Ground Cover Management in Walnut and Other Hardwood Plantings

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ABSTRACT—Ground cover management in walnut plantings and established stands can include (1) manipulating the resident vegetation, (2) mechanical control, (3) chemical control, (4) mulching, (5) planting cover crops, or (6) interplanting woody nurse crops. Data from over 110 reports were used to compile a database that compared growth of black walnut and other hardwoods under different ground cover treatments as either a percentage of tree growth in the absence of ground cover vegetation or with little or no management of the resident vegetation. Overall, ground cover treatments with the best tree growth were application of organic mulches and annual cultivation. Ground covers associated with the slowest tree growth were grass sods and unmanaged or mowed resident vegetation. Black walnut tended to be slightly more sensitive to ground cover management practices than other hardwoods. The choice of a vegetation management system is largely controlled by management objectives, site characteristics, equipment costs, and, most importantly, labor availability.

Vegetation management, especially weed control, is second in importance only to site selection in establishing plantations of black walnut (*Juglans nigra* L.) as no silvicultural practice can rescue a black walnut plantation on an unsuitable site (Burde 1988, Burke and Pennington 1989). Unlike many other hardwoods, walnut in managed plantings will not dominate a site sufficiently to exclude a ground layer of semi-shade tolerant vegetation. Because they have thin, open crowns, walnut trees absorb less than 60% of the incoming solar radiation in fully stocked stands (Smith 1942). In addition, walnut is one of the last tree species to leaf-out in the spring and one of the first to defoliate in the fall. This makes it possible to grow a wide variety of shade-tolerant forbs and grasses within plantings and agroforestry practices that use walnut. The questions addressed in this paper are (1) does the type of ground cover management affect the growth of hardwood saplings and pole-sized trees and (2) is the response of black walnut to ground cover management similar to that for most other hardwoods? If the latter is true, we can use the research information from other hardwoods to recommend alternative management scenarios for walnut without actually testing them.

The wide variation in growth rates both within and among hardwood species such as that reported by Hansen and McComb (1955) for Iowa makes it difficult to use measurements such as annual height, diameter, or volume growth to directly compare tree response to different ground cover treatments. One alternative is to calculate the growth under different ground cover treatments as a percentage of the growth to a treatment commonly used in most ground cover studies. A quick survey of the literature suggests there are two commonly used treatments that have this potential: unmanaged plots and vegetation-free plots. For example, Schlesinger and Van Sambeek (1986) reported that walnut saplings in a tall fescue sod grew 0.56 inches in DBH over a 5-year period while walnut saplings in cultivated plots grew 1.85 inches over the same period. In this case, walnut diameter growth in tall fescue was only 30% of that in the vegetation-free control. As another example, Van Sambeek and others (1986) reported that walnut saplings planted with hairy vetch on a bottomland site averaged 4.7 feet in height after 3 years compared to only 3.7 feet for walnut saplings in unmanaged plots growing with a normal succession of weeds. Similarly, height of walnut with hairy

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vetch on an upland site averaged 6.4 feet compared to that of 5.3 feet in the unmanaged control. In this case, height growth of walnut planted with hairy vetch was 127% and 121% of that in the unmanaged control for the upland and bottomland plantings, respectively.

For this paper, we examined the methods and results from over 110 reports (52% of which included walnut) resulting in over 2,500 comparisons that examined effects of different ground cover treatments on growth of hardwood saplings and pole-sized trees. To create the ground cover management database, we compiled the following information into a spreadsheet: literature source, planting location by state, the year experiment was initiated, tree species, growing space and percent of growing space in experimental treatment, initial and final tree ages, control treatment (resident vegetation or vegetation free), experimental treatment(s), initial and final measurements (height, diameter, volume, fruit yield, or foliage nitrogen) for both control and treatment trees, and whether or not the authors reported statistical differences ($P < 0.05\%$). (The spreadsheet titled "BW_GCM_Database_Dec2003.xls" is available electronically from the FS-NC-4154-02-03 study files of the Ecology and Management of Central Hardwoods Project of the U.S.Department of Agriculture, Forest Service, North Central Research Station.)

Criteria for being included in the database were that (1) one or more hardwoods or broad-leaved tree species were included in the study, (2) at least one treatment was left unmanaged or one or more treatments were maintained relatively free of competing vegetation, and (3) reported measurements spanned two or more years to minimize responses to transplant shock or atypical climatic conditions.

We calculated tree growth response to each ground cover treatment as a percentage of either the unmanaged or vegetation-free control for each hardwood species included in each paper. We assume the vegetation-free control is an estimate of maximum tree growth in the planting and is the average of one or more treatments with mulches, mechanical and/or chemical weed control. Preliminary analysis of the resultant percentages showed responses were normally distributed with only a few outliers. Outliers primarily occurred in studies where trees in the experimental treatment showed excellent growth with little or no growth in an unmanaged control (resident vegetation). For this paper, treatment responses as a percent of the control exceeding two standard deviations of the group mean were treated as missing values. Because of unequal variances and degrees of freedom, adjusted variances and tabulated t-values (t') were calculated according to Steel and Torrie (1960) to determine appropriate degrees of freedom and probability of statistical differences.

Ground cover management treatments can be divided into six broad categories that include (1) manipulation of the resident vegetation (mowing, nitrogen fertilization, irrigation, or applying selective herbicides), (2) bare ground maintained by mechanical methods (scalping, disking, or rototilling), (3) bare ground established using various chemicals, (4) mulching (organic or inorganic), (5) cover crops (legumes or grass sods), and (6) woody nurse crops. Average percentage + standard deviation (the range within which two thirds of all results are expected to occur) were computed for each category for walnut and for all other hardwoods. We used analyses of variance to test for differences among the categories and for differences between black walnut and other hardwoods within the six broad categories and several subcategories (SAS Institute, Cary, NC). The following sections report the average response of black walnut and of other hardwoods to each ground cover approach. The advantages and disadvantages of using each approach in hardwood plantings are also discussed in the following sections.

RESIDENT VEGETATION

Resident vegetation is the forbs and grasses that naturally emerge following site preparation or disturbance and are left to grow with minimal management (Ingels and others 1998). On previously cropped lands or following intensive site preparation, resident vegetation will consist of a succession of plant species dominated first by annual forbs and grasses, giving way to, presumably, more competitive perennial forbs, and then eventually perennial grasses. To minimize competition in new hardwood plantings, perennial vegetation should be minimized. The best time to do this is during site preparation before the trees are planted. During site preparation, landowners can choose from a wider range of post-emergent herbicides and tillage equipment that will be easier to implement and be more effective than after trees are planted.

