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

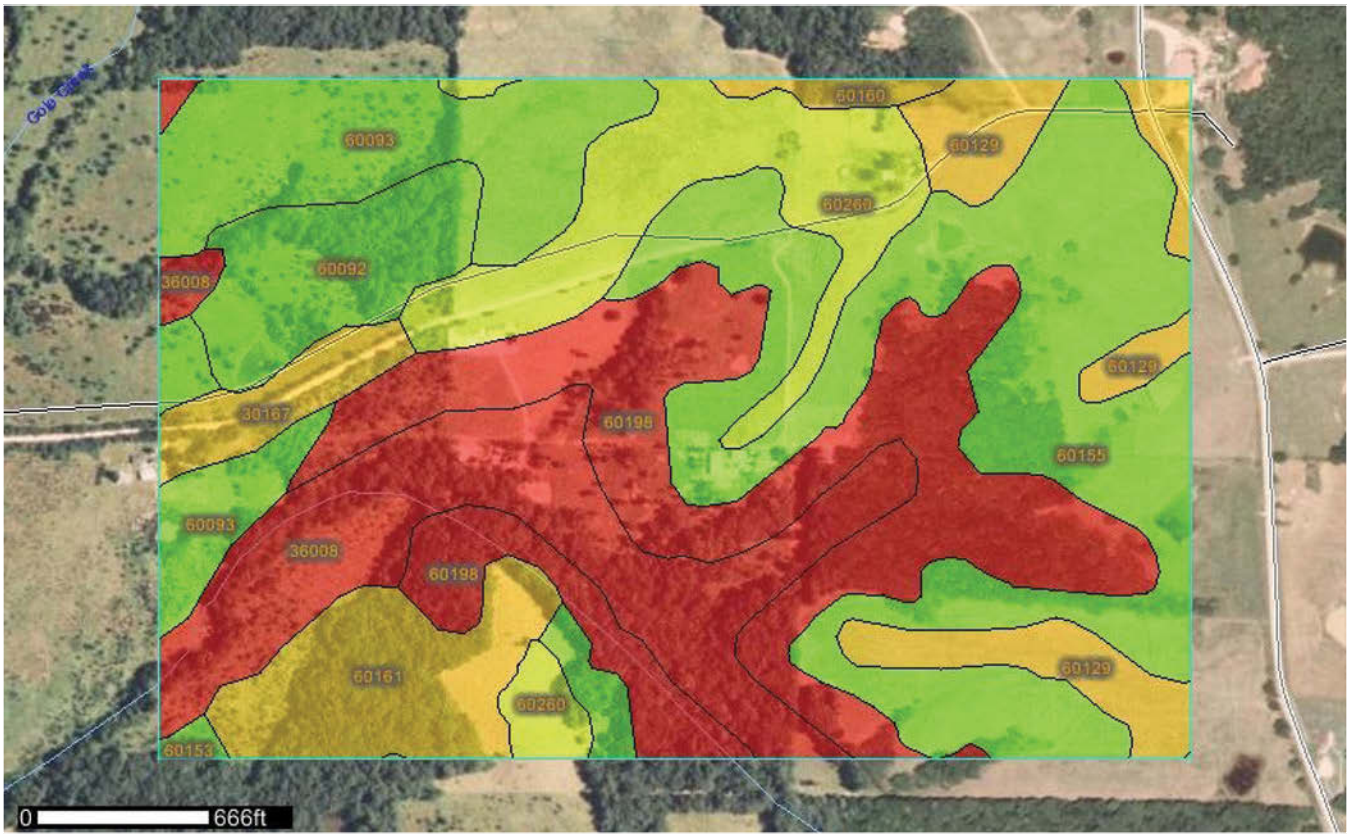

Figure 2.—Computer screen image from the NRCS Web Soil Survey illustrating walnut suitability ratings across a 235 acre area of interest (AOI) that included acreage proposed for a 100 acre hardwood planting in Howard County, Missouri.

