alternatives. Keep in mind that as you mix and include other species with walnut, you will need to make sure herbicides and your application methods are compatible with them.

Animal Management

Various animal problems are common in newly established plantations (McKenna and Woeste 2004). The most problematic animal species in many places today is white-tailed deer (*Odocoileus virginianus*). Deer browse the new growth of young trees during the growing season, causing the trees to become bushy, lose growth, and expend more energy on regrowing new shoots and leaves. As the trees get larger, after their first year of growth and up until their fifth year or so, male deer will rub their antlers on the young stems in the fall, and in worse cases, they can completely girdle or break the stems. Deer damage can be reduced through fencing or other physical barriers like tree tubes or wire cages, increased hunting pressure to reduce populations, repellents that may be based on odor or taste, extremely high density plantings, habitat manipulation to make deer entry difficult, or scare techniques like dogs or noise (Lee 2009, Pierce and Wiggers 1997).

Rabbits and voles can be destructive in young plantations. Controlling vegetation around young trees and reducing the height of vegetation between rows in late summer/fall by mowing will reduce habitat for these animals. Mowing is not necessary and may even be discouraged by some conservation programs; it can exacerbate deer browse problems if your plantation is not fenced. However, installing hawk and owl perches and mowing the middles of rows twice a year at the end of spring and summer can help avoid rabbit and vole damage to young trees by keeping the plantation more open for these predators to control small mammals.

Training and Pruning

Pruning normally involves the removal of live shoots and branches from a tree. By removing branches, pruning inherently reduces tree growth by reducing photosynthetic leaf area. Pruning of young walnut and other trees in a timber plantation is less critical in the first years after planting if your survival is high and if you have included other species to help shade side limbs. Pruning the least amount of material possible to meet quality goals is generally best. Training a young tree into a desired form takes time. Training is often accomplished by a few timely pruning cuts but can also include tying the stem to a stake to keep it straighter. Training trees into well formed timber trees is a function of pruning and your general plantation design. Pruning alone cannot entirely train your trees. A good plantation design to suit your site and objectives is crucial and can decrease the amount of pruning required.

Consider two general pruning needs when establishing the plantation: (1) correcting multiple leaders or crooked main stems, and (2) removing side limbs. For details on pruning, see McKenna and Woeste (2006). Do not prune planted trees during their first 2 to 3 years of development because newly transplanted trees spend their first years establishing a root system in the field and good vigorous top growth will not occur until roots are well established.

During dormancy after the second or third growing season, walk the plantation and be prepared to prune all of your walnut and other finer hardwoods that have multiple leaders, crooked main leaders, or whirls of

branches due to the loss of a terminal bud the year before. This is the most critical pruning to do for a timber plantation. Young terminal shoots of walnut are easily damaged by frost, insects, and animals (Beineke 1994). If the apical bud of the young central leader is damaged, a whirl of three to five branches can develop below the damage, forming what is called a crow's nest. These young trees are best corrected by coppicing. To coppice a poorly formed tree, cut below the whirl of branches into straight solid wood. Pay attention to the position of lateral buds on the stem and make the coppice cut so that you have the top bud 1 inch below your cut in the windward position (typically the southwest). By doing so, when that bud grows out in the spring with a slight crook, the prevailing wind will blow toward the bend and help the new stem to straighten.

In cases where two fairly straight codominant shoots arise, keep the straightest shoot and remove the other. As with the coppice cut, consider your prevailing wind direction and keep a shoot that will be pushed straight by the wind, even if it is slightly smaller than a shoot that is vulnerable to be blown more crooked by the wind. Lower side limbs that interfere with mowing or spraying may be removed at any time.

Once the trees are 4 to 6 years of age, plan to walk the entire plantation again to make a second round of corrective pruning cuts. At this time, there will be trees you coppiced several years earlier that have competing leaders. Any additional crow's nests or very crooked trees can also be coppiced at this time. In addition to these corrective pruning cuts, consider removing lower side limbs up to 3 to 4 feet above the ground. Lower limbs should be removed before they reach 2 inches in diameter. Prioritize pruning decisions from the top down and from largest to smallest diameter branches. Eliminate forks or other branching issues that will threaten straight log development. Prune large, fast growing limbs first. Smaller limbs in the shade will grow very slowly.

At 6 to 8 years, lower limbs should be pruned off of potential crop trees, whether they have been naturally shaded out and are dead or dying, or still alive, clearing the stems up to 4 to 6 feet above the ground. This will begin clearing the stem of unwanted defects. Around 10 years of age, you can prune off the remaining side limbs of crop trees to a height of 8 to 12 feet from ground level if less than 40 percent of the total tree height.

Pruning should be focused on crop trees. By 10 years any walnut or other fine hardwood that is poorly formed, crooked, or bushy with no timber value can be left alone and considered a trainer tree itself to be thinned out later. After your first round of thinning is complete, you may consider removing side limbs on identified crop trees higher than 12 feet as your time and resources allow, but that is not essential. At this point, managing your stand density through thinning is more critical. If you are prepared to continue pruning, always prune from the top down, looking to remove competing forks and codominant branches that interfere with the length of your future log.

CONCLUSIONS

Have a clear vision of how you want your plantation to look at 20 years and keep that vision in mind as you design your plantation. Your keys to having a successful walnut plantation will be a function of your site preparation and, most importantly, how well you have matched the species to your site. Always plant high quality seedlings and control weed competition around the trees for the first few years. Protect trees from excessive deer damage when needed. A well-designed plantation layout that guides how you will thin trees after the first and second decades will greatly improve the odds that your plantation will contain a high proportion of potential veneer trees.

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HERBICIDE PRACTICES IN HARDWOOD PLANTINGS

Brian D. Beheler and Charles H. Michler[1]

Abstract.—Control of competing vegetation is an important early cultural practice that can improve survival and vigor in hardwood tree plantings. The type of program used depends on landowner objectives, species of weeds present, equipment available, and types of herbicides available. Pre-planting planning can greatly increase effectiveness of an herbicide program for the first several critical years. Basic knowledge of weed species, herbicide modes of action, calibration of equipment, and herbicides available is essential to having an effective program. Although there have been few changes in the types of herbicide available in recent years, a couple of new labels have expanded the options for controlling weeds in hardwood tree plantings.

INTRODUCTION

Early success in hardwood tree plantings is often attributed to vegetation control. Weed control is especially needed on well-drained, fertile soils like those favored by black walnut (Siefert 1996). The options for weed control include mowing, shallow tillage, desirable ground covers, mulching, chemical control, and combinations of these (Van Sambeek and Garrett 2004). Control of competing weeds right next to the tree's root zone and beyond is more important in establishment than making sure the weeds between the rows are maintained. Keeping the immediate area around the tree roots absolutely weed free year round or just keeping it moderately clean for the spring and early summer depends on the landowner's objectives and his or her willingness to invest in a weed control program.

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VEGETATION DIFFERENCES

Determine what type of weed species you have and which ones are known to negatively affect hardwood tree growth. Weeds compete with planted trees for sunlight, water, and nutrients and some compete by excreting chemicals into the soil that will reduce hardwood tree growth. Identifying a plant as an annual grass or a choking perennial can help guide decisions on what type of weed control is needed and what type of herbicide to use. If biennials such as thistle are present, there are optimal times to kill that plant. Knowing the difference between sedges and grasses is also important as sedges can be harder to control using herbicides specific to grasses. Glyphosate mixed at 2 percent or less will only temporarily stunt sedges.

Some weed species have allelopathic characteristics and produce phytotoxic chemicals in the root zone that slow tree growth. Tall fescue and goldenrod are allelopathic to hardwood trees. Various vines such as field bind weed and morning need to be controlled as they will grow the trunk of trees and wrap around branches causing crooked and deformed stems or even death if they cover and shade out young trees. Once vines are out of control, they can be costly to control and usually require a rescue type of action (Stringer et al. 2009).

PRE-PLANTING PLANNING

A successful weed-control program starts before planting the trees, especially on sites with known competitive weeds. Following an agronomic crop like soybeans makes for a great site preparation to plant trees into but in reality many tree plantings go on old pasture, fallow land, or unproductive portions of fields. Getting rid of unwanted vegetation like tall fescue will greatly increase the effectiveness of the post planting weed control. Methods for site preparation can include chemical burndown (glyphosate) with and without tillage (Seifert and Woeste 2002). Some sites, especially on heavier soils, have plow pans and if possible, deep tillage to break that up can help with root penetration as well as drainage (McKenna and Farlee, this proceedings). The fall before planting is the best time to prepare the site for spring planting (Fig. 1). Also, a cover crop may be seeded as well to help suppress broadleaf species.

EQUIPMENT CONSIDERATIONS

The type of equipment used to deliver herbicide depends on the size of the planting, management objectives, and the landowner's budget. Band spraying is the most common form of spraying hardwood plantings and the ability to minimize the number of passes while maintaining accuracy of the spray is important, especially on larger scale plantings (Fig. 2). Backpack sprayers and ATV-mounted sprayers are great for smaller jobs with each having advantages and disadvantages. For smaller plantings, these two combinations are typically used for spraying.

Figure 1.—Fall site preparation to eliminate perennial vegetation and spring tillage has left this new planting weed free and ready for application of a pre-emergent herbicide to control weed competition through the first growing season. (Photo by Brian B. Beheler, Purdue University)

Figure 2.—Two nozzle tractor- or ATV-mounted boom for strip spraying young hardwood planting where height is adjusted so spray pattern of flat; fan nozzles are directed at base of tree seedlings and just barely overlap. (Photo by J.W. Van Sambeek, U.S. Forest Service)

Tractor-mounted sprayers are more expensive but are extremely effective and provide limitless possibilities for setting up booms and the best means of controlling application rates.

When setting up sprayers and tanks, make sure there is recirculating agitation in the tank, especially when using many pre-emergent chemicals which will otherwise settle at the bottom of the tank and spray out too dilute to begin with and too strong at the end. Other important considerations are having a sufficient sized pump, a pressure gauge, a means of adjusting pressure, and easy shut-off by the operator.

The nozzle type is equally important. Flat fan type nozzles have proven to be most effective and larger angles (i.e., 110 degrees vs. 80 degrees) allow for lowering the boom and reducing drift. The control droplet applicator (CDA) used in the fruit and vineyard industry makes a mist of concentrated solution that is sprayed over the target area and shields the stems and branches of the young trees (Fig. 3). There are various sizes CDA sprayers which have a shield allowing for spraying glyphosate after leaf out of tree seedlings even in windier conditions.

CHOOSING HERBICIDES

Knowledge of herbicide properties and mode of action helps in selecting an herbicide. Pre-emergent herbicides are applied before weed seeds germinate. Post-emergent are applied to plants that are actively growing. Some chemicals translocate, which means they move within the plant; these are known as systemic herbicides. Other chemicals only affect what they touch; these are known as contact herbicides. Chemicals like glyphosate are non-selective, meaning they are not specific to any species and will kill trees if applied incorrectly. Selective herbicides affect only some plant types or species—some just kill grasses, some only kill broadleaved plants. The label will help identify how the specific chemical works, how and when it should be applied, and what conditions to avoid to prevent damage to your trees.