There are disadvantages to using resident vegetation as a ground cover in hardwood plantings. When hardwood plantings are established using resident vegetation as living mulch (without spot or strip weed control), seedling and sapling growth is typically as little as 60% of the growth found in plantings maintained free of vegetation through cultivation or use of herbicides (Fig. 1). Growth response of walnut to resident vegetation is

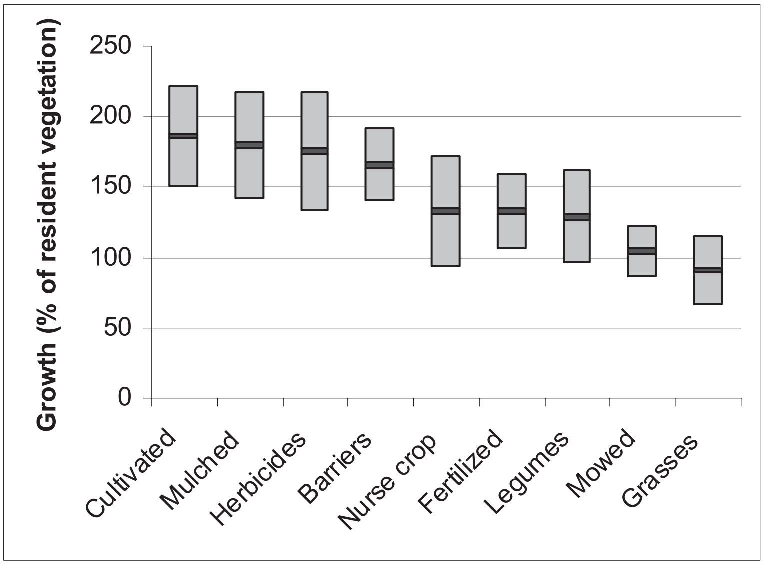

Figure 1.—Average hardwood growth (dark band) for nine ground cover management approaches as a percentage of growth for black walnut and other hardwoods in unmanaged controls or resident vegetation. Approximately two-thirds of all reported values occur within one standard deviation as shown within the shaded area.

statistically similar to that of most hardwoods (56 and 63% of vegetation-free control, respectively; $t' = -1.22$, 37 *df*, $p < 0.30^{ns}$). With resident vegetation there is little control on what the succession of species will be or whether it will include noxious weeds. In addition to competing for light, nutrients, and water, several weeds including tall fescue (*Festuca arundinacea* Schreb.), quackgrass (*Agropyron repens* (L.) Beauv.), yellow nutsedge (*Cyperus esculentus*), and goldenrod (*Solidago* spp.) have been shown to secrete toxins into the soil which stress and slow the growth of trees (Larson and Schwarz 1980; Rink and Van Sambeek 1985, 1987; Rice 2001).

There are some advantages to growing unmanaged ground covers in hardwood plantings. It is the least expensive and least labor intensive method for establishing a ground cover. During the summer, resident vegetation provides shade that can reduce soil temperature maximums and daily fluctuations. A vegetative cover also slows surface run-off and results in greater infiltration of water.

On excellent walnut sites where vegetation is controlled, we should expect annual height growth around 2.5 feet per year for which there would be an expected diameter growth of 0.5 inches per year. If this rate of diameter growth is sustained throughout the rotation, we should expect a rotation length of 45 years to produce an 8-foot veneer log with a 20-inch top diameter or 55 years for a similar length veneer log with 20-inch core of heartwood. In contrast, walnut trees competing with resident vegetation would have rotation lengths of 75 and 85 years or more, respectively. Because of poor site selection, growth rates for walnut plantings are typically 0.2 to 0.3 inches DBH per year which effectively doubles rotation lengths. Although the ground cover approach using resident vegetation involves the least cash outlays, it is unlikely that the high initial costs to establish the planting can profitably be carried over rotation lengths of 75 or more years.

MANIPULATION OF RESIDENT VEGETATION

Presumably, reduced growth of walnut in resident vegetation compared to vegetation-free plantings is due to competition for soil nutrients, especially nitrogen, and competition for limited available soil moisture during the summer. A number of approaches can be used to reduce competition when using resident vegetation as a cover crop. The most common approaches to manipulating the resident vegetation include mowing to reduce transpiring biomass, irrigation to increase available soil moisture, fertilization to increase available nitrogen, and grass-selective herbicides to eliminate grass competition.

Mowing

Mowing of the resident vegetation does not significantly improve tree growth over that of trees growing in unmanaged resident vegetation (Fig. 1). Walnut growth in frequently mowed plantings averages 16% less (84% of the unmanaged control) than that of walnut with unmanaged resident vegetation. In contrast, growth of other hardwoods in mowed plantings is increased by 10% (110% of unmanaged control) over that of hardwoods in resident vegetation. Tree responses to mowing are statistically different between walnut and other hardwoods (t' = -3.60, 20 *df*, p <0.01**). Similar reductions in growth are also found for studies with vegetation-free controls where walnut growth is 43% of the controls compared to 61% for other hardwoods (t' = -2.58, 23 *df*, p <0.02*). Rice (2001) indicated the practice of mowing shifts the competitive advantage away from mostly forbs in which growing points are sheared off with each mowing to grasses which have their growing points near the soil line. Davies (1985) and Ponder (1991) also suggest that reduced tree growth is a consequence of shifting competition to grasses and the renewal of vegetative growth following mowing.

For the small growth gains achieved with other hardwoods, mowing is an expensive, labor intensive management practice that must be completed 2 to 5 times a year for 3 to 5 years before hardwood saplings will dominate the site. In addition to little improvement in tree growth, mowing leads to “mower blight” or the inadvertent damaging of tree stems when accidentally hit by tractor or mowing equipment. Also, repeated mowing can lead to compaction of upper soil layers where walnut feeder roots are located. Mowing, however, has the advantages of preventing noxious weeds from going to seed, exposing rabbits and mice to predators, maintaining a ground cover to protect the soil from wind and water erosion, aesthetically creating a more pleasing appearance to the planting, and facilitates the harvesting of nuts. To reduce risks of wildfires and to slow plant succession from forbs to grasses, we recommend mowing only in the fall after a hard killing frost.

