Accepted for publication 8 November 2004. Published 9 December 2004.

Considerations for Establishing and Managing Silvopastures

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Fike, J. H., Buergler, A. L., Burger, J. A., and Kallenbach, R. L. 2004. Considerations for establishing and managing silvopastures. Online. Forage and Grazinglands doi:10.1094/FG-2004-1209-01-RV.

Introduction

Silvopasture managers deliberately integrate trees, forages, and livestock (15) to take advantage of their beneficial interactions. Silvopasture systems require challenging, yet rewarding management strategies not employed in traditional monoculture systems (44). Correctly managed, production of each component can be greater than in traditional forestry and forage-livestock systems (17,26,36,46,47). Silvopasture systems support greater biological and economic diversity and provide environmental benefits as well.

"Silvopasture management ... requires shifting our thinking in both spatial and temporal domains and demands skills in managing [complexity] rather than reducing complexity" (28).

Silvopasture concepts and practices are not new, but their research and use in North America is limited, particularly with hardwood trees. Primary sites of activity include the pine plantations of the Southeast and coniferous forestlands of the West, while research with temperate hardwoods is ongoing in the Midwest and Virginia. Despite great potential, expansion of silvicultural practices to other regions of the USA has been constrained by lack of producer familiarity and a scarcity of management recommendations. In this review, we discuss issues relevant to establishment and management of trees in pastures and potential benefits to system productivity, primarily in relation to hardwood species.

Selection of Tree Species for Silvopastures

Tree species is an important consideration when establishing silvopastures. Desirable characteristics include: (i) marketable timber; (ii) high-quality wood; (iii) rapid growth; (iv) deep-rooted morphology; (v) drought tolerance; (vi) production of additional products such as nuts or fodder; and (vii) provision of environmental conservation services (6,61,62,69).

Tree growth patterns and morphology should complement production of the understory forage crop. Species such as honey locust (*Gleditsia triacanthos*) (Fig. 1), black walnut (*Juglans nigra*) (Fig. 2), and black locust (*Robinia pseudoacacia*) (Fig. 3) that produce leaves late in spring, have sparse, open canopies, and release leaves early in fall are preferable, as they allow penetration of sufficient light to support forage growth (25,26,69). Rapid leaf decomposition is also desirable.

Fig. 1. In future, specific varieties of trees may be developed for silvopastoral systems. The 'Millwood' honey locust was selected for production of high-energy pods that potentially can serve as a valuable source of livestock feed (77). The pulpy pods contain up to 35% sugar, and yields are similar to an equivalent acreage of oats (67). Two management considerations include vulnerability to livestock damage and end use for the timber.

Fig. 2. Of the hardwood species considered for temperate silvopastures and multi-cropping systems, black walnut has received the most attention. Black walnut produces both high-value wood and generates an annual nut crop. Management for either or both outputs is possible; the chosen strategy will depend on producer objectives and local markets, among other factors (76).

Fig. 3. Black locust (*Robinia pseudoacacia*) has potential as a multi-use, nitrogen-fixing tree for temperate silvopastures. Black locust can increase forage production by improving soil fertility and soil moisture, while reducing microclimate temperatures (31,69). Black locust makes excellent fence posts and firewood and may be suitable for browse, but the species is susceptible to a stem borer (*Megacyllene robiniae*) (19). Photo courtesy of Charlie Feldhake, USDA-ARS.

Deep-rooted trees with limited lateral extension in the topsoil are preferred because such root architecture allows for nutrient recycling from the subsoil, creates a "safety net" against nutrient leaching below the forage rooting zone, and limits interference with root systems in the topsoil (2,61). Temporal differences in root activity between trees and forages are also desirable, allowing for greater resource sharing (62).

Depending on producer goals and tenure needs, rotation length may also affect tree selection. For example, honey locust rotations may be between 30 to 50 years. In contrast, black walnut requires 30 to 50 years' growth before being suitable for veneer, and quality saw logs may not be achieved for 80 years or more (76).