Another important factor to consider is the chemical's persistence in the soil. Some chemicals have both pre- and post-emergent activity. Clopyralid, sold under the trade names of Transline™ and Stinger™, recently changed to be labeled for use in hardwood plantings, is effective for managing some problematic broadleaves late in the growing season (June-July). Clopyralid is selective on some specific broadleaves like ragweed and thistle, but safe for most trees except leguminous trees such as locust or red bud.

Figure 3.—Tractor-mounted control drop applicator with shield to control drift; this system is suitable for application of nonselective post-emergent herbicide. (Photo by J.W. Van Sambeek, U.S. Forest Service)

There is no silver bullet yet to knock out broadleaf weeds completely, although selectivity is improving. There are challenges when dealing with broadleaf weeds and hardwood trees since trees are broadleaves as well (Stringer et al. 2009). When choosing a herbicide or mix of herbicides, pay attention to species controlled, mode of herbicide action, timing, and how the chemical is labeled for use (i.e., hardwood tree plantings, CRP, and industrial sites), and toxicity (i.e., Caution, Warning, and Danger) that may indicate if it is restricted to use only by licensed applicators. One helpful resource is Crop Data Management Systems, Inc. (Crop Data Management Systems 2013). Type in a chemical name or brand and the Website will display all the labels and MSDS sheets. Cost also can play a role when purchasing a chemical. Table 1 lists common herbicides (and brand names) registered for use in hardwood plantings, recommended rates (which vary depending on vegetation and soils), and average cost in 2011 at a dealer in Indiana, using the highest recommended application rates to entirely cover 1 acre. Read and follow all directions as they are legal documents and based on extensive testing and research. Failure to follow the instructions and directions on a label will void any warranty from company. The applicator is also responsible if problems occur that can be traced back to application and directly linked to noncompliance with the label.

RATES AND CALIBRATION

Once herbicides have been selected, it is important to use a properly calibrated sprayer to get the correct amount of product to the target. Information on how to calibrate sprayers is available on the Internet, local agriculture co-ops, and university extension programs. It is important to make sure the correct measuring tool is used for the specific product type (Fig. 4). Some herbicides such as sulfometuron are effective at very small concentrations (0.5 to 1 ounce per treated acre)

Table 1.—Registered herbicide products for hardwood plantations.

Type of Herbicide	Chemical	Common trade names	Rate per treated acre	Cost per unit	Cost per treated acre (high rate)
Post-emergent (grass and broadleaves)	Glyphosate	Various names, i.e., Roundup	20-64 ounces	$20-40/gallon	$7-$12
Post-emergent (only certain broadleaves)	Clopyralid	Transline, Stinger	4-21 ounces	$200-$270/gallon	$30-$45
Post-emergent (grass only)	Clethodim	Envoy, Envoy Plus	17-34 ounces	$110-$135/gallon	$20-$40
Pre-emergent	Simazine	Princep, Caliper	2-4.4 pounds	$4-$5/pound	$20-$25
Pre-emergent	Pendimethalin	Pendulum, Aquacap	2-4.2 quarts	$50-$70/gallon	$60-$85
Pre-emergent	Oryzalin	Surflan	2-4 quarts	$70-$80/gallon	$70-$80
Pre-emergent, Post-emergent	Flumioxazin	SureGuard	8-12 oz	$115-125/pound	$85-95
Pre-emergent, Post-emergent	Sulfometuron	Oust XP	0.5-1.0 oz	$96/pound	$6

Figure 4.—Measuring amount of herbicide discharged from a flat fan nozzle for a minute as part of calibration to determine area covered when tractor is driven 3 to 4 miles per hour. (Photos by James R. McKenna, U.S. Forest Service)

and if applied too strongly, can significantly damage or kill hardwood seedlings. Water pH, turbidity (muddy water), or hardness can also reduce the effectiveness of certain herbicides and carefully reading the label will inform you of water quality considerations (see pages 8-17 in Whitford et al. [2009]). The rate of chemical to use for post-emergent herbicides (given as a range on labels) depends on the growth stage of weeds. For pre-emergents, the rate will be based on the soil type and the desired length of time to be effective. Unsatisfactory results can occur with lower rates for many chemicals, especially with pre-emergents. Also beware that when spraying over existing vegetation or thick thatch, some chemical will get bound up and not make it to the soil or target, reducing effectiveness. Increasing the amount-per-acre of liquid sprayed can help with increasing effectiveness in these situations.

RECORD KEEPING

Finally, record what was sprayed, how much, the date, and which weeds were present, so effectiveness can be compared from year to year. If in the next 2 months after spraying there are major weed issues, then the applicator can determine what did not work and plan on how to deal with the problem. Successful hardwood plantation establishment typically requires weed control for 3 or more years to get tree seedlings above the competing vegetation.

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TREE IMPROVEMENT

BREEDING BLACK WALNUTS IN THE AGE OF GENOMICS

Mark V. Coggeshall and Jeanne Romero-Severson[1]

ABSTRACT

Molecular markers have been used in several walnut species to help reconstruct breeding program pedigrees (Pollegioni et al. 2009), to characterize genetic structure in natural *Juglans* populations (Hoban et al. 2010, Karimi et al. 2010, Robichaud et al. 2010, Victory et al. 2006), to determine the impact of different timber harvest scenarios on residual levels of genetic diversity (Robichaud et al. 2010), and to quantify the effects of interspecific hybridization on subsequent reproduction success (Hoban et al. 2009). Pijut et al. (2007) reviewed technological applications of molecular markers used on several temperate hardwood tree species. Modern genomics-based tools are currently being used in several black walnut (*J. nigra*) studies.

A number of informative microsatellite markers, also called single sequence repeat (or SSR) markers, have been developed for black walnut (Robichaud et al. 2006). These markers have been used to help identify all trees currently in the University of Missouri (MU) germplasm collection through the development of "genetic fingerprints" for each tree, which can then be compared with standardized phenological descriptors to confirm identity (Coggeshall and Woeste 2010). These same markers have also been used to confirm the parentage (or pedigree) of black walnut trees derived from hand pollinations, as well as to identify new, full sib seedling families derived from large open-pollinated seedling populations through paternity exclusion techniques. Further, both temporal and spatial patterns of pollen flow in seed orchards and natural stands can be quantified using these markers (see Robichaud et al. 2010).

Work is underway to develop the first genetic linkage map for black walnut, based on a suite of genetic markers derived from nuclear DNA and RNA sources. In contrast to morphological markers (such as flower color), these genetic markers are *not* actual genes; instead they *represent* those genes that influence a trait (such as flowering date) in an individual. Such markers are located *near* genes that actually control a trait of interest. Defining the location and arrangement of markers on a genetic map will facilitate the identification of regions of each chromosome that may be associated with commercially important traits. It is anticipated that such knowledge will facilitate future breeding efforts to develop improved black walnuts for both timber and nut production by means of marker assisted selection techniques.

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STAND MANAGEMENT AND AGROFORESTRY

USING BIOLOGICALLY FIXED NITROGEN BY NATIVE PLANTS TO ENHANCE GROWTH OF HARDWOOD SAPLINGS

J.W. Van Sambeek and Nadia E. Navarrete-Tindall[1]

ABSTRACT

Available soil nitrogen is frequently low in old-field plantings. Underplanting forage legumes and interplanting nitrogen-fixing shrubs can improve growth of hardwood saplings, especially black walnut and pecan. Most of the nitrogen-fixing shrubs and forbs have been introduced, and several are now considered invasive species.

Research trials have been established on old-field sites to evaluate the potential benefits of establishing native forbs, grasses, shrubs, and trees with seedlings of black walnut, pecan, chestnut, and five oak species. Four native legumes seeded individually or as a mix 8 years earlier had no effect on sprout height 2 years after a prescribed burn in a planting with walnut and four oak species. Growth of bur oak followed by white oak was greater than that of walnut, northern red, and Shumard oak. Mixes of native legumes, native grasses, or both had no effect on sixth-year sapling height or their sprouts 2 years after a prescribed burn on grafts of black walnut, pecan, and Chinese chestnut.

Four native and two introduced cool-season grasses seeded individually with and without native legumes had no impact on seedling survival of black walnut, pecan, bur oak, and swamp white oak; however, tall fescue, redtop, and Virginia wildrye did suppress growth of black walnut compared to walnut in control plots. Mid-season foliar nitrogen concentrations were not a good predictor of tree growth in this planting where birdsfoot trefoil and goldenrod initially dominated the living mulch ground cover.

Interplanting six native legume shrubs or trees failed to stimulate growth of pecan grafts and seedlings. Although black locust increased pecan foliar nitrogen, it rapidly overtopped and suppressed pecan growth. In our research, we continue to assess additional native plants (Figs. 1-4) established as ground covers or nurse crops that can stimulate the growth of hardwood saplings.

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Figure 1.—Dense stand of partridge pea (*Chamaecrista fasciculata* (Michx.) Greene) being evaluated as a native cover crop for hardwood plantings. (Photo by Nadia Navarrete-Tindall, Lincoln University)

Figure 2.—Closeup of the flowers of the partridge pea (*Chamaecrista fasciculate* (Michx.) Greene), a native nitrogen-fixing legume. (Photo by Nadia Naverrete-Tindall, Lincoln University)

Figure 3.—Closeup of the flowers of Illinois bundleflower (*Desmanthus illinoensis* (Michx.) MacM.), a native nitrogen-fixing legume. (Copyright photo by Randy Tindall, used with permission)

Figure 4.—False indigo (*Amorpha fruticosa* L.), a native nitrogen-fixing nurse crop species, in full flower. (Photo by Nadia Navarrete-Tindall, Lincoln University)

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HERBICIDES TO CONTROL SPROUTING ON HIGH STUMPS OF BLACK WALNUT AND GREEN ASH

W.A. Geyer and Leyre Iriarte[1]

Abstract.—After thinning hardwood stands, sprouts often develop on the girdled stems or cut stumps. While sprouts may be left for wildlife, it is usually best to deaden each tree to minimized future competition for soil moisture and nutrients. By applying select herbicides to the stump, sprouting can be eliminated. This study evaluated five herbicides applied as basal bark or cut stem application to black walnut and green ash stumps 90 days after cutting. Trimec®, Crossbow®, Chopper®, Vista®, and Garlon 4® were applied in diesel oil solutions. All herbicides effectively controlled stump sprout when applied in a 3- to 4-inch-wide basal bark application around the base of the stump. Only Vista® was effective as a cut surface application to 18-inch-high stumps of both black walnut and green ash. Cut surface application showed species specific responses where Chopper was effective on black walnut but not green ash while Garlon 4® was effective on ash but not walnut.