Irrigation

Too few reports were found to indicate if irrigation could be used to increase available soil moisture sufficiently to increase tree growth. Dey and others (1987) and Van Sambeek and McBride (1991) found little or no increased growth of walnut in response to irrigation on their sites with grass ground covers. It is possible that the resident vegetation and grass sods may benefit more from irrigation than will the trees.

Fertilization

On most sites, especially old field sites, available soil nitrogen tends to be the nutrient limiting hardwood growth. The published literature shows a slight increase in tree growth with the addition of nitrogen fertilizers (Fig. 1). Walnut may not compete as successfully with ground covers for added nitrogen as other hardwoods because growth increases for walnut average 24% compared to 52% for other hardwoods (124 and 152% of unmanaged control, respectively; t' = -2.37, 27 *df*, p < 0.05 *). Similar patterns exist when nitrogen fertilizers are applied to plantings where ground covers have been eliminated. In this case, growth increases for walnut averaged 14% compared to 31% for other hardwoods (114% and 131% of vegetation-free control, respectively; t' = -2.68, 41 *df*, p < 0.02*). Ponder (1997) previously did an in depth review on walnut fertilization and reported responses to added nitrogen can be quite variable and concluded that it is not uncommon to see little or no response to fertilization, especially on good walnut sites.

Selective Herbicides

Grasses tend to be more competitive than broad-leaved legumes or other forbs (Fig. 1); thus, selective removal of resident grasses should improve tree growth. Selective control can be done with over-the-top applications of post-emergent herbicides such as Fusilade (fluazifop-butyl) or Poast (sethoxydim). These herbicides are selective for grasses, although we found no reports in the literature documenting their effectiveness in hardwood plantings. Multiple applications may be needed as they are most effective if applied when grasses are 6 to 12 inches tall. Fusilade is more effective than Poast on perennial grasses; conversely, Poast is more effective than Fusilade on annual grasses such as foxtail and crabgrass. Selective control of annual grasses can also be achieved with Surflan (oryzalin) and Stomp (pendimethalin), two pre-emergent herbicides that require 1 to 2 inches of rainfall within several weeks of application for activation. These herbicides are more effective on germinating grasses than broad-leaved forbs. After tree seedlings are established, pre-emergent herbicides that are selective for germinating seeds are unlikely to harm deeper-rooted perennial plants or established tree seedlings. Selective control of the tallest and usually most competitive weeds can also be achieved using wipe-on applications of broad spectrum herbicides if care is taken to keep the herbicide from coming in contact with the walnut foliage.

MECHANICAL VEGETATION CONTROL

Mechanical vegetation control involves the cutting off at or below ground line, i.e., scalping, or the uprooting and burial of competing plants, i.e., cultivation. Mechanical control of competing ground covers tends to nearly double hardwood growth over that of trees with a ground cover of resident vegetation (Fig. 1). Growth of walnut with mechanical weed control increases on average by 117% compared to 79% for other hardwoods (217% and 179% of unmanaged control, respectively; $t' = 1.40$, 9 *df*, $p < 0.20^{ns}$). The result of no statistical difference should be considered preliminary because too few studies were found that compared growth of walnut in plantings with unmanaged control and cultivated plots.

It is generally assumed that mechanical control of competing vegetation will allow hardwood seedlings and saplings to grow at their full biological potential for the site. It is one of the more effective methods of controlling competing ground cover vegetation, especially if done when weeds are small and perennial weeds are not yet established. Exposed soils usually have higher soil temperatures which increases decomposition of organic matter and nitrogen mineralization, making more nutrients available to the trees. Cultivation also buries diseased walnut leaves that disrupt the normal dispersal of disease spores (Kessler 1988). Vegetation-free plantings also allow for better air drainage reducing the risk of spring frost injury and destruction of female flowers. Finally, bare ground treatments provide little winter cover for rabbits and mice that chew on tree seedlings and saplings.

Besides the increased potential for soil erosion, cultivation has a number of other potential disadvantages. Cultivation is relatively labor intensive because it must be repeated two to five times a year depending on the weed seeds present in the seed bank and rainfall. In years with heavy spring rainfall, cultivation on a timely basis may not be possible. Traffic from heavy equipment needed for cultivation can lead to soil compaction and impede water infiltration. Frequent and close cultivation means a higher proportion of tree stems are likely to be damaged than with other ground cover management treatments, except maybe mowing. Deep tillage also results in destruction of shallow feeder roots in the uppermost fertile layers of the topsoil. It is not uncommon to find walnut roots extending out more than twice the width of the crown. Repeated cultivation for several years decreases the amount of organic matter in the soil reducing stable soil aggregates needed for the retention of soil water and nutrients. While accelerating nitrogen mineralization, high soil temperatures in exposed soil also accelerates nitrogen loss through volatilization. Unless cleaned frequently, tillage equipment may aggravate future weed problems by spreading seed or chopped plant parts that can become established in other parts of the planting. Finally, it is unclear whether the costs incurred to cultivate a planting three or four times a year can be offset by a mere doubling of the tree growth expected in unmanaged plantings.

It is generally assumed that bare soil treatments retain significantly more soil moisture than treatments with a vegetative cover. Unless the trees are large enough to shade the planting, this may not be true. Lull and Fletcher (1962) report soil moisture depletion rates of 0.35 inches/day from surface evaporation for bare ground compared to 0.37 inches/day from evapotranspiration by herbaceous ground covers. By comparison, soil moisture depletion from woodland soils was deeper and averaged 0.42 inches/day.

There are several things that can be done to minimize the detrimental impact of cultivation. Cultivating when the ground is dry and hard and when the weather is hot is more effective and will cause less compaction than when the soil is moist. Use tractors with floatation tires to reduce compaction. Use cultivators with V-shaped sweeps or weed knives that sever weeds off near the soil line rather than deep penetrating disks or rototillers that tend to bring new weed seeds to the surface and damage tree feeder roots (Rice 2001). Specialized equipment such as the Weed Badger can be used for precision, within row tillage to reduce damage to saplings or pole-sized trees (Garrett and others 1989). Although not experimentally tested, tilling one half the planting (between alternate rows) may be as effective as annually tilling the entire tree planting (Schlesinger, personal communication).