Long rotation lengths should not discourage producers and managers looking for rapid returns on investment. Trees may provide products and services long before their harvest at the end of a rotation. Even if managed only for timber, trees may be viewed as a bank account accruing interest with real value that can be sold. Moreover, long rotation lengths need not be perpetual, because multiple rotations can be created. At the appropriate stage, the next generation tree stand is strategically planted in the understory (28), allowing future harvests to be spread out in space, time, or both.

One other consideration for tree selection is the potential allelopathic effect of some species against forage plants. Both black walnut and pecan (*Carya illinoensis*) trees produce juglone, a chemical that inhibits shoot elongation in crimson clover and sericea lespedeza (*Lespedeza cuneata*) (57) and may be toxic to alfalfa (*Medicago sativa*) (18). However, no negative effects of juglone on cool season grasses have been reported and allelochemicals may benefit pastures by preventing growth of weed species such as bull thistle (*Cirsium vulgare*) (20) and horse nettle (*Solanum carolinense*).

Protecting Seedling Trees in Pastures

Silvopastures can be successfully established and managed by planting trees and forages at the same time, by planting trees into existing pastures, or by thinning existing tree stands and planting forages (15). Planting trees into pastures offers managers greater flexibility than thinning existing forests. Tree spatial arrangement can be structured to meet management needs, and species with greatest utility or economic merit can be selected.

Trees planted into existing pastures need protection from competition until their root systems are below the forage crop's root layer (61). Early spring herbicide applications that control cool-season pasture can double tree stem volume (5). Mulches can also be effective, but growth benefits are not as great (5). The degree of protection required depends upon the vigor of the seedling. For example, slash pine (*Pinus elliottii*) can be successfully established into thick ground cover while Monterey pine (*P. radiata*) requires extended suppression of vegetation (43).

Trees also need protection from livestock and wildlife (1,5) to prevent damage from trampling or browsing, especially during early years of establishment (5,21,41) (Figs. 4, 5, and 6). Protective measures include removal of livestock from the site, protecting individual trees with tube shelters, cages, or repellents, or use of electrified fencing to protect rows or groups of trees.

Fig. 4. Honey locust tree protected by both cage and tree tube. The staked cage is adequate for thwarting deer, but small rodents may chew the bark without the tube.

Fig. 5. Tree tubes protect trees from small rodents and browsers. Over time the tree will grow out of the tube (lower left). Corrugated pipe can be slit and used as an alternative tubing (lower right).

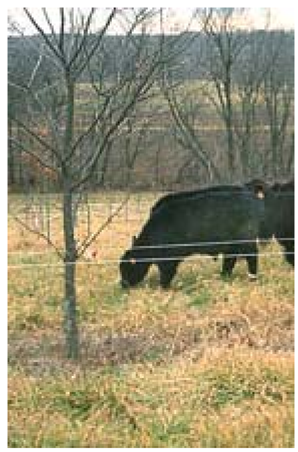

Fig. 6. Cattle grazing among trees protected with electric fencing.

Both tree and animal species must be considered when determining protection requirements (43). Palatable trees (e.g., honey locust) require greater protection, especially from animals that browse (e.g., goats and deer). Conversely, a single strand of electric fence over the tree row may prevent cattle from trampling young conifers. Complete exclusion of livestock from new plantings can be useful, provided wildlife pressure is low. Livestock can be returned to pasture once trees are no longer vulnerable to damage, and the forage crop may be mechanically harvested until that time (21).