INTRODUCTION

Eastern black walnut (*Juglans nigra* L.) and green ash (*Fraxinus pennsylvanica* L.) are two high value hardwoods planted at relatively close spacing that will requires a series of precommercial thinnings to remove inferior individuals and maintain diameter growth rates. Effectively preventing regrowth on stumps of cut trees can be accomplished by application of herbicides to the exposed cambium of cut stumps or as basal bark treatments for some tree species (Jobidon 1997). Cut surface applications of stumps require thoroughly wetting the cambium area just inside the bark for absorption and translocation of the herbicide within the stump (Miller and Glover 1991). Basal bark treatments thoroughly wet a narrow band of bark completely around the circumference of the stump using a carrier that may facilitate diffusion of the herbicide to the cambium and any buds at the bark surface (Miller and Glover 1991). While sprouts have a wildlife benefit, it is usually best to deaden the entire stump of each tree to reduce completion for soil moisture and nutrients. This study was designed to evaluate the effectiveness of five "off-the-shelf" herbicides to eliminate stump sprouting either as delayed cut surface or basal bark applications to black walnut and green ash stumps.

METHODS AND MATERIALS

The study site is located in east-central Kansas on an alluvial site just below Tuttle Creek Reservoir. The soils are silty clay loams and very fertile with a site index of 70 to 75 feet at 50 years for black walnut. The area had been in fallow about 20 years prior to tree planting. Several experimental plantings of black walnut and one planting of green ash were established over the last 30 years. For this study we selected recently thinned plantings of 15-year-old black walnut established on 12 by 12 foot spacing with average stem diameter of 4 to 6 inches, and of 10-year-old green ash planting established on 12 by 5 foot spacing with average stem diameter of 3 to 9 inches.

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Trees marked for thinning were cut in January with a chain saw leaving an 18-inch high stump for ease of sawing. Herbicides were applied late in the dormant season (about 90 days after cutting) either as cut surface application to the top of the stumps or basal bark applications with a 3- to 4-inch wide band sprayed near ground line around the stump. Treatments included a control left untreated and low-volatile ester formulations in diesel oil at the following rates: 5 percent Trimec® (active ingredients = 0.27 percent dicamba + 1.6 percent 2,4-D + 1.59 percent dichoprop); 5 percent Crossbow® (active ingredients = 1.72 percent 2,4-D + 0.725 percent triclopyr); 3 percent Chopper® (active ingredient = 0.86 percent imazapyr RTU); 10 percent Vista® (active ingredient = 2.62 percent fluroxypyr), and 5 percent Garlon 4® (active ingredient = 3.0 percent triclopyr). Herbicides were applied with a common garden sprayer with a nozzle adjustable from a mist to a stream. After two growing seasons, the total number of sprouts in the upper and lower half of each stump was recorded.

The study was designed in a randomized complete field design with 10 single-tree replications of 11 treatments for a total of 110 trees in both the black walnut and green ash plantings. Individual tree data for total number of sprouts were subjected to analysis of variance (SAS Version 9.1, SAS Institute, Inc., Cary, NC) followed by Duncan's New Multiple Range Test to identify when significant differences existed among treatments within species at alpha = 0.05 percent.

RESULTS

Black Walnut

Many stumps had sprouts after 1 year, but this number was reduced substantially during the second year. After 2 years, the percentage of stumps with no sprouts increased and ranged from 30 to 100 percent (Table 1). We achieved an acceptable level of stumps without sprouts with basal bark application by all five herbicides after the second growing season, however, only Chopper® and Vista® had acceptable levels as cut-

Table 1.—Percent of stumps without live sprouts and mean number of live sprouts 2 years after applying five herbicides to cut surface or basal bark treatment to 18-inch-high stumps of black walnut and green ash.

			Black walnut		Green ash	
Herbicide	Rate (% a.i.)	Application method	Mean number sprouts per stump[a]	% stumps without live sprouts[b]	Mean number of sprouts per stump[a]	% stumps without live sprouts[b]
5% Trimec in oil (dicamba + 2,4-D + dichorprop)	0.27 + 1.62 + 1.59	Cut surface	4.1 c	30	1.8 b	50
		Basal bark	**0.4 a**	**80**	**0 a**	**100**
5% Cross bow in oil (2,4-D+ triclopyr)	1.72 + 0.725	Cut surface	1.0 b	50	2.4 b	50
		Basal bark	**1.0 b**	**70**	**0.3 a**	**70**
3% Chopper in oil (Imazapyr RTU)	0.86	Cut surface	**0 a**	**100**	7.2 c	0
		Basal bark	**0 a**	**100**	**0.1 a**	**90**
10% Vista in oil (Fluroxypyr)	2.62	Cut surface	**0.4 a**	**70**	**1.5 b**	**70**
		Basal bark	**0 a**	**100**	**0 a**	**100**
5% Garlon 4 in oil (Triclopyr)	3.0	Cut surface	0.8 b	60	**0.2 a**	**90**
		Basal bark	**0 a**	**100**	**0.1 a**	**90**
Control	None	None	3.8 c	30	>10 d	0

[a] Values in the same column followed by the same letter are not significantly different at $p \geq 0.05$.
[b] **Bold type** indicates acceptable control.

surface treatments. Trimec as a cut surface application had the same number of live sprouts after 2 years as the control treatment without any herbicide. Based on the mean number of live sprouts after 2 years, Chopper® and Vista® as cut surface applications were more effective than Crossbow® or Garlon 4®. We found no significant differences between the number of sprouts on the upper and lower halves of herbicide-treated walnut stumps. In addition, we did not observe any symptoms of chemical injury or flashback to the residual trees in part because of the wide distances between trees.

Green Ash

Green ash stumps also had many sprouts after the first year and again the number of stumps with sprouts was reduced substantially after the second year. After 2 years, the percentage of stumps with no sprouts ranged from 0 to 100 percent (Table 1). Stumps in the control treatment without any herbicide all had sprouts and averaged more than 10 live sprouts on each stump after the second year. With basal bark application of any of the five herbicides, we achieved an acceptable level of stumps without sprouts after the second growing season; however, only Vista® and Garlon 4® yielded acceptable levels as cut-surface treatments. Based on the mean number of live sprouts, Chopper was less effective as a cut surface application than Crossbow® and Trimec®. As with walnut, we found no differences in the number of sprouts originating in the upper and lower halves of green ash stumps.

DISCUSSION

When thinning hardwood plantings by cutting, it is easier and safer to cut trees leaving a tall stump than cutting near the groundline, especially if the sawyer can delay application of herbicides to control stump sprouting as a separate operation. Delayed application of all five herbicides to stumps following thinning was effective when applied as basal bark treatments for both black walnut and green ash. A similar result was found when treating stumps of Siberian elm (*Ulmus pumila* L.) using the same herbicides and application methods (Geyer 2003). The five herbicides used in this study were also effective when sprayed around recently cut stumps at the ground line, however, only Chopper® and Garlon 4® were effective as cut surface treatments 18 inches above the ground line.

Effectiveness of delayed cut surface applications can be species dependent as Chopper was effective on black walnut but not green ash while Garlon 4® was effective on ash but not walnut. In an earlier study, Walter et al. (2004) found Garlon 3®, but not Banvel® or Roundup®, was effective on black walnut as a cut surface application. While Vista® was effective on black walnut and green ash as both a basal bark and cut surface application, it was ineffective as a cut surface treatment on elm (Geyer 2003).

CONCLUSIONS

All herbicides tested in this study can be applied up to 90 days after cutting during the dormant season to control sprouting on high stumps of walnut and green ash when applied as a basal bark treatment (3- to 4-inches wide herbicide band around the stump near the ground line). When sprayed on the cut surface of the stump (18 inches above the ground), Chopper® and Vista® were effective on black walnut, while Vista® and Garlon 4® were effective on green ash. While sprouting can be reduced during the first year after treatment, it took 2 years to fully evaluate the effectiveness of each herbicide treatment.

ACKNOWLEDGMENTS

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INTEGRATING WALNUT AND OTHER HARDWOODS INTO AGROFORESTRY PRACTICES

Shibu Jose[1]

Abstract.—Agroforestry systems have been proposed as alternative, environmentally benign systems for agricultural production in temperate North America. Walnut and other hardwoods have been successfully integrated in most agroforestry practices include alley cropping, silvopastural, windbreaks, and riparian buffers. Because of walnuts relatively thin crowns and nut production, it has been the most frequently used woody species. The biophysical research has revealed that the success of complex hardwood-based agroforestry systems will depend on minimizing the negative interactions, especially above and below ground competition, while enhancing the synergistic interactions between system components. Research has shown that agroforestry systems can provide significant ecosystem services in addition to the direct economic benefits.

Agroforestry systems, the planting of perennial trees and/or shrubs with annual agronomic crops or pasture, have been proposed as more environmentally benign, alternative systems for agricultural production in temperate North America. In addition to environmental pressures, the economic benefits of multiple crops within agroforestry systems have also generated interest in their adoption by farmers (Garrett 2009). Alley cropping, a form of agroforestry in which trees and/or shrubs are established in hedgerows on crop land with agronomic crops or pasture grasses cultivated in the alleys, has been a subject of numerous experiments in the tropics. Interest in diversifying farm income and reducing environmental impacts of agricultural practices has led to the development of alley cropping systems in the temperate region. The crops most often planted in the United States and Canada include corn (*Zea mays* L.), soybean (*Glycine max* L. (Merr.)), wheat (*Triticum* spp.) and oats (*Avena* spp.), combined with trees such as black walnut (*Juglans nigra* L.), pecan (*Carya illinoinsis* (Marsh.) Engl. Graebn), oaks (*Quercus* spp.) and poplars (*Populus* spp.). In the north-central United States, systems combining crops with timber producing trees, especially black walnut, have been established on several sites. Research conducted over the past three decades on the biophysical and socioeconomic aspects of the black walnut-based alley cropping systems has provided encouraging results that should help promote these practices in the Midwest (Idassi 2012).

A number of positive and negative interactions have been postulated for both the tree and crop components of these systems, and the direction and magnitude of these interactions are determined by the patterns of resource sharing and the time scale at which these patterns are measured. Biophysical research has revealed that the success of these complex hardwood-based agroforestry systems will depend on minimizing negative interactions while enhancing the synergistic interactions between system components. The acceptability of black walnut-based alley cropping by landowners would be improved if interactions that exist between trees, crops and/or livestock remain largely beneficial so that productivity per unit area of

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land is increased while reducing environmental risks associated with monocultural systems. While many shade tolerant C_3 crops (most forbs and cool season grasses) perform well in terms of growth and yield under shade in mature walnut agroforestry systems, C_4 crops (corn and other warm season grasses) can suffer greatly if shading exceeds 40 percent. It has also been shown that belowground competition for water and nutrients can be a major determinant of growth whether C_3 or C_4 crops are grown in combination with walnut trees. Since black walnut is known for its allelopathic properties mediated by the phenolic compound juglone, care should be taken to avoid planting juglone-sensitive crops in association with black walnut.