CHEMICAL VEGETATION CONTROL

The growth response of hardwoods to herbicide applications to control competing vegetation is very similar to that for mechanical control and nearly twice that for trees in unmanaged controls (Fig. 1). Increased growth of walnut averages 95% for trees with chemical weed control compared to that in unmanaged controls and is not statistically different from increased growth of other hardwoods that averages 72% (195 and 172% of unmanaged control, respectively; $t' = 1.33$, 33 *df*, $p < 0.20^{ns}$). Tree response to chemical weed control has a large standard deviation partially because all herbicides are not equally effective and some herbicides may be slightly phytotoxic to the trees at reported experimental application rates. Hardwood plantings with repeat applications of Roundup™ (glyphosate) tend to have slightly higher growth rates than trees in treatments using pre-emergent herbicides (131% and 102% of vegetation-free control, respectively). Seifert and Woeste (2002) reported that walnut growth is greater with tillage than with spring-applied pre-emergent herbicides, especially when using Oust (sulfometuron) alone or in mixes.

Chemical vegetation control has several distinct advantages over other methods of ground cover management. It may be the least costly and least labor intensive method for reducing or eliminating ground cover competition. The application of chemicals requires fewer workers and equipment costs are less than equipment for mechanical weed control. Post-emergent herbicides are more effective for eliminating grass sod and perennial weeds than is cultivation. In many cases, a single application of a pre- and post-emergent herbicide mix will control ground cover competition for the entire growing season. Timing of herbicide applications are less critical than with cultivation. Chemical treatments usually result in higher available soil moisture and less erosion during the growing season than mechanical vegetation control.

The most significant problem associated with chemical control of ground cover vegetation is the limited and declining choice of registered herbicides that can be used (Seifert 1993). Other problems include the lack of selectivity among the currently registered herbicides and the tree damage they can cause if not applied properly (Seifert and Woeste 2002). Improper calibration, herbicide drift, or accidental spraying of saplings can result in either mortality or slowed tree growth. Wet field conditions can prevent entry into the planting when vegetation is at the appropriate stage. Conversely, lack of rainfall can keep some pre-emergent herbicides from becoming soil activated. Post-emergent herbicides generally require multiple applications per year for effective control of competing vegetation. Because soils remain relatively undisturbed, the impact of rain droplets on bare soil can lead to surface compaction thus reducing surface infiltration and increasing surface run-off and soil erosion compared to that in unmanaged plantings.

There are several approaches that can be used to minimize negative impacts of using herbicides. Resident vegetation can be allowed to develop in the spring before application of post- and pre-emergent herbicides creating a layer of dead vegetation that will shade the soil reducing surface evaporation and decreasing impact of rain drops. Because herbicides can effectively control perennial plants, spraying is not required every year assuming that annuals are less competitive than perennial vegetation. Alternatively, the area between every other tree row could be treated in alternate years retaining resident vegetation on half the planting. When more than one herbicide will control the target vegetation, the herbicide(s) that is least toxic to earthworms and other soil macrofauna and macroflora should be selected. Earthworms alone can move more soil/year than is moved with one plowing using a tractor-pulled moldboard plow (Minnich 1977). When managing for nut crops, use strip chemical control within the tree row during the growing season followed by fall mowing between rows to facilitate harvesting of nuts.

MULCHES

Ground cover management using mulches falls into two broad categories: organic carbon-based mulches and inorganic or barrier mulches. The ideal mulch will (1) be opaque or block sunlight discouraging germination and growth of weeds, (2) be porous enough to allow water to infiltrate, (3) protect the soil from sun and wind to conserve soil moisture by reducing evaporation, (4) moderate daily soil temperature fluctuations and extremes, (5) be made of biodegradable materials but still have the strength and durability to last until trees are established, (6) be easily transported to the tree planting, (7) blend into the landscape, and (8) be relatively easy to install (Windell and Haywood 1996). Other benefits of mulching include making trees more visible thereby reducing the chances for mechanical damage from mowers and other maintenance equipment.

Organic Mulches

Applying organic mulches around the base of hardwood trees is about as effective as mechanical or chemical weed control (Fig. 1). Organic mulches increase walnut growth on average by 89% compared to walnut growth in unmanaged plantings. Growth increases are similar for other hardwoods (78%) when mulched and are not statistically different from walnut (189% and 178% of unmanaged control, respectively; $t' = 0.41$, 12 *df*, $p < 0.50^{ns}$). In studies that have compared organic mulches to other vegetation-free treatments, mulching usually results in better tree growth than other bare ground treatments (Fig. 2). Based on very few studies, organic mulches may increase walnut growth by 29% over other vegetation-free treatments with similar increases for other hardwoods (26%) when mulched compared to that of other bare ground treatments (129% and 126% of vegetation-free control, respectively; $t' = 0.17$, 7 *df*, $p < 0.50^{ns}$).

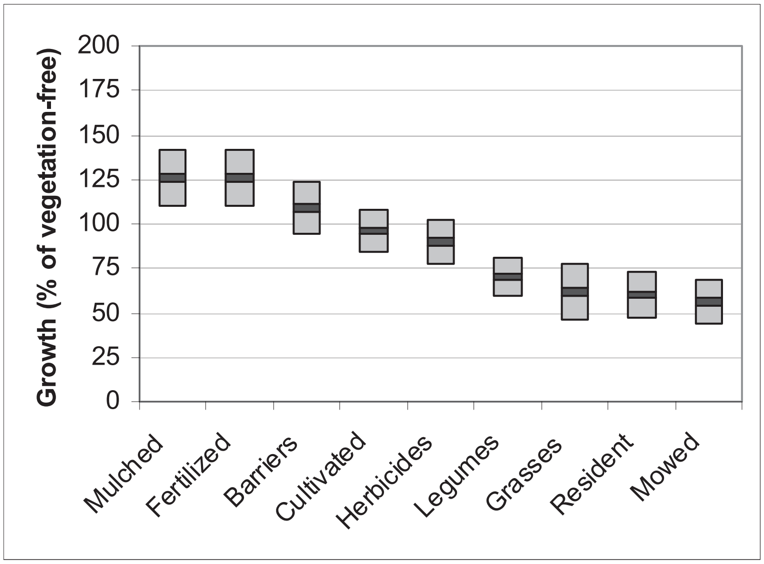

Figure 2.—Average hardwood growth for nine ground cover management approaches as a percentage of growth for black walnut and other hardwoods planted in vegetation-free control plots. Approximately two-thirds of all reported values occur within one standard deviation as shown within the shaded area.