Rating – Color code	Summary by rating value	
	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

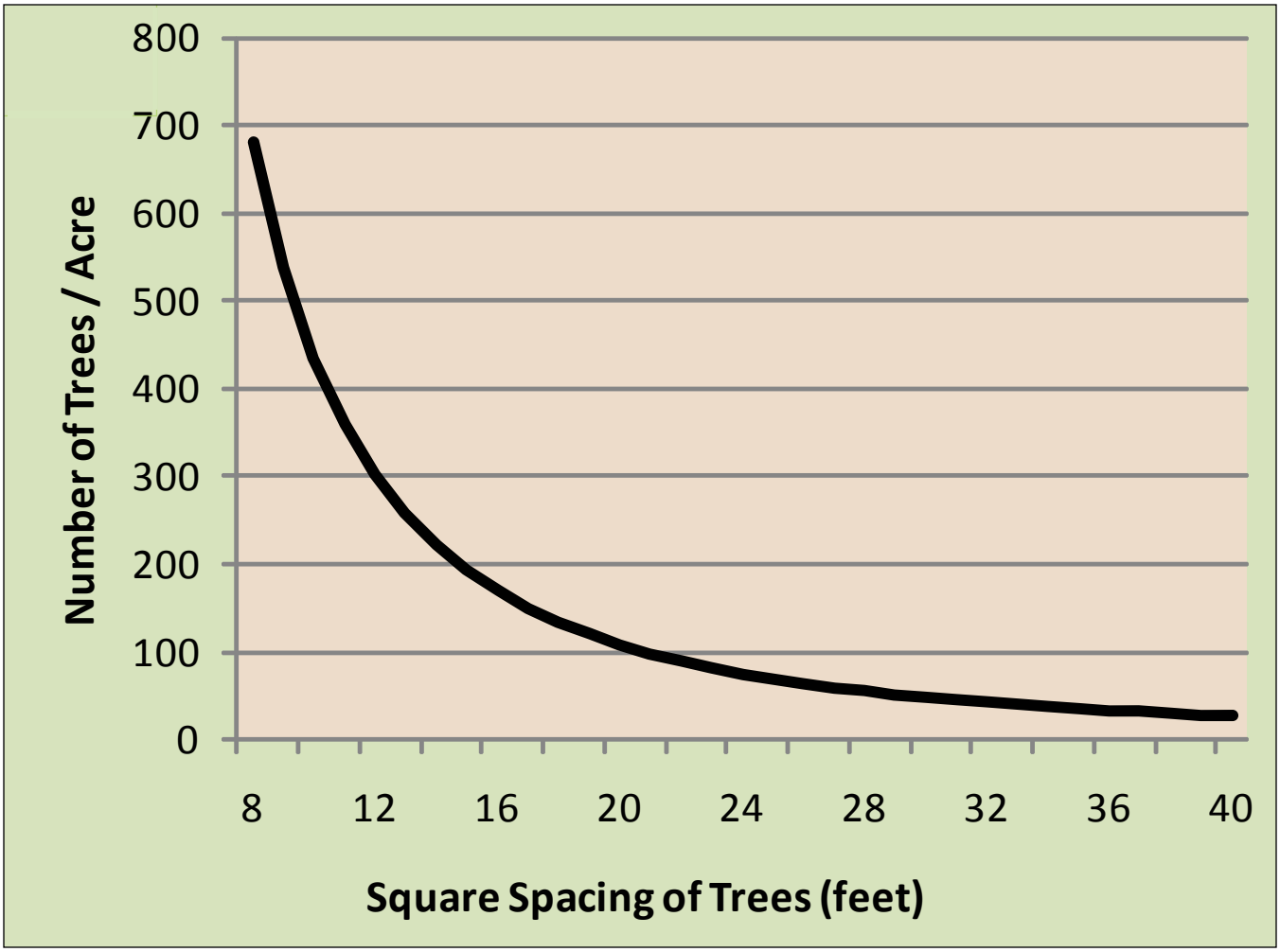

Figure 3.— Exponential relationship of trees per acre and spacing over time that show the spacing of trees increases and the number of trees per acre decreases from an initial density of 680 trees/acre at an 8-foot by 8-foot spacing with a maximum of 40 timber trees/acre at maturity.