Both the aboveground and belowground competition can be alleviated through management practices. Studies of other tree species have revealed that deep disking of the alleys in early years of establishment can train the roots to go deeper and reduce the competitive stress in the crop rooting zone. Thinning the overstory to allow optimum light levels in the understory or changing to a shade tolerant crop in the understory can prolong the life of a timber-based agroforestry system.

Economic research has shown that walnut alley cropping can be a viable economic alternative to landowners interested in nut production without an income lag as the trees mature. Establishment of grafted, genetically-improved trees can substantially reduce the time it takes to reach commercial production and increase net income to the landowner (Godsey 2012). From a financial perspective, black walnut alley cropping is best suited to marginal cropland that is being transitioned from crops to a more sustainable land use. Planting black walnut can ensure that the land that was once used for marginal crops can still produce a high annual income once the trees reach commercial production level. Landowners that are looking for a potential long term investment can expect rates of return ranging from 4 percent to 6 percent. In addition to annual income from nut production, black walnut wood is the most valuable timber grown in Missouri. Although grafting and shaking of trees during nut harvesting may have a negative impact on the value of that timber, the timber is still marketable for lumber and would increase the financial returns for the landowner's future generations.

Various ecosystem services and environmental benefits have been reported from hardwood-based agroforestry systems, in addition to direct economic benefits (Jose 2009). Hardwood alley-cropping, for example, has been shown to have higher soil organic matter and soil nitrogen compared to sole cropping systems (Kremer and Kussman 2011). Researchers have also reported higher diversity both above (e.g., arthropod) and belowground (e.g., microbial activity) in hardwood agroforestry systems (Kremer and Kussman 2011, Stamps et al. 2002).

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NUT PRODUCTION

NUT PRODUCTION IN RESPONSE TO THINNING AND FERTILIZATION FOR PLANTED BLACK WALNUT

Felix Ponder, Jr., Steve Rutledge, and J.W. Van Sambeek[1]

Abstract.—Nut production from nursery-run black walnuts grown on 225 acres at the Hammons Products Company's Sho-Neff Black Walnut Farm in Stockton, MO, was evaluated from 1995 to 2010 to determine if nut production increased after thinning and fertilization in 2001. The farm consists of 11 upland and 10 bottomland plantings on sites ranging from unsuitable to well suited for growth of walnut. All 21 stands were thinned in 2001, removing about one-third of the trees, and fertilized with 60, 20, and 60 pounds per acre of nitrogen, phosphorus, and potassium, respectively. Nine stands were limed to raise pH to 5.5 or higher. Five stands received an additional spring and fall application of nitrogen. Milled walnut shells and husk waste were periodically applied to 11 stands. Hay was harvested between rows 40 feet apart both before and after thinning and fertilization. Nut production increased on average 20 pounds per acre with one-third fewer trees over the 9-year post-treatment period compared to the 7-year pretreatment period. The modest gain in nut production suggests that competition between trees and low soil nutrients were not the major factors limiting nut production. These results cause us to wonder: can a grower expect early economic returns from nut production on an investment made in the culture of young black walnut from nursery-run or unimproved seedlings?

From the founding of the Walnut Council in 1970 to now, many acres of planted nursery-run seedlings of black walnut (*Juglans nigra* L.) have reached nut-bearing age and size, but few of these trees are producing substantial nut crops. While the species is well known for its desirable wood characteristics exhibited in furniture, paneling, lumber, and other products, nut production on unimproved walnut remains a value-added consideration as an early return on the investment. Suspected reasons for low production include unsuitable soils, poor cultural treatments, environmental factors, and genetics (Ponder et al. 2001). Most stands are not thinned sufficiently to encourage development of large crowns that create the branching structure needed to support and encourage large nut crops. Also confounding nut production is the irregular bearing pattern that is typical of many fruit and nut trees (Sparks 1974). The remedy for this problem is believed to be linked to adequate carbohydrate reserves during the growing season (Sparks 1974, Van Sambeek 1998).

While much more attention has been directed to increasing the growth of black walnut than to increasing nut production, a few authors report that nut crop production can be increased by fertilization and other treatments (Garrett et al. 1991, Garrett and Kurtz 1983, Jones et al. 1995, Ponder 1976). The Hammons Products Company, using seedlings grown from nuts of unimproved or wild trees, developed one of the first eastern black walnut farms in the United States, named Sho-Neff Black Walnut Farm in honor of the farm's previous owners. The farm is being managed to produce black walnut veneer, lumber, and nuts. In

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2001, the company tried a number of treatments to increase nut production including thinning, liming, fertilization, and application of mill and husk waste (Ponder et al. 2001). In this paper, we compare black walnut nut production before and after the application of various combinations of these treatments within 21 walnut plantings on the farm.

METHODS AND MATERIALS

The Sho-Neff Black Walnut Farm is located in Cedar County in southwest Missouri and is owned and operated by the Hammons Products Company of Stockton, MO (37 N latitude, 94 W longitude). The farm is bordered on the north by Cedar Creek and partly on the east by the Sac River. Some areas of the farm are influenced by lowland conditions, while other areas are on uplands. Soils are deep to very deep, nearly level, moderately sloping, and range from poorly, to moderately well drained, to well drained. These soils are fine-loamy, mixed, mesic, and were derived primarily from acid sandstone. Overall, soils had a mean pH of 6.4, cation exchange capacity (CEC) of 11.2, 64 pounds per acre of available phosphorus (P), and 179 pounds per acre of available potassium (K). Since the early 1970s, the farm has implemented several soil conservation improvements including the application of lime, soil placement, and drainage way construction.

The farm, which includes acreage in mature forest, was divided into 25 stands based primarily on landscape, drainage, and vegetation (Fig. 1). This was done before the black walnut soil suitability (BWSI) ratings were available on the Web Soil Survey (Natural Resource Conservation Service (NRCS) state offices). Wallace and Young (2008) described in detail the development and parameterization of this computer model for assessing walnut suitability using the properties assigned to the soils as mapped within the NRCS soils database. BWSI ranges from well suited to unsuited across the 11 upland stand (stands 16 to 25) and 10 bottomland stands (stands 1 to 12).

Beginning in 1975 and continuing over several years, the farm was planted to eastern black walnut using bare-root seedlings obtained from the Missouri Department of Conservation nursery in Licking, MO. The seedlings were planted in rows spaced 40 feet apart. Within-row spacings were 6, 10, or 20 feet between planted trees. During the first few years after planting, crops of soybeans, wheat, or milo were planted annually between rows. After several years of row cropping, many of the alleys were planted to red clover and grasses including timothy (*Phleum pratense*), tall fescue (*Festuca arundinacea*), and orchard grass (*Dactylis glomerata*) for hay production. Weeds within rows were controlled with glyphosate (N-(phosphonomethyl) glycine) and simazine (6-chloro-N', N'-diethyl-1, 3, 5-triazine-2, 4-diamine) applied annually in 5-foot-wide bands along both sides of the row using a tractor-drawn sprayer. Lateral branch pruning was done periodically over the years up to 12 feet or higher depending on the perceived tree quality.

Beginning in 1995, nuts were harvested manually from each stand and mechanically husked before determining green hulled weight. After nut production began to decline, thinning and fertilization treatments were initiated in the fall of 2000 and during 2001 within all stands, along with various combinations of liming, split application of fertilizers, and application of husk and mill wastes (Table 1). The treatments were not designed and applied as planned research and are not ideally suited to statistically test for increased nut production. The treatments did give us an opportunity to provide additional insights on the effects of these cultural practices over a large number of acres planted to the species on a range of sites ranging from well suited to unsuitable for growth of walnut.

Thinning removed about one-third of the trees and the stumps were ground in place. Soils were tested and nine stands were limed according to recommendation for growing soybean and corn as prescribed by

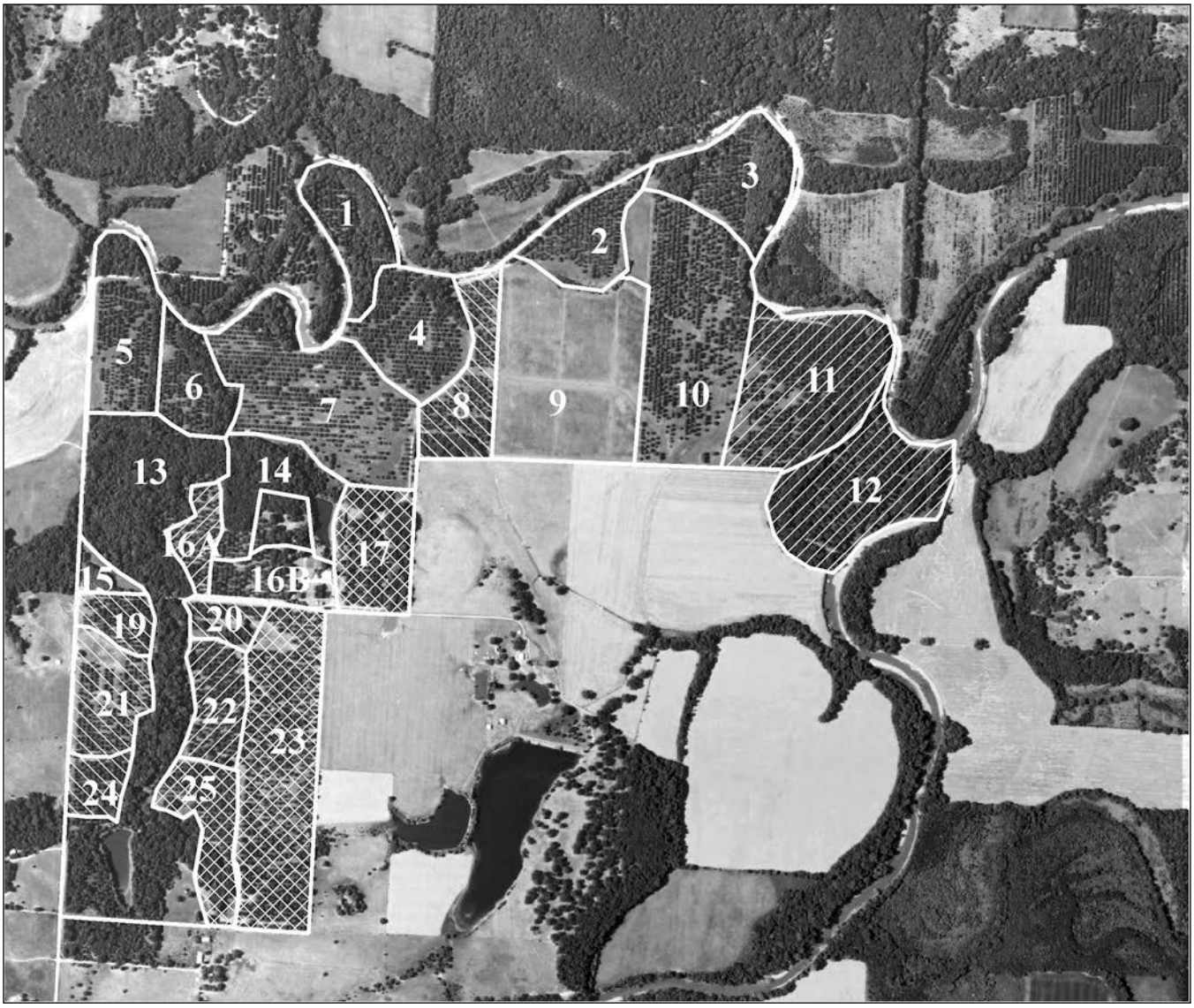

Figure 1.—Aerial photo of Sho-Neff Black Walnut Farm showing location of bottomland plantings (1 to 12) and upland plantings (16 to 25) with Cedar Creek along the north side (top) and the Sac River along the east side.