Duryea and others (1999) indicate the physical effects of mulching are much greater than the fertilizer value associated with the release of nutrients as mulches decompose. Decomposition of organic mulches increases the organic matter content of the soil leading to better soil aggregation and increased retention of soil water and nutrients. Organic mulches also reduce the impact of raindrops, slow the flow of water over the soil surface, reduce soil erosion, and increase rates of water infiltration. Organic mulches also can increase the activity of worms, fungi, and other soil organisms resulting in increased diffusion of soil oxygen, organic matter, nutrient availability, and root growth.

Although somewhat dependent on the density and texture of the materials used, a 4-inch thick layer of an organic mulch is a good compromise—not so deep as to inhibit soil aeration but still thick enough to prevent emergence of germinating seedlings. Mulches with a good balance of carbon to nitrogen (30C:1N) are likely to increase both organic matter and mineral nitrogen in the soil. Examples of balanced C:N mulches include rotted manures and compost (20C:1N), grass clippings (20C:1N), pine needles, shredded leaves (60C:1N), chipped landscape and utility right-of-way trimmings, baled hay, and straw (80C:1N). During decomposition, mulches with high carbon to nitrogen ratios such as shredded waste paper, sawdust (500C:1N) and wood shavings (700C:1N) will compete with the trees for available soil nitrogen. When using high carbon mulches, a nitrogen fertilizer should be incorporated into the mulch or broadcast under the tree before applying the mulch.

A major problem with using organic mulches is subsidence, especially mulches with a high proportion of leaves, and the need to reapply additional mulch annually to remain effective. Without specialized equipment, mulching trees is a labor intensive operation. A cubic yard of mulch will cover approximately 20 square feet and it may require 150 cubic yards per acre to mulch hardwood plantings when applied as twenty 4-foot wide strips. Other concerns include the introduction of new weed seeds or pathogens into a planting, especially with mulches such as manure, compost, or straw. Since mulches provide cover for mice and voles, they need to be pulled away from trees during the winter when these animals do the most damage.

Inorganic or Barrier Mulches

Examples of inorganic or barrier mulches include gravel, crushed rock, or manufactured products such as plastic films and landscape fabrics. Inorganic mulches used in hardwood plantings are primarily opaque polyethylene (plastic) films and woven polypropylene (landscape) fabrics. These materials are usually placed under gravel and crushed rock to keep them from sinking into the soil. Barrier mulches can be very effective for increasing early growth in hardwood plantings (Fig. 2). When compared to other methods of maintaining vegetation-free growing space, barrier mulches increased growth of black walnut by 35% compared to a 5% increased growth of other hardwoods (135% and 105% of vegetation-free control, respectively; $t' = 1.99$, 12 *df*, $p < 0.10^{ns}$). Too few studies have been done with walnut to make statistical comparisons; however, increased growth of other hardwoods established with barrier mulches may average 66% more than for hardwoods growing in resident vegetation (Fig. 1).

Major advantages of inorganic or barrier mulches are one-time installation with minimal annual maintenance to achieve a vegetation-free zone around tree seedlings and saplings for 2 or more years. By incorporating carbon black into the polyethylene or polypropylene, the harmful effects of the sun's ultraviolet radiation can be slowed so that materials will last for 3 or more years. Woven polypropylene or landscape fabrics readily permit water infiltration; whereas, polyethylene films must be punched or fabricated with holes to permit infiltration of water. Clear and dark-colored mulches absorb and trap more solar radiation than mulched or bare soil resulting in warmer soils (3 to 10^{o} F) and earlier root growth in the spring. Consequently, these films can result in summer soil temperatures lethal to roots and tender stems. It has lead to development of promising colored and light-reflective films that block sunlight but absorb less solar radiation (Ham and others 1993).

There are significant problems associated with use of barrier mulches besides the high cost for materials and labor. The main difficulty with plastic films and landscape fabrics is holding the material in place. Both labor costs and anchorage problems can be reduced by using tractor-drawn machines that will lay and bury edges of polyethylene films or landscape fabric on cultivated fields. Because woven polypropylene tends to be thicker, they are both more durable and more expensive than polyethylene films. Although permeable to water, infiltration rates for landscape fabrics are still relatively slow and can lead to surface runoff. In contrast, polyethylene films restrict surface evaporation, retain available soil moisture much later into the growing season, and are much slower to recharge soil moisture in the fall. Polyethylene films are readily punctured by animal hooves and sprouts of some plants, so woven polypropylene fabrics should be used in areas with high nutsedge (*Cyperus* spp.) or deer populations. Barrier mulches can lead to significant tree damage because these mulches provide an ideal habitat for rodents and screen them from predators.

Operationally, it is easiest to install barrier mulches with machines on recently cultivated sites either before or after tree seedlings are planted. Rolls 6 feet wide by 300 feet long are usually recommended, because this size allows the outside edges to be buried and still provide a 4- to 5-foot wide vegetation-free strip in which to hand-plant trees. Costs for fabric and installation are typically $0.25 to $0.40 per linear foot. Tree seedlings can also be machine-planted before laying polyethylene or polypropylene mulches. In this case, a small cut is made next to bent-over seedlings so the stem can be pulled out. The heated air under barrier mulches usually keeps most weeds from growing through the planting hole or cut slits. A shovel full of soil placed near each seedling helps to direct rain water toward the opening at the base of each tree and prevents wind from lifting the mulch. Using side-discharge mowers, clippings of resident vegetation can be blown into the tree row to cover barrier mulches during the summer, thereby, reducing the high soil temperatures encountered with dark-colored impermeable films.

COVER CROPS

Cover crops are established ground covers designed to reduce the amount of resident vegetation and delay normal succession to perennial weeds. A number of forage legumes and grasses are tolerant of light shade and could be grown in managed black walnut plantings (Lin and others 1999, Alley and others 1999). In walnut plantings managed for timber (CCF 100 to 120), light levels are approximately 40% of full sunlight (Smith 1942). In contrast, in more open walnut plantings managed for nuts (CCF 80 to 90), light levels are approximately 50% of full sunlight. Obtaining sufficient understory light can be problematic when managing cover crops in mixed hardwood plantings or natural stands. The light intensity in the understory of a mature mixed hardwood forest is generally less than 20% of full sunlight and can be as low as 1% (Dey and MacDonald 2001). At full leaf expansion, walnuts in plantings with CCF's of 100 to 120 (full site occupancy or B-level stocking) absorb approximately 60% of the incoming solar radiation. Light infiltration is curvilinear-related to CCF or residual stocking density (a function of the number of trees/acre and their average DBH) (Dey 2002). To provide light levels on the forest floor of 40% to 60% of full sunlight, may require maintaining 30% to 40% residual stocking densities and removal of approximately one-third of the overstory trees during each thinning (Schlesinger and Funk 1977, Sander 1979).