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

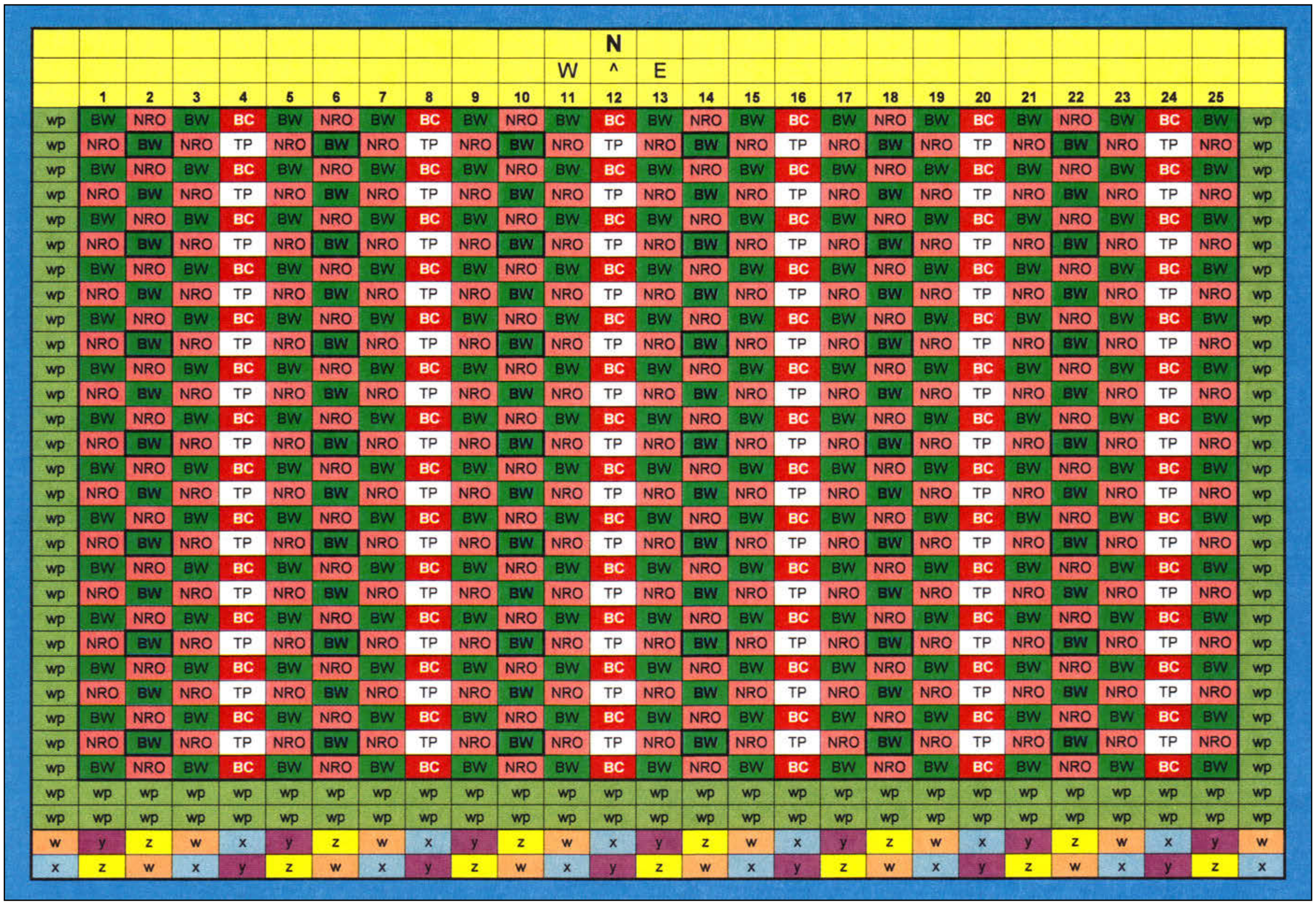

Figure 4.—Hypothetical plantation design mixing black walnut and red oak in a checkerboard fashion (75%) with black cherry and tulip poplar (25%) that includes select genetic sources of black walnut (bold) in even rows including a grafted elite cultivar as every fourth walnut (boxed). The plantation 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