the University of Missouri Soil and Plant Testing Laboratory. Fertilizer (NPK) was broadcast applied in August of 2001 to all 21 walnut stands. Nitrogen, P, and K were applied at 60, 20, and 60 pounds per acre, respectively. In addition, a 50:50 split application of 120 pounds per acre of N as ammonium nitrate was applied to five stands in February and September 2001. Milled walnut shell and husk wastes were applied to 14 stands at rates from 0.2 to 11 tons per acre (Table 1). The nutrient content of the walnut mill and husk waste was not determined before each application, except on stand 17. For stand 17, NPK concentrations of mill and husk wastes were 2.4 to 2.7 percent, 0.3 to 0.4 percent, and 1.0 to 1.2 percent, respectively. Past observations of pastures in areas where walnut wastes were applied showed no visual phytotoxicity and were greener than in areas where wastes were not applied.

Table 1.—Cultural treatments applied in 2001 to 11 bottomland and 10 upland walnut stands on the Hammons Products Company's Sho-Neff Black Walnut Farm located near Stockton, MO.

Position and stand	Acres	BWSI[a]	Treatments				
			Thinned[b]	Fertilized[c]	Limed[d]	Split N[e]	Mill wastes[f] (tons/ac)
Bottomland							
1	3.7	Well	X	X			11.2
2	8.7	Well	X	X	X		
3	6.4	Well	X	X			
4	13.4	Unsuited	X	X	X		0.2
5	11.9	Unsuited	X	X			2.6
6	6.6	Unsuited	X	X			5.2
7	41.6	Unsuited	X	X	X		3.1
8	9.2	Unsuited	X	X	X		2.7
10	35.6	Unsuited	X	X	X		0.2
11	23.1	Well	X	X		X	
12	15.6	Well	X	X	X	X	
Upland							
16A	11.1	Somewhat	X	X			7.7
16B	3.4	Somewhat	X	X			4.6
17	5.9	Somewhat	X	X			7.1
19	5.8	Poorly	X	X		X	
20	3.0	Poorly	X	X	X	X	2.4
21	8.4	Poorly	X	X	X		4.0
22	10.4	Poorly	X	X			
23	33.4	Moderate	X	X		X	0.8
24	5.0	Moderate	X	X	X		9.5
25	8.3	Somewhat	X	X			

[a] Black walnut soil suitability index rating (Natural Resources Conservation Service).
[b] Approximately one-third of all trees were removed in fall 2000 or spring 2001.
[c] Fertilizer was applied at a rate of 60, 20, and 60 pounds per acre NPK in August 200l.
[d] Lime was applied to adjust pH to 5.5 or higher in August 2001.
[e] Split application of 60 pounds N per acre applied in February and again in September 2001.
[f] Tons per acre of milled shell and husk wastes applied during 2001.

Because there was no control available to compare treatments, prethinning nut production data were compared to post-thinning nut production data for this report. Thus, nut data were designated as "before or pre" and "after or post" treatments. Years 1995 through 2001 (flowers for 2001 were initiated during the 2000 growing season) were considered pretreatment and years 2002 through 2006 as post-treatment for statistical analyses. Annual nut production data during the two periods were compared using repeated measures ANOVA (SAS Institute, Cary, NC) and differences between annual nut crops were tested for significance using the Tukey-Kramer method ($a = 0.05$). Nut production for stands receiving lime, the additional 120 pounds of N, and mill wastes were compared to stands not receiving the respective treatment (Table 1) by analysis of variance using PROC GLM procedure in SAS Version 8.2 (SAS Institute). Tukey's test for mean separation was used to identify significant differences ($a = 0.05$).

RESULTS

Annual nut production from 1995 to 2010 was highest in 1997 and very low in 1998 and then low again in 2004, 2007, and 2010 (Fig. 2). The erratic bearing pattern is relatively consistent for both bottomland and upland stands. Sparks (1974) suggested that wild

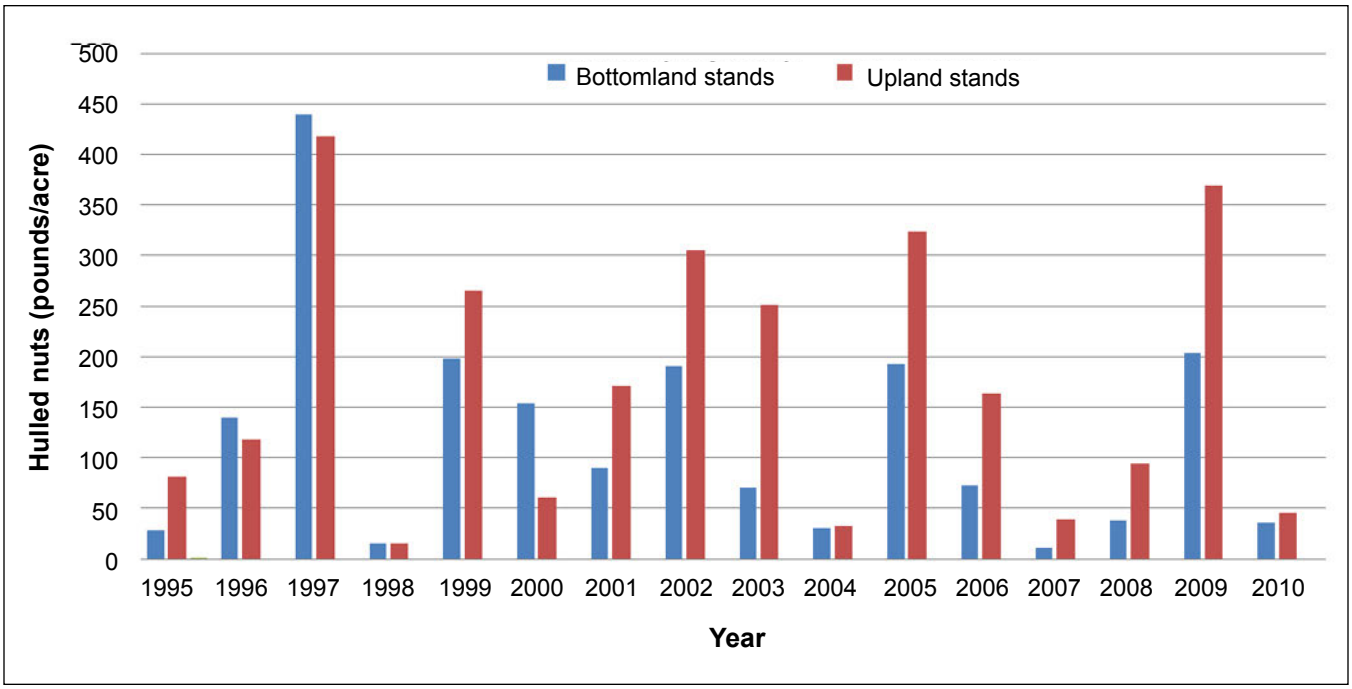

Figure 2.—Mean annual hulled nut weight per acre for bottomland and upland stands during the pretreatment years (1995-2001) and post-treatment years (2002-2010) when most stands had one-third fewer trees.

trees usually develop a bearing pattern demonstrated by a high bearing year followed by one or more low bearing years before production increases. The trend for decreased nut production of 400 to 450 pounds of hulled nuts per acre in 1997 prompted the decision to thin the stands and apply lime, nitrogen, and/or mill wastes. The lack of experimental design in the application of the treatments makes it difficult to separate causal effects on nut production variation. But there appears to be a relationship between position on the landscape (bottomland versus upland) and nut production. For simplicity, portions or all of stands 1 through 12 are considered bottomland while stands 16 through 25 are considered upland. Figure 2 suggests these treatments failed to substantially increase nut production although there are interesting differences between the response in the bottomland and upland stands.

Dividing the nut production data from 1995 through 2010 into before- and after-treatment periods meant that there were 7 years of pretreatment (1995-2001) data and 9 years of post-treatment (2002-2010) data with approximately one-third fewer trees. Mean nut production for the pretreatment period (1995 to 2001) for all stands was 150 pounds of freshly hulled nuts per acre compared to 170 pounds of freshly hulled nuts for post-treatment years (2002 to 2010) after thinning and application of 60 pounds of nitrogen per acre in 2001.

Nut production response to thinning and fertilization did vary by stands (Fig. 3). The top nut producing stands after applying treatments were consistently on upland soils in the southwest part of the farm while the converse was true during the pretreatment period. Although both have soils 60 inches or more in depth, bottomland stands 11 and 12 have soils with an average of 0.20 to 0.24 inches of available water per inch of soil while the upland stands 2 and 3 have an average of 0.18 to 0.20 inches of available water per inch of soil according to the Cedar County soil map. We must note, however, that some of the soils in both the upland and bottomland stands are not well drained and are less than ideal for growing black walnut (Table 1). Above average annual precipitation in many of the post-treatment years may have restricted oxygen movement in the poorly drained bottomland soils