Cover crops can significantly reduce the amount of labor needed for controlling resident vegetation in new plantings with only a modest increase in costs. Other benefits include the natural accumulation of decaying plant residues on the soil surface that reduce summer soil temperatures and a rapid increase in soil organic matter by organisms that naturally till soil (Minnich 1977, Shribbs 1985). Besides increasing nutrient availability, oxygen, and water infiltration, earthworms also create soil pores that facilitate deeper root penetration by the trees. A vegetative cover either as a living mulch or decaying residues shades the soil resulting in lower soil temperatures because less solar radiation is absorbed by the soil. Wohlstenholm (1970) reported that planting legume or grass covers in pecan orchards can delay bud burst by 6 to 12 days, thereby reducing damage by late spring frosts. Cover crops also provide excellent habitat for wildlife, including rabbits, mice, and voles that frequently damage young trees.

Legume Cover Crops

The growth of hardwoods is generally better when grown with legume cover crops than with resident vegetation (Figs. 1 and 2). Legume cover crops increase walnut growth on average by 28% compared to walnut growth in unmanaged plantings. Growth increases are similar for other hardwoods (30%) and are not statistically different from walnut (128% and 130% of unmanaged control, respectively; $t' = -0.22$, > 100 *df*, $p < 0.50^{ns}$). Most studies with vegetation-free control treatments report reduced hardwood growth with legume cover crops; however, they also report legume cover crops reduce growth less than does resident vegetation. Legume cover crops reduce walnut growth by 31% compared to 44% for resident vegetation (69% and 56% of vegetation-free control, respectively; $t' = 2.36$, 35 *df*, $p < 0.05^*$). Responses for other hardwoods are similar where legume cover crops reduce growth by 32% compared to 37% for resident vegetation (68% and 63% of vegetation-free control, respectively; $t' = 1.24$, >100 *df*, $p < 0.20^{ns}$).

Because nitrogen tends to be the nutrient most often limiting tree growth, increased hardwood growth with legume cover crops is generally attributed to the ability of most legumes to fix atmospheric nitrogen (White and others 1981). Unless heavily fertilized, forage legumes on average obtain about 75% of their nitrogen through the fixation process. If the above ground biomass is not harvested, some of this nitrogen becomes available to the trees when plant residues decompose and organic nitrogen is converted to ammonia or nitrate nitrogen. Some mineral nitrogen is also made available to the trees through atmospheric deposition; however, the burning of fossil fuels and lightening only account for 5 to 10 pounds per acre in the central United States and 15 to 20 pounds per acre in the eastern United States. In contrast, fixation rates for forage legumes average 100 to 300 pounds per acre (Table 1). Although fixation rates are largely unknown for most native legumes,

Table 1.—Average growth and standard deviation for black walnut and other hardwoods as a percentage of tree growth in plantings without ground covers and the average shade tolerance percentile rank and reported nitrogen fixation rates for different forage legumes.

Legume Cover Crop	Tree Growth[1]	Shade Tolerance[2]	Nitrogen Fixation Rate[3]
	%	*%*	*lbs/acre*
Soybeans	99 + 26 (5)	ND	50
Crownvetch	83 + 23 (18)	78	230
Subterranean clover	81 + 66 (5)	43	90
Crimson clover	79 + 37 (18)	57	90
Hairy vetch	74 + 29 (119)	ND	120
Sweet clover	72 + 7 (4)	ND	--
Red clover	70 + 24 (91)	44	250
Sericea lespedeza	69 + 12 (22)	30	--
Kura clover	66 + 11 (9)	66	155
Birdsfoot trefoil	63 + 26 (22)	36	150
Striate lespedeza	63 + 14 (5)	ND	--
White clover	62 + 23 (43)	34	200
Resident vegetation	60 + 28 (156)	--	--
Korean lespedeza	57 + 9 (23)	12	--
Alfalfa	44 + 25 (7)	32	300

[1] Growth is percent of vegetation-free control + standard deviation (approximately 66% of reported responses) and in () number of replications extracted from the literature. Mean least significant difference is 14%.

[2] Average percentile rank under moderate and heavy shade estimated from three or more screening trials where 0% was assigned to the least and 100% was assigned to the most shade tolerant species within each light level and screening trial. ND = not tested.

[3] Average of values reported in six publications identified in vegetation management database.

several shade tolerant native legumes have been identified that could be used as living mulches in hardwood plantings and natural stands (Ponder 1994, Van Sambeek and others 2004).

Establishing legume cover crops is more expensive and requires more labor than seeding forage grasses or manipulating the resident vegetation. Legumes usually require a well prepared seedbed and may require application of lime and fertilizers to produce a stand capable of suppressing resident vegetation (Jorgenson and Craig 1983, Ingels and others 1998). Because seed of most legumes are small, they should be seeded with companion crops such as oats (*Avena sativa* L.) or barley (*Hordeum vulgare* L.) that quickly germinate providing a plant cover to minimize soil erosion and suppress potential resident vegetation (Simmons and others 1992). Stamps and others (2002) have shown that combining trees and alfalfa (*Medicago sativa* L.) will increase the number of insects that prey on other insects including those that feed on black walnut foliage. Legume ground covers have also been shown to interfere with anthracnose spore dispersal from diseased leaves or infection of new walnut leaves in the spring (Van Sambeek 2003).

Although most legumes make a better cover crop than resident vegetation, substantial variation exists among forage legumes as to their effects on hardwood growth and relative tolerance to shade (Table 1). In general, annual legumes tend to reduce tree growth less than perennial legumes. Subterranean clover (*Trifolium subterraneum* L.) and crimson clover (*Trifolium incarnatum* L.), both annual legumes, are probably excellent choices for walnut plantings; however, neither will overwinter throughout most of the black walnut range. Likewise, legumes that have decumbent stems such as crownvetch (*Coronilla varia* L.) or are vines such as hairy vetch (*Vicia villosa* Roth) are excellent choices for cover crops because they require less biomass to effectively smother other vegetation than upright legumes such as sericea lespedeza (*Lespedeza cuneata* (Dumont) G. Don). Legumes with upright stems may also require mowing after a killing frost each fall to reduce the wildfire risk. Based on few published reports, alfalfa may be the poorest choice for a cover crop in black walnut plantings.