Tube shelters allow producers to graze livestock among young trees, but results of their effects on trees are mixed and are likely species-dependant (21,56). Red oaks (*Quercus rubra*) sheltered in tubes were initially taller than unsheltered trees, but height growth was similar for both after 10 years (56). In contrast, negative effects on height growth of green ash (*Fraxinus pennsylvanica*) were observed after five years (56). With black walnut, tube shelters have had no effect (56) or have promoted height growth at the expense of tree diameter (21). Furthermore, height of unsheltered trees matched that of sheltered trees after seven years and sheltered trees often have poor form and weaker stems more susceptible to damage (21). Improved tube design may overcome these problems, but beneficial claims should be viewed with caution, particularly if based on short-term (< five-year) studies.

Staked wire cages can provide protection when sufficiently strong. Chicken wire may thwart rodents that girdle trees but is unlikely to be adequate against large animals (5). With cages, gaps must be small enough with placement far enough from the stem that animals cannot reach the trees.

Abrasive paint-on products and repellents also may prevent animals from girdling trees (21,22). Manure slurry sprayed on seedlings can both repel livestock and fertilize the young tree (29). Responses to chemical repellants are mixed (41,78), although application method and timing may affect results (41). Regardless, repellents likely will not prevent trampling and rubbing damage.

Electric fencing may be the most practical exclusion method, although some grazing land is lost. Fencing may be most convenient and economical where multiple rows or large clumps of trees can be fenced. For any protection method, increased establishment costs must be weighed against potential benefits.

Spatial Arrangement and Planting Density of Tree Stands

Appropriate design is essential to create positive interactions among the plants and animals in silvopastures. Traditionally, square planting configurations were used in pine plantations to utilize all space for root and crown growth (43). However, double-row configurations of slash pine with open spaces between sets of rows are effective both for forage and tree production (43). Such arrangements provide open spaces for pasture, support high forage production, and facilitate agricultural operations and animal herding (64).

Some trees may benefit from planting in high-density clumps (70). Clumped arrangements can be compatible with forage-livestock production while providing benefits of a woodland environment for trees (70). Open spacing may reduce growth of some trees due to greater environmental exposure, particularly wind (30,70).

Planting configuration also can be an important tool for overcoming the spreading habit of some tree species (27). A three-row configuration with pines in the outer rows can train the inner row to grow up straight. This reduces the need for pruning due to basal sprout formation or spreading morphology (27). After 10 or 15 years, the outer rows are cut for pulpwood, leaving higher value trees for future harvest of saw logs (27,72) (Fig. 7). Appropriate spacing and species mixtures may be critical for such configurations if outer-row trees are highly competitive with inner row trees for resources.

Fig. 7. Black walnut trees growing between rows of pines. Pines encourage upright growth of walnuts and can be ready for pulpwood harvest after 10 to 15 years. Pastures in the photo were newly seeded to annual ryegrass (*Lolium multiflorum*).

For planting density, recommendations are to establish trees at four to six times the number required at the end of the crop tree rotation, although this may be reduced with trees of superior genetic merit (50). For black walnut, initial density of 100 trees per acre with ultimate density of about 25 trees per acre (40-×-40-ft spacing) is recommended (26). This spacing, considered appropriate in most temperate zones (25), is in marked contrast to the 200 to 1800 trees per acre used in establishing pine plantations (43,50,53), where high levels of thinning are required to maintain forage production over time unless pines are planted at low densities and pruned.

Early in the rotation, additional trees may benefit the system by buffering cool-season pastures and training the final crop trees to grow straight and tall. When tree canopy closure limits forage production (66), trees can be pruned or thinned to increase light available to the forage canopy. For ryegrass (*Lolium perenne*) growing under *P. radiata* trees, pasture yield is negatively linearly related to size of the tree crown (66). However, differences in sensitivity of forage species to shading (44) may have marked effects on the nature and function of this relationship.

Higher-density plantings may be preferred by producers primarily interested in timber production and where trees are managed for eventual closure of the tree canopy. Such strategies may be suitable where management inputs are limited and pulp- or firewood production is an acceptable end use of young stands (50). High-density plantings also can be suitable for log production with trees that "self-prune" (72), although frequent thinning may be necessary to maintain forage production.