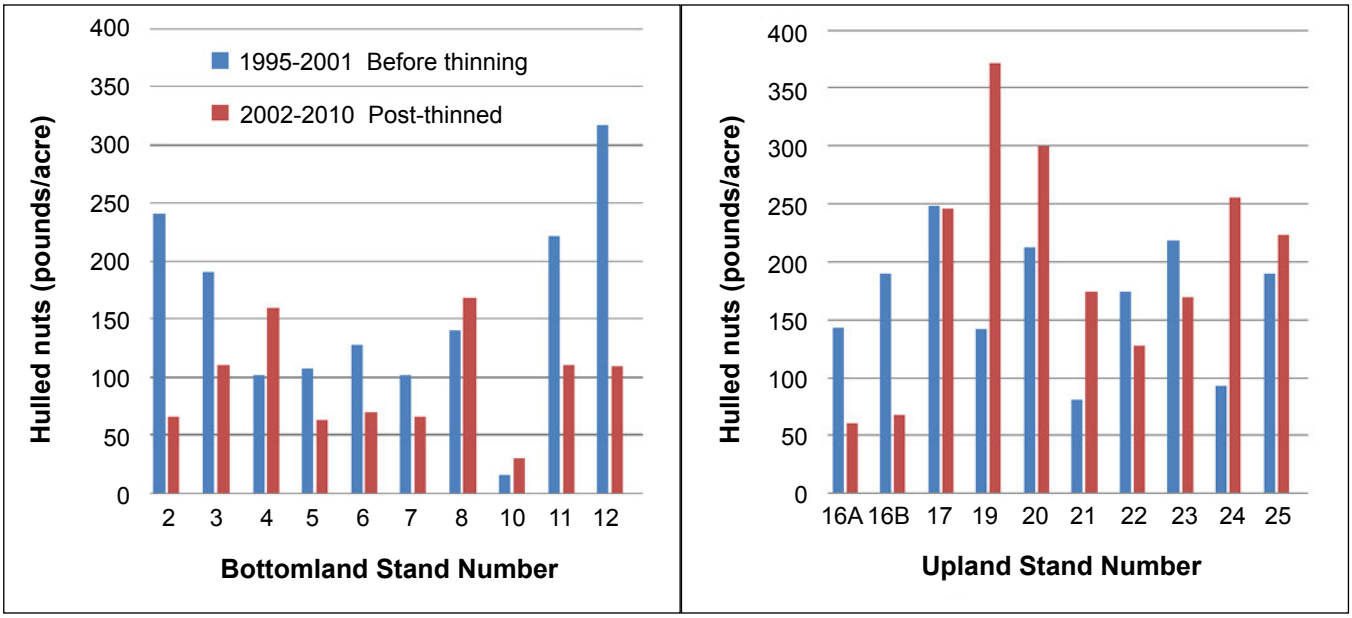

Figure 3.—Average annual hulled nut production for the 6 years before thinning and fertilization and the subsequent 9 years for 10 bottomland and 10 upland stands.

and provided trees on the upland with adequate soil moisture during the growing season, which cannot be stored in these soils. In addition, trees in stands along Cedar Creek and the Sac River, especially areas 11 and 12, were taller, larger in diameter, and had crown closure within row much earlier than trees in upland areas (James E. Jones, pers. commun., former Vice President, Hammons Products Company, Stockton, MO). Presumably tree-to-tree competition was still limiting nut production in these stands during the post-treatment period.

The stands that produced a crop each year also changed. Stands 11, 12, 17, 22, 23, and 25 were among stands producing a crop in 4 or more of the 7 years before treatment application. After treatment, however, only stands 17, 23, and 25 continued to consistently produce nut crops. The new stands now regularly producing nuts crops were 8, 19, 20, and 21.

Mean annual nut production over the 16-year period varied little when stands were grouped into the five black walnut suitability index values except for the unsuited classification where stands averaged only 84 pounds per acre annually. Plantings in the other BWSI classes ranged from 171 pounds per acre on land somewhat suited to 188 pounds per acre on land poorly and moderately suited for growth of walnut,

In August 2001, about 2.3 tons of lime was applied per acre to nine stands. Before application of lime, these stands tended to have lower nut production than the 15 stands that did not receive lime in 2001 (Fig. 4). There is a trend for liming in 2001 when the flowers for the 2002 nut crop were initiated to have reduced nut production in 2002 but not in subsequent years. Statistically, the effect of liming on post-treatment nut production (2002 to 2006) was insignificant in part due to the wide variability between stands and annual nut crops.

An additional application of 120 pounds of N as ammonium nitrate in a 50:50 spring:fall split in 2001 was tried because fall application of N has been shown to increase female flower initiation. Statistically there were no post-treatment differences (2002 to 2006) in annual nut production for the 5 stands receiving three applications of nitrogen and 18 stands that received only 60 pounds of nitrogen. Before the split application of nitrogen, there was a trend for these five

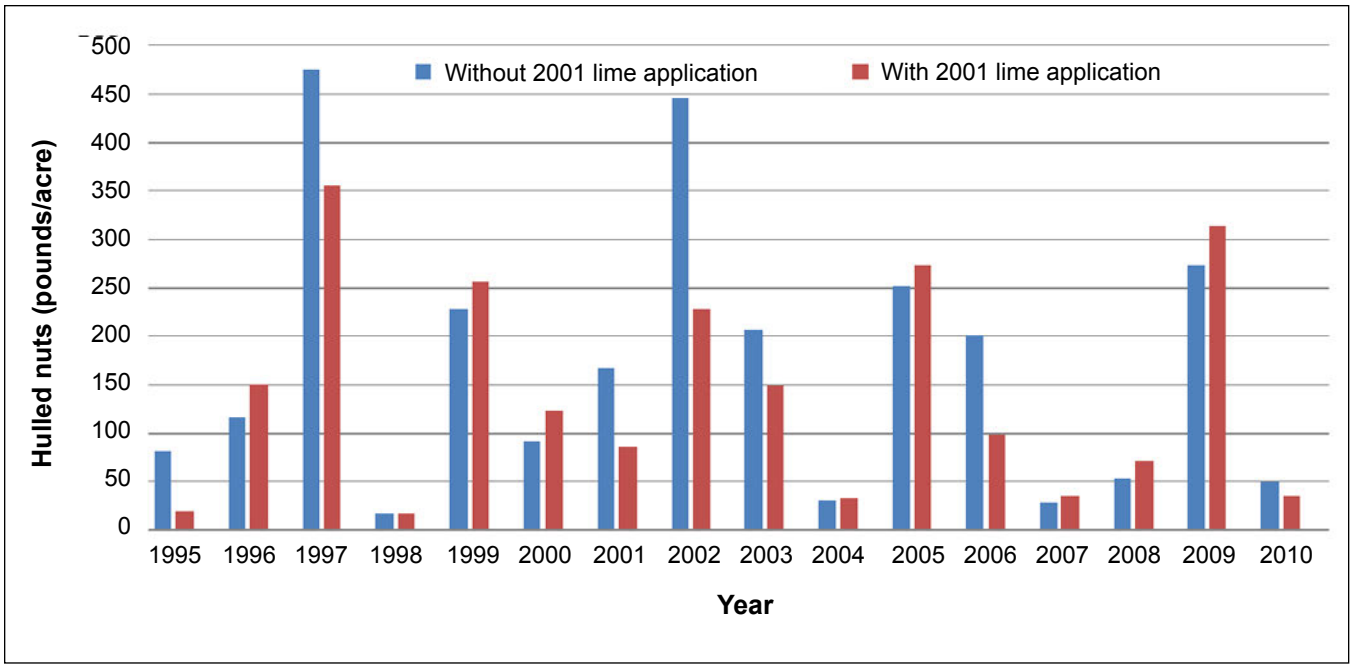

Figure 4.—Average annual nut production on 9 stands before and after application of lime in 2001 compared to the 12 stands that were not limed in 2001.

stands to be slightly more productive than the other stands (Fig. 5). Ponder and Schlesinger (1986) found that the response of walnut to a single application of nitrogen fertilizers usually disappears after 2 to 3 years. There is a trend for increased nut production in 2002 and 2003 for stands receiving the spring/fall split application of nitrogen (Fig. 5). Of the five stands that received the split N application, only stands 19, 20, and 23 were in the top consistent producers over the post-treatment period; however, all five stands were among the top producing stands in 2002, the first year after treatment.

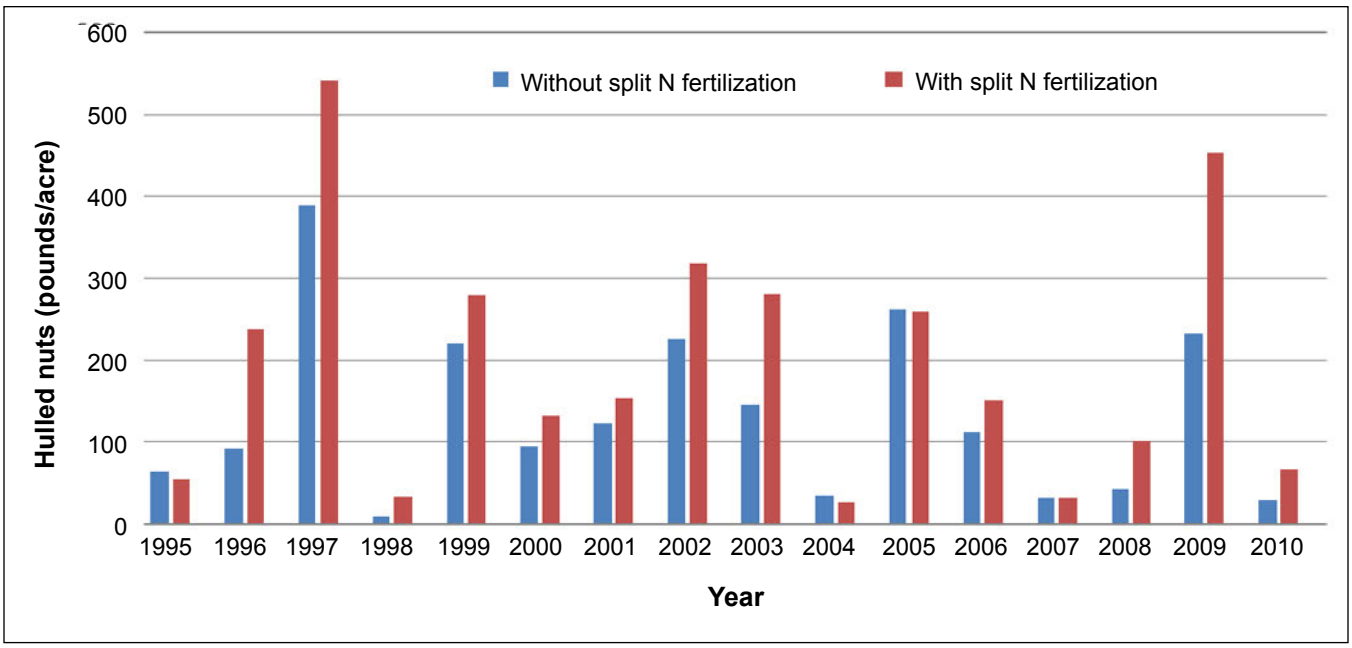

Figure 5.—Average annual nut production on 5 stands before and after a 50:50 spring:fall split application of 120 pounds of nitrogen in 2001 compared to 16 stands that received only 60 pounds of nitrogen during August 2001.

About 510 tons of husk and mill wastes were applied to 14 stands with rates per acre ranging from 0.2 to 11 tons per acre. Statistically, application of husk and mill waste did not result in increased nut production after treatment (2002-2006) compared to pretreatment nut production (Fig. 6). This finding may be partly because application rates varied considerably among stands with less than 1 ton per acre in stands 4, 10, and 23 to more than 7 tons per acre in stands 1, 16A, 17, and 24.

DISCUSSION

There is little evidence that a thinning and one-time application of several fertilizer treatments have substantially increased nut production on walnut from nursery-run planting stock. Ponder and Jones (2001) found repeated applications of NPK were needed to interrupt the alternate bearing pattern in young black walnut stands. Because tree diameters are not measured periodically across the farm, we do not know if tree growth has increased in response to any of the treatments.