Legume cover crops should not be harvested for several reasons. Approximately 75% of the plant biomass is in the above ground portion; thus, harvesting removes nearly all the nitrogen obtained through fixation (Watson and others 1984). If harvested, legumes may be no better than unmanaged broadleaved forbs such as rapeseed (*Brassica napus* L.) or resident vegetation. Cool-season legumes such as hairy vetch and crownvetch that produce most of their vegetative growth in the spring when available soil moisture is high are better cover crops than warm-season legumes, such as sericea lespedeza and Korean lespedeza (*Lespedeza stipulacea* Maxim.). If not harvested, most cool-season legumes set seed in the spring and remain relatively dormant throughout the summer, effectively mulching the soil surface. Harvesting stimulates new vegetative growth and a continued demand for limited available soil moisture during the summer. Lyons and others (1952) found evapotranspiration rates for annual legumes and forbs average about 4.5 inches of precipitation per ton of above ground biomass produced per acre. Within the walnut range, typical yields for forage legumes are 3 to 4 tons per cutting per acre indicating that regrowth following harvesting makes a significant demand on limited available soil moisture in the summer (Barnes and others 1995).

Grass Sods

The growth of hardwoods when grown in grass sods is similar to that of hardwoods grown with resident vegetation (Figs. 1 and 2). Growth of walnut might be reduced more by grass sods than growth of other hardwoods. In studies with unmanaged control plots, growth of walnut is 21% less than growth in control treatments compared to only a 5% reduction for other hardwoods (79 and 95% of resident vegetation or unmanaged control, respectively; $t' = -1.76$, 40 *df*, $p < 0.20^{ns}$). In studies with vegetation-free control plots, growth of walnut in grass sods is 47% less than growth in control treatments compared to only 32% reduction for other hardwoods (53 and 68% of vegetation-free control, respectively; $t' = -3.23$, > 100 *df*, $p < 0.01^{**}$). In these studies, growth of walnut in grass sods is slightly less than growth of walnut in resident vegetation (53 and 56% of vegetation-free control, respectively; $t' = -0.49$, $df = 40$, $p < 0.5^{ns}$). Similar growth differences exist for other hardwoods grown in grass sods compared to that of growth for other hardwoods in resident vegetation (68 and 63% of vegetation-free control, respectively; $t' = 1.24$, > 100 *df*, $p < 0.40^{ns}$).

The small increases or decreases in growth of walnut and other hardwoods compared to growth of trees in resident vegetation is partially due to differences among grass species (Table 2). Preliminary results suggest annual grasses such as cheat (*Bromus secalinus* L.), annual ryegrass (*Lolium multiflorum* Lam.), and cereal grains are less competitive than perennial grasses. Perennial turf-type grasses such as red fescue (*Festuca rubra* L.) and Kentucky bluegrass (*Poa pratensis* L.) also tend to be less competitive than perennial forage grasses such as orchard grass (*Dactylis glomerata* L.) and perennial ryegrass (*Lolium perenne* L.). Overall, tall fescue (*Festuca arundinacea* Schreb.) is the only grass that, based on available data, statistically reduced growth of black walnut and other hardwoods below that of resident vegetation (32% and 60% of vegetation-free control; $t' = -7.14$, > 100 *df*, $p < 0.001$***). Warm-season forage grasses should be avoided because they lack shade tolerance, vegetative growth occurs primarily when available soil moisture is low, and mowing in not recommended in the fall when nuts are to be collected in well-managed black walnut plantings (Lin and others 2000, Van Sambeek and others 2004).

Besides the reductions in potential tree growth, there are a number of other potential problems when using grass sods. Most grasses have extensive, finely branched root systems that can effectively explore greater volumes of soil than forbs and trees resulting in drier and nutrient poor soil profiles. Deep-rooted grasses like tall fescue exploit the same soil horizons as will walnut and can significantly reduce available soil nitrogen within the tree rooting zone. Van Sambeek and others (1989) reported that in stagnated walnut stands, tree growth was limited more by low available nitrate nitrogen than it was by competition for available soil moisture. Lyon and others (1952) reported average evapotranspiration rates for annual grasses of 4 inches of precipitation per ton per cutting. As with forage legumes, regrowth of grasses following cutting puts a significant demand on limited available soil moisture in the summer. Grasses that maintain their dominance through the production of phytotoxins such as tall fescue, smooth bromegrass, and broomsedge probably should also be avoided (Ponder 1986; Miller and others 1987; Rink and Van Sambeek 1985, 1987).

There are a few advantages to managing grass sods in hardwood plantings. This plant cover is probably the best to slow surface run-off and increase water infiltration, especially on steep slopes. Because equipment and labor needs for mowing are less costly than for disking or tilling, grass sods cost less to maintain than legume cover crops (Jorgenson and Craig 1983). Mowing shifts the competitive advantage toward grasses that have their growing points at the soil line and, thus, grass sods are easier to maintain than legume cover crops. A sod cover provides year-round footing for equipment to complete maintenance including mowing, spraying, pruning, or harvesting. It may be desirable to establish grass sods near the end of the rotation to concentrate on hay and nut production and allow the wide growth rings within the sapwood to convert to the more desirable heartwood if walnut trees have been managed for veneer log production. Preliminary results from shade-tolerance screening trials indicate mixes of orchard grass or Kentucky bluegrass with red clover should produce acceptable yields in closed canopy walnut plantings (Tables 1 and 2).

Managing cool-season grass and legumes offers the opportunity to implement the agroforestry practice of silvopasture management. Although forage yields are variable, several studies have shown higher

Table 2.—Average growth and standard deviation for black walnut and other hardwoods as a percentage of tree growth in plantings without ground covers and shade tolerance percentile rank for selected grass species.

Grass Sod	Tree Growth[1]	Shade Tolerance[2]
	%	%
Bromegrass	76 + 20 (10)	55
Annual cool-season	75 + 38 (8)	41
Red fescue	71 + 26 (77)	35
Bluegrass	69 + 36 (19)	58
Cereal grains	68 + 39 (15)	ND
Orchard grass	65 + 24 (84)	58
Quackgrass	64 + 19 (2)	ND
Timothy	64 + 14 (9)	37
Redtop	62 + 17 (4)	38
Resident vegetation	60 + 28 (156)	--
Perennial ryegrass	62 + 15 (8)	36
Mixed grass sod	52 + 24 (11)	--
Tall fescue	32 + 31 (93)	50

[1] Growth is percent of vegetation-free control + standard deviation and in () number of replications extracted from the literature. Mean least significant difference is 20%.