If the goal is to keep a productive forage-livestock enterprise over the length of the rotation, lower tree densities are needed. This will require greater efforts to protect, prune, and thin the tree stand, but this intensive management has a positive trade-off in production of higher-value logs.

Additional factors in thinning decisions include debris management, pruning requirements, and tree crop production. Thinning pines after five years resulted in a 12% loss of ground cover due to debris, compared with a 28% loss at seven years (3). While thinning allows for greater forage production, it also increases pruning requirements if trees produce branches from dormant buds upon exposure to light (28). Pruning increases production costs but can be a good investment if premiums are paid for knot-free logs (15). However, when tree crops (i.e., nuts, pods, or fruits) are part of farm income, profit is likely maximized by sacrificing log length in favor of crown development (76).

Silvopasture Management and Animal Production

Shade and shelter from trees can benefit livestock by mitigating environmental extremes. Trees provide evaporative cooling, reduce radiant heat loss at night, and reduce wind speed. These buffered environmental conditions allow animals to spare energy for growth, particularly under hot conditions. Increased gain, milk yield, and conception rates have been reported for cattle or sheep grazing pastures with trees in warm environments (9,37,46,51).

Reduced heat stress boosts animal health. In the tropics, silvopastoral management benefits animal performance by improving grazing patterns (49) and increasing grazing time (9). In a Mediterranean climate, ewes maintained under small (11 ft tall with 16-ft-wide crowns), sparsely planted (about 24/acre) *Acacia caven* trees had double the weight gain and half the water consumption of ewes maintained on open pasture during the breeding season (51).

Greater animal performance in silvopastures is likely due to increased forage production and direct effects on animal comfort. Pasture productivity is usually the most important factor affecting livestock carrying capacity (23). Trees can increase forage production across diverse grassland environments (4,26,71), potentially supporting increased stocking rates. However, decreased animal performance can occur when trees have neutral or negative effects on forage production (55).

Animal performance data from temperate hardwood silvopastures with mature trees are lacking. Gains were unaffected when cattle grazed newly-planted deciduous silvopastures in Missouri (41). However, in this study the trees were seedlings and not old enough to significantly impact forage production. Animal performance results from conifer silvopastures are mixed. Positive responses predominate early in the tree growth cycle, and negative responses predominate as conifers close canopy. Sheep gains were lower in silvopastures with 10-year-old radiata pines due to reduced forage yield; no changes in forage nutritive value were detected (55). Similarly, lamb gains in Sitka spruce (*Picea sitchensis*) silvopastures were satisfactory when trees were young, but animal production declined with closure of the tree canopy and concomitant forage yield reduction (1). Yield and quality of wool also were reduced due to loss of wool on trees and accumulation of needles and twigs in the fleece (1).

Forage nutritive value (39), digestibility (26), and botanical composition (8,69) can be improved in silvopastures, but contrasting research shows reduced palatability, forage growth, and animal gain (35,55). Decreased palatability may be related to reduced non-structural carbohydrates observed in shaded plants (7,60), because livestock prefer and gain better on forages with greater non-structural carbohydrate concentrations (11,24,45).

While most research suggests moderate shade (about 50% of full sun) is best for forage production (28,44), this may be difficult to maintain as an endpoint. Changes in resources (light, temperature, and moisture) available to the forage sward occur as trees mature, thus forage production will necessarily change over time (44,53). Systems managed for continuous livestock production (versus animal removal with closure of the tree canopy) need to focus on maintenance of ideal tree density to maximize the benefits of the tree-grass association and minimize the negative effects of competition between these two components. Forage production in pastures planted with conifers decline as trees close canopy (40), but this is not necessarily the case for pastures planted to open-canopied deciduous trees. More research is needed to define forage response in deciduous silvopastures through time.