Recommendations exist for proper spacing of walnut trees for nut production and timing of thinning for orchards; however, recommendations are less clear on how to apply in an agroforestry situation when trees are planted in widely spaced rows and narrow spacings within rows. Reid et al. (2009) suggested that, when tree crowns begin to shade each other, nut production will begin to decrease and planting needs thinning. Walnut orchards with trees grafted to nut producing cultivars should be established at a 30 by 30 foot spacing followed by careful selection of trees to be removed to reach a desired final spacing of approximately 60 by 60 feet. In 2001, diameter at breast height averaged between 10 and 12 inches for stands 11, 17, 22, and 23 (unpublished data from other studies). With trees this size and a desired crown competiton factor (CCF) of 100, these stands would not need thinning unless they had more than 70 to 90 trees per acre. With initial spacing of trees in rows 40 feet apart and within-row spacing of 6 feet (180 trees per acre), 12 feet (90 trees per acre), and 20 feet (56 trees per acre) that were used on the Sho-Neff

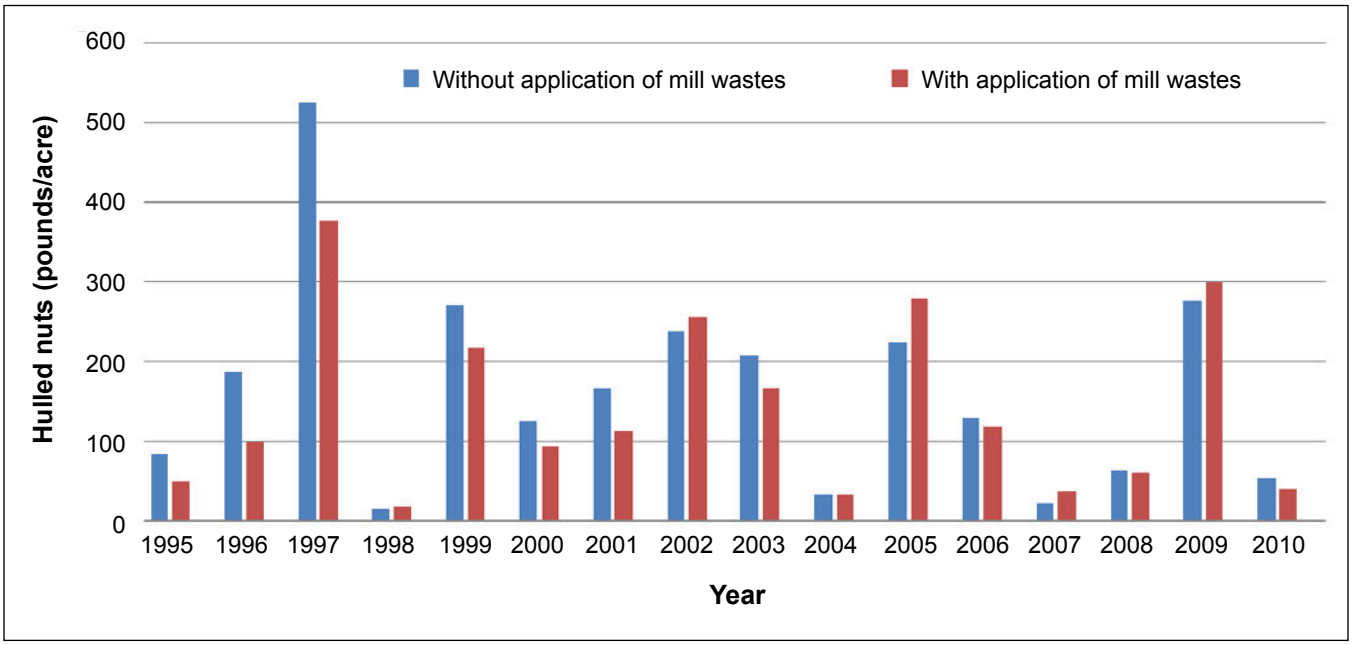

Figure 6.—Average annual nut production in 14 stands before and after application of husk and mill wastes during the 2001 growing season compared to average nut production in 7 stands where husk and mill wastes were not applied.

farm and a thinning in 2001 to remove one-third of the trees, tree-to-tree competition is unlikely to be the major cause of low nut yields.

Although cultural treatments, especially fertilization, have been shown to increase stem diameter growth and nut production (Jones et al. 1995; Ponder 1976, 1998), Garrett et al. (1991) reported that genetic selectivity among wild trees for nut production could also increase production. Nut production over a 7-year period for wild trees that were described as average for nut production was a little less than 3 pounds per tree per year compared to 26 pounds per year for trees selected for their favorable nut-bearing characteristics. Variability in nut production among wild trees was further documented by Jones et al. (1995). Out of a population of 934 trees from nursery-run planting stock, 41 trees had no nuts through age 15, and almost 80 percent of the trees produced fewer than 100 nuts per tree from age 7 through 15. Only three trees averaged more than 300 nuts annually, and the most prolific tree produced an average of 345 nuts per year.

There are wild black walnut plantations that produce abundant nuts. The black walnut trees that were planted on the Al Goetsch tree farm (A. Goetsch, pers. commun.) in Wisconsin are very productive and dependable for high nut yields. However, the trees are more than 70 years of age, the crowns are large, and the trees are widely spaced. Some of the trees are better and more dependable for nut production than others. They also are veneer quality trees. This plantation of wild black walnut trees demonstrates quite clearly that a plantation can be managed for tree quality as well as nut production, but perhaps significant nut production does not begin until the trees are more mature than those on the Sho-Neff farm.

Another reason for the poor response in nut production to treatments was likely due to the continued harvesting of hay. For some years, hay was cut more than once. Grasses produced for hay remove moisture and nutrients during their growth and the harvesting of hay removes nutrients from the site. On good walnut sites, competition from grasses and other weeds reduced growth significantly (Van Sambeek 1989, Van Sambeek and Garrett 2004, von Althen 1977). On marginal walnut sites, the reduction in tree growth due to grass cover may be even more severe (Ponder 1991). Holt and Voeller (1975) reported that plots where tall fescue sod had been eliminated averaged 28.7 pounds of nuts compared to only 13.6 pounds of nuts in tall fescue sod over 5 years. Grasses such as tall fescue have long fibrous roots that can extract water and available soil nitrate nitrogen from deep soil volumes, resulting in a drier and more nutrient-poor profile (Burch and Johns 1978, Van Sambeek et al. 1989).

It has been demonstrated in fertilization of pecan orchards that a potentially undesirable side effect of high nitrate concentration within the tree is that it acts as a “quasi-hormone” (Wood and Reilly 2011). High nitrate nitrogen can stimulate vegetative growth processes such as shoot growth at the expense of reproductive processes such as flowering and kernel filling. Thus, if black walnut behaves in a similar manner, high endogenous nitrate caused by the application of nitrate-N sources could reduce flowering, nut yield, and nut quality of trees. This means that excessive tree nitrate concentrations in young trees are more likely to promote vegetative growth than to maximize nutmeat yields. By comparison, pecan trees fertilized with ammonium-N sources tend to have higher carbohydrate and protein concentrations than those fertilized with nitrate-N sources. Although we are not sure how much can be extrapolated from the findings from pecan fertilization research (Wood and Reilly 2011), it is remarkable when we consider that tree carbohydrate reserves play a major role in ensuring return flowering and reduced alternate bearing in pecan. Additional studies are needed on walnut of nut bearing age to determine if the N source also affects their nut quantity and quality.

MANAGEMENT IMPLICATIONS

The treatments of thinning and additions of fertilization and walnut mill and husk wastes were applied to wild plantation walnut trees between 20 and 25 years old to increase soil nutrients, growing space, and presumably nut production. Nut production increased only slightly and this increase was not the same for all stands. This finding suggests that nutrients were not the primary limiting factor for nut production. Tree density was reduced and most likely the availability of light and soil resources was increased, creating conditions that were favorable for growing grasses for hay, which removed nutrients from the site, but did not increase nut production. After treatment, nut production was somewhat higher on trees on the upland fields than on trees on the bottomland fields suggesting that treatments benefited upland trees more than bottomland trees. We attribute the small increase in nut production on the upland to increased available soil moisture. Alternate-year bearing was not eliminated by treatments. The modest gain in nut production suggests that neither soil fertility nor thinning was a major factor limiting nut production for trees in this study. It appears that the wild black walnut tree delays significant nut production until it is able to compete for sun in the forest environment.

It is unfortunate that thinning and fertilization were done simultaneously because it eliminated the opportunity to draw meaningful conclusions about the efficacy of either procedure regarding nut production. Without better prescriptions for increasing nut production of wild black walnut, growers of these trees should not assume that nut production will respond to thinning and fertilization before trees are physiologically mature.

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The content of this paper reflects the views of the author(s), who are responsible for the facts and accuracy of the information presented herein.

INFLUENCE OF FOLIAR FERTILIZATION ON FOLIAR ZINC LEVELS AND NUT PRODUCTION IN BLACK WALNUT

William R. Reid and Andrew L. Thomas[1]

Abstract.—The impact of foliar zinc fertilizer application on nut-bearing black walnut (*Juglans nigra* L.) trees was studied. Foliar sprays were applied three times per season on two cultivars during four growing seasons by wetting the foliage of the entire crown using a tank mix containing 500 ppm zinc, starting at leaf burst and continuing at 2 week intervals. The fertilizer treatment increased leaf zinc levels but did not impact nut production. Results from this trial indicate that the zinc standard for black walnut foliar nutrient analysis may be similar to the zinc standard of 25 to 100 ppm established for Persian walnut (*J. regia* L.).

INTRODUCTION

The yield of black walnut (*Juglans nigra* L.) cultivars growing under standard levels of management is low compared with other nut crops (Reid et al. 2004). The influence of major nutrients on black walnut seed production has been studied with nitrogen fertilizers providing the largest increase in nut production (Jones et al. 1993, Ponder and Jones 2001, Ponder 2004), however the micronutrient needs of black walnut have not been firmly established. Phares and Finn (1971) proposed tentative critical foliar nutrient levels for hydroponically-grown black walnut seedlings (Table 1) but these recommendations have not been adequately tested under field conditions. A limited number of reports establish observed micronutrient ranges, but do not establish critical sufficiency ranges (McHargue and Roy 1932, Mills and Jones 1996). Micronutrient standards for other commercially important nut crops in the Juglandaceae, Persian walnut (*Juglans regia* L.) and pecan [*Carya illinoinensis* (Wang.) K. Koch], have been established (Smith 2003).

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Table 1.—Standards for leaf tissue nutrients for pecan and Persian walnut as compared to suggested black walnut standards and prestudy observations.