[2] Average percentile rank under moderate and heavy shade estimated from three or more screening trials where 0% was assigned to the least and 100% was assigned to the most shade tolerant species within each light level and screening trial. ND = not tested.

protein content and increase digestibility of most forages when grown under moderate shade (Garrett and Kurtz 1983; Lin and others 1999, 2001; Huck and others 2001). Compared to open pastures with artificial shade structures, hardwood plantings alleviate heat stress better producing greater weight gains and result in more uniform grazing and waste deposits (Garrett and others 2004). Under silvopasture management, established trees must be protected from soil compaction and physical damage of roots near the soil surface through the use of rotational grazing and livestock removal during wet periods. Most silvopastoral studies have not examined effects of forage production and grazing on hardwood growth. Rotational grazing will stimulate regrowth of grasses increasing total annual biomass and expected evapotranspiration that will result in greater soil moisture depletion than may occur with grass sods that are not grazed or mowed. Although forage legumes can increase growth of hardwoods compared to grasses or resident vegetation, no studies were found that examined the growth of hardwoods with forage legume and grass mixes. We hypothesize that grasses will benefit more from the nitrogen fixed by the legumes than will the trees resulting in an improved livestock forage but even slower tree growth.

WOODY NURSE CROPS

Woody nurse crops are trees or shrubs introduced into a hardwood planting to improve growth and quality of the crop trees during the sapling and pole stages. The resulting growth of hardwoods grown with woody nurse crops is intermediate between the potential growth that occurs under treatments with no ground cover vegetation and that with cover crops or resident vegetation (Fig. 2). The increase in growth of walnut in mixed plantings averages 22% compared to growth in pure walnut plantings usually managed with a ground cover of resident vegetation. The growth increase of other hardwoods in mixed plantings tends to be greater than for walnut, but is not statistically different (122 and 138% of unmanaged control, respectively; $t' = -1.19$, 50 *df*, $p < 0.30^{ns}$). Schlesinger and Williams (1984) found that the growth of walnut with woody nurse crops is highly dependent on the planting site and which nitrogen-fixing tree species were interplanted.

The planting of other trees and shrubs that have relatively dense crowns with walnut will create a shady, cooler, more humid microenvironment more typical of that found in woodlands (Funk and others 1979, Burke and Pennington 1989). More soil moisture is made available to the trees because shade reduces surface evaporation and decreases evapotranspiration by eliminating most grasses and forbs. Mixed hardwood plantings will still result in more rapid and deeper depletion of available soil moisture than in pure walnut plantings with resident vegetation (Funk and others 1979). Lull and Fletcher (1962) reported average soil water depletion rates in the upper 20 inches of 0.099 inches/day when mulched, 0.166 inches/day with resident vegetation, and 0.197 inches/day under trees. In contrast, soil water depletion rates in the 20- to 40-inch depth averaged 0.018 inches/day when mulched, 0.039 inches/day with resident vegetation, and 0.102 inches/day under trees. A shaded microenvironment also moderates the extremes and fluctuations in soil temperature and frequently supports a wider range of beneficial soil fauna and flora than found in exposed soils. Although lateral branches still need to be pruned, creating a dense canopy results in death of most branches while still relatively small in diameter growth. Woody nurse crops may be the best alternative for ground cover management on sites not readily accessible to farm equipment such as those along meandering creeks and other riparian areas.

The major problem with using woody nurse crops in hardwood plantings is matching the growth of the woody nurse crops to the crop trees. Maximum benefits of planting woody nurse crops are usually achieved when the growth rate of the woody nurse crop is slightly greater than for the crop tree species. This can occur naturally with shrubs like autumn olive or culturally through repeated coppicing as has been demonstrated with black locust. For 2 to 4 years after establishment, mixed hardwood plantings will require some other method of ground cover management until the dense canopy of the nurse crop shades out the competing understory vegetation. Differences in sensitivity of hardwood species to herbicides may restrict which can be used to establish mixed plantings (Seifert and Woeste 2002). Compared to plantings with well managed ground covers, woody nurse crop plantings have an unkempt appearance (Burke and Pennington 1989). Pruning, thinning, and nut harvesting operations are more difficult in mixed plantings than in pure walnut plantings. Growers must make a decision balancing appearance and growth rate, but in plantings managed for timber where optimum growth and quality are the main objectives, creating a woods-like condition is probably the preferred method for ground cover management.

Currently, the species of choice as a woody nurse crop in black walnut plantings is autumn olive (*Elaeagnus umbellata* Thunb.). Unfortunately, it is an invasive exotic species and most states discourage its planting. Research is needed to identify native or less invasive shrubs or trees that produce dense canopies capable of shading out perennial resident vegetation and are capable of fixing atmospheric nitrogen (Van Sambeek and others 1985). European black alder (*Alnus glutinosa* (L.) Gaertn.), an actinorhizal tree, black locust (*Robinia pseudoacacia* L.), a nitrogen-fixing leguminous tree, and silver maple (*Acer saccharum* Marsh.) need frequent pruning and/or coppicing to keep them from overtopping walnut (Schlesinger and Williams 1984, von Althen 1989). In a recent review of the nutritional interactions in mixed tree plantings, Rothe and Binkley (2001) concluded nutritional benefits of nurse crops are mostly additive; however, when using nitrogen-fixing nurse crops, they concluded benefits can be synergistic with greater than expected yields. Evaluation of recently established hardwood plantings under the Conservation Reserve Program may yield meaningful information in the future as these plantings now require a mix of hardwoods that can include walnut.

CONCLUSIONS

The vegetation management program chosen will be influenced by many factors including management objective (timber only, nuts only, or timber and nuts), site characteristics (location, slope, hydrology), type of planting stock (seed, bare-root seedlings, or large container stock), access to equipment (tractors, cultivators, spray rigs), and, possibly most importantly, labor availability. Ultimately, the primary objective of any program is to maximize nut production or growth of quality trees while minimizing establishment and maintenance costs. The primary objective of any ground cover management system is to reduce tree competition for water and nutrients, minimize labor and equipment costs, and create a ground surface that will support equipment needs for maintenance and nut collections. After considering the advantages and problems of the various vegetation management approaches, managers of walnut or mixed hardwood plantings should be able to develop the most appropriate strategies to meet their objectives for their particular plantings.

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