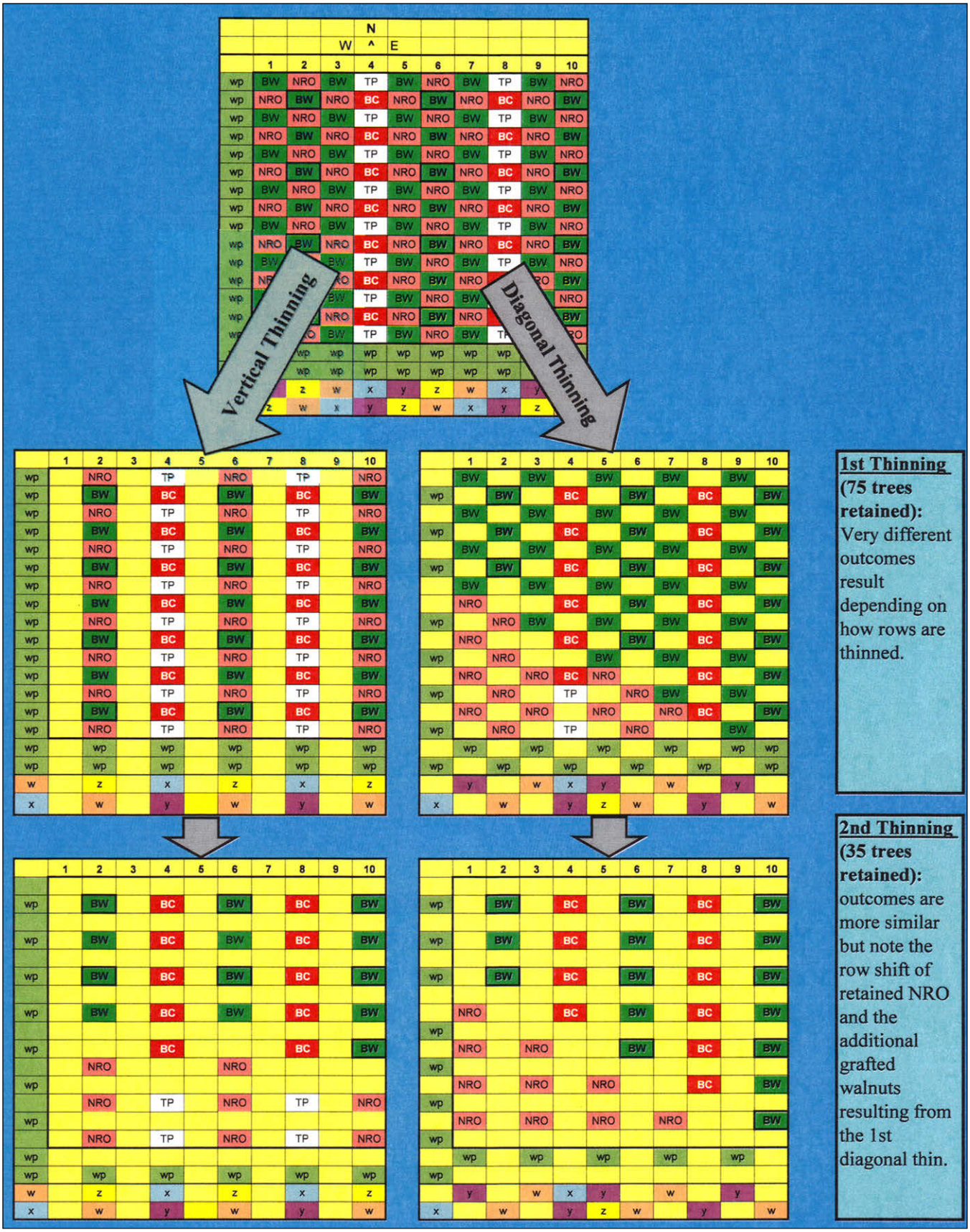

Figure 5.—Alternative thinning approaches for the Figure 4 plantation that leave 150 crop trees primarily from genetically improved sources as a pure walnut and cherry plantation or as a pure red oak plantation.

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

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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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