			Black walnut		
Element	Pecan[a]	Persian walnut[a]	Deficient[b]	Hidden hunger[b]	Observed pre-study (2004) range[c]
N (%)	2.3-3.5	2.2-2.6	<2.0	2.0-2.6	2.1-3.1
P (%)	0.12-0.30	0.12-0.20	<0.10	0.10-0.25	0.19-0.33
K (%)	0.75-1.75	1.0-1.75	<0.75	0.75-1.30	1.0-2.2
Ca (%)	0.7-2.5	0.75-2.00	<0.50	0.5-1.1	1.3-2.7
Mg (%)	0.3-0.7	0.20-0.75	<0.15	0.15-0.45	0.26-0.52
Zn (ppm)	60-150	25-100	<15	15-50	25-47

[a] From Smith (2003)
[b] From Phares and Finn (1971)
[c] Range observed from study trees in 2004 before commencement of treatments

The recent experience of a commercial black walnut grower in Iowa suggests that zinc foliar sprays may prove critical for reducing alternate bearing and increasing nut yield (Hansen 2003 personal communication). Zinc foliar sprays have been used effectively to correct zinc deficiency and increase nut yield in pecan (Sparks 1993). Leaf samples collected in July 2004 from black walnut trees growing at the Southwest Research Center study site (before the current study commenced) revealed that the trees accumulated 24.8 to 53.5 ppm Zn in foliage by mid-summer (Table 1). Most trees in our study area would be classified as having "hidden hunger" by Phares and Finn (1971) and would likely respond to zinc fertilization. Normal Zn levels in the foliage of Persian walnut and pecan are ≥ 25 ppm and ≥ 50 ppm, respectively (Table 1). This study was conducted to test the effectiveness of foliar zinc fertilization for increasing zinc levels in the foliage and increasing nut yield of black walnut.

MATERIALS AND METHODS

The trees used in this study are growing at the University of Missouri's Southwest Research Center near Mt. Vernon in southwestern Missouri (lat. 37.0851, long. –93.8695, alt. 337 m), USDA hardiness zone 6. Annual precipitation averages 1,106 mm. The soil is an alluvial Huntington silt loam that is deep, level, well-drained, and rarely flooded. Black walnut seedlings were established at the site in 1993, spaced 12.2 m within and between rows. Blocks of trees four rows wide were grafted to 'Sparrow' and 'Emma K' cultivars between 1996 and 2001 using bark or three-flap methods (Reid 2001).

During this study, the orchard area was fertilized annually in early spring with 84-39-84 kg/ha N-P_2O_5-K_2O, respectively. A grass hay crop consisting of a mixture of orchardgrass (*Dactylis glomerata* L.) and tall fescue (*Festuca arundinacea* Schreb.) was harvested twice annually from alleys between tree rows. Vegetation and weeds near the trees were controlled with glyphosate herbicide applied twice annually. Trees were not irrigated.

Eight trees within each of the two cultivar blocks were selected for the study based on uniform tree size and past nut yield. Two treatments were applied: application of zinc foliar sprays (three per season) versus no foliar zinc applications. Before assigning treatments, trees were ranked according to zinc nutrient status as revealed in leaf analysis conducted in July 2004. Treatments were then assigned at random using a completely randomized experimental design.

Zinc foliar applications started in the spring of 2005 and continued each spring through 2008 (Table 2). The first application of each season was at leaf burst followed by two additional applications at 2 week intervals. The cultivars used in this study often break bud at different times with 'Emma K' initiating new growth earlier than 'Sparrow'. As a result, treatment applications based on physiological stage of growth often resulted in treatments made on different calendar days (Table 2).

Commercially available zinc foliar fertilizer (Texas Pecan Zinc, Traylor Chemical & Supply Co., Inc., 1911 Traylor Blvd., Orlando, FL 32804) containing 10 percent zinc derived from zinc citrate and zinc sulfate was applied with a hand-held, high-pressure spray gun. This product also contains 10 percent nitrogen (urea form), a proven adjuvant for increasing

Table 2.—Dates of zinc foliar applications of 500 ppm zinc to 'Sparrow' and 'Emma K' black walnut trees at the Southwest Research Center in Mt. Vernon, MO.

	Spray dates		
Cultivar and Year	First	Second	Third
'Emma K'			
2005	17-May	31-May	15-Jun
2006	27-Apr	12-May	26-May
2007	10-May	29-May	5-Jun
2008	19-May	2-Jun	17-Jun
'Sparrow'			
2005	17-May	31-May	15-Jun
2006	12-May	26-May	9-Jun
2007	10-May	29-May	5-Jun
2008	2-Jun	17-Jun	2-Jul

zinc absorption from foliar sprays (Smith and Storey 1979). Foliar applications were made by wetting the foliage of the entire tree canopy using a tank mix that contained 500 ppm zinc (1:200 dilutions with water).

The leaf tissue samples were collected in July 2004 prior to the onset of the study, and during July of each year of the study (2005-2008). Post study evaluation of zinc status was determined by collecting leaf samples during July 2009. The leaf samples were taken by removing the mid-leaf pair of leaflets from mid-shoot leaves. Fifty leaflet pairs were collected per tree. Leaf samples were submitted to the Kansas State University soil testing laboratory, Manhattan, KS, for determination of total N, P, K, Ca, Mg, and Zn. Walnut yields were determined by harvesting, hulling, air-drying, and weighing the nuts produced by each tree.

RESULTS AND CONCLUSIONS

Standard protocols for using foliar sprays to increase zinc levels in pecan foliage (Krausz and Lee 2006) can be used to increase zinc levels in black walnut foliage. Foliar sprays are only effective for correcting zinc deficiencies when applied during early spring, during leaf expansion (Sánchez and Righetti 2002). Foliar spray programs to correct zinc deficiency in Persian walnut have been successful (Uriu and Chaney 1970). However, Zhang and Brown (1999) found that only 3.5 percent of foliar applied zinc is absorbed by Persian walnut leaves and becomes biologically active.

Levels of zinc found in black walnut leaves receiving zinc foliar sprays were significantly higher than those that did not receive treatment (Table 3). Zinc levels were increased by foliar fertilization during all 4 years of this study with both cultivars responding similarly. We detected no phytotoxicity related to the application of foliar zinc to black walnut at the concentrations applied in this test. Increases in foliar zinc levels as a result of foliar zinc fertilization did not carry over to the year (2009) following the completion of this trial (Table 3). This observation is consistent with results obtained with tree fruit crops demonstrating that foliar zinc fertilization provides only a single-season fix for zinc deficiency thus requiring annual foliar zinc applications to ensure long term plant health (Swietlik 2002).

Black walnut yield was not consistently influenced by zinc foliar fertilization (Table 4). Yields harvested from 'Emma K' trees were more erratic (year to year) than yields of 'Sparrow' trees. This trend confirms an earlier report by Reid et al. (2004) that 'Emma K' trees are more prone to alternate bearing than 'Sparrow' trees. The yield response from zinc fertilization observed in an Iowa black walnut orchard may have been the result of the destruction of soil organic matter caused by frequent tillage of the orchard floor. Zinc available to tree roots is largely held in the soil within the organic fraction (Stevenson and Ardakani 1972). The destruction of soil organic matter by tillage can lead to zinc deficiency in pecan (Skinner and Demaree 1926) and most likely the black walnut orchard in Iowa.

Table 3.—Concentration of foliar zinc following annual zinc foliar fertilization from 2005 to 2008 of black walnut trees growing at Southwest Research Center, Mt. Vernon, MO. The concentration of foliar zinc in black walnut foliage was also determined in year 2009 after the completion of the trial to test for treatment carry over.

	Foliar Zn Treatment		t test
Cultivar and Year	with (ppm)	without (ppm)	p-value
'Emma K'			
2005	116	54	0.032
2006	83	33	0.032
2007	71	43	0.034
2008	117	45	0.016
2009[a]	43	46	0.84
'Sparrow'			
2005	132	30	0.0003
2006	119	32	0.04
2007	67	44	0.02
2008	181	34	0.003
2009[a]	28	27	0.65

[a] No trees received zinc foliar sprays in 2009

Table 4.—Nut yields with and without annual zinc foliar fertilization did not affect nut yield of black walnut trees growing at Mt. Vernon, MO, 2005-2008.

Cultivar and Year	Foliar Zn Treatment with (kg/tree)	Foliar Zn Treatment without (kg/tree)	t test p-value
'Emma K'			
2005	21.2	17.5	0.675
2006	20.8	16.2	0.539
2007	0	0	–
2008	13.4	5.6	0.016
'Sparrow'			
2005	21.8	25.4	0.544
2006	13.0	14.6	0.741
2007	12.3	10.6	0.687
2008	9.6	7.5	0.376

Leaf analysis standards for Persian walnut developed in California indicate that healthy tree leaves should contain between 25 and 100 ppm zinc (Smith 2003). Results from our study indicate that zinc standards for black walnut may be more similar to Persian walnut or to those suggested by Mills and Jones (1996) than to the standards suggested by Phares and Finn (1971) from hydroponically growth walnut seedlings. The leaves of nontreated trees averaged between 27 and 50 ppm zinc with no symptoms of deficiency or negative impact on yield.

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The content of this paper reflects the views of the author(s), who are responsible for the facts and accuracy of the information presented herein.

APPENDIX

English and Metric Equivalent Units of Measurement

Length

1 inch = 2.54 centimeter (cm)	1 centimeter = 0.394 inches
1 foot = 30.48 centimeters (cm)	1 centimeter = 0.0328 feet
1 foot = 0.3048 meters (m)	1 meter = 3.28 feet
1 mile = 1.609 kilometers (km)	1 kilometer = 0.621 miles

Area

1 square foot = 0.0929 square meters	1 square meter = 10.76 square feet
1 square foot/acre = 0.22957 square m/ha	
1 acre = 0.405 hectares (ha)	1 hectare = 2.47 acres
1 board foot = 0.00348 cubic meters	

Volume

1 quart = 1.06 Liters (L)	1 Liter = 0.946 quarts
1 cubic foot = 0.02832 cubic meters	1 cubic meter = 35.3 cubic feet

Mass

1 pound = 0.454 kilograms (kg)	1 kilogram = 2.205 pounds
1 ton = 0.90718 metric tons	1 metric ton = 1.102 (U.S.) tons

Yield and Rate

1 pound/acre = 0.893 kilogram/hectare	1 kilogram/ha = 1.12 pounds/acre
1 milligram/kilogram = 1 part/million	1 part per million = 1 mg/kg

Conversions

Breast height = 1.37 m above ground level or 4.5 feet above ground level

Fahrenheit (°F) = (9/5 °C) + 32	Celsius (°C) = 5/9(°F – 32)

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This report presents information from the Seventh Walnut Council Research Symposium, held August 1-3, 2011. This report includes 14 papers and abstracts relating to economics and utilization, pest management, nursery production, plantation establishment, tree improvement, stand management, agroforestry, and nut production of black walnut, related Juglans species, and other high value hardwoods.

KEY WORDS: *Juglans*, plantation culture, nut production

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