Timber Production and Quality in Silvopastures

Several studies indicate well-managed tree-forage intercropping can increase timber yield above typical management (12,13,14,17,36,75). Grazing new conifer plantations increased tree height and diameter growth and these positive effects were maintained several years after grazing ceased (36). Increased wood production and greater growth of loblolly (*P. taeda*) and radiata pines also have been reported (17,75).

Grazing of understory vegetation reduces trees' exposure to water stress, fire hazard, and competition for soil nutrients (32,63). Increased tree production may also occur due to capture of fertilizers applied to forages (17). For radiata pine, faster growth associated with greater soil nutrients may negatively affect timber quality if wood density is reduced (33), affecting strength-related uses but not appearance or utility grade. In contrast, slash pine specific gravity was not affected by over 30 years of cattle grazing (16). Concentration of nutrients under trees likely will not occur in well-managed silvopastures because well-spaced shade improves grazing distribution (47). Total output of agroforestry systems is often greater than that of plantation forests, even when tree production is similar, given the production of additional crops (i.e., livestock, nuts, fodder, or pine straw) (10,48).

For timber producers, effects of grazing livestock on tree stands may be of greater concern than tree-forage interactions. On overgrazed, poorly managed lands, livestock may browse or debark trees, damage roots by compacting wet soils, or reduce wood quality via concentrated nutrient deposition (29,34).

Susceptibility to browsing likely varies by tree species and defoliation intensity. In artificial defoliation studies, slash pines were unaffected unless defoliation treatments were severe (43). However defoliating Norway spruce (*Picea abies*) caused permanent reductions in height growth, volume production, and wood quality (74).

With the exception of highly palatable species, browsing damage is likely greatest with young trees and seedlings. Based on research with slash pine, Lewis and Pearson (43) gave three recommendations regarding introduction of livestock to newly-established silvopastures: (i) have plenty of feed on hand; (ii) provide water, minerals, and supplements away from new trees; and (iii) be willing to accept some damage. The authors noted that young seedlings could sustain production despite some damage if injuries were not repeated. This advice may not hold for hardwoods or sensitive conifers, but damage rates may be less critical where heavy thinning is planned (54). Keeping stocking rates at half of typical capacity until pines were between 3 and 5 feet tall, and frequent monitoring of the young tree stand was also recommended (43).

Livestock management may have implications for tree production beyond defoliation and trampling. For example, numerically greater height growth was reported for protected black walnut trees managed with continuous (versus rotational) stocking (42). The authors postulated that greater water competition limited tree growth under rotational stocking.

Mechanical damage is a concern common to both traditional and silvopastoral management. Wounding trees causes decay and discoloration (65), reducing timber production and quality. Damage from logging activities during thinning can be high (52) but should be avoidable with appropriate planning. For silvopastoral managers, debarking by animals or scraping with equipment (e.g., when clipping pastures) may be of greater concern but will be of less economic consequence in systems with resinous species such as pines (33).

Concerns exist about reduced tree production due to allelopathy from fescue. Sensitivity appears species dependent; fescue leachate has limited effect on walnut (59) but reduces growth of pecan (68) and sweet gum (*Liquidambar styraciflua*) trees (73).

Knowledge Gaps in Silvopasture Management

Numerous aspects of silvopasture systems need further investigation. Comparisons detailing differences in animal performance, behavior, and health between silvopasture and open pasture is limited, particularly with mature deciduous trees in temperate environments.

Interactions of trees and forages on forage energetics and palatability also warrant research. Conditions which reduce forage palatability might be offset by gains in forage digestibility and increased animal comfort, but this dynamic is not well defined.

Forage selection for silvopastures needs greater exploration. Although several studies have reported changes in forage yield and nutritive value under shade (38,39,44), forage suitability for "silvopastoral systems should be assessed from the perspective of total plant and animal production and species persistence rather than 'shade tolerance'" (55).

Development of trees with greater seedling vigor and competitiveness may reduce establishment costs for silvopasture systems. Trees selected for greater early competitiveness should also have positive interactions with forages and livestock in time. Effects on system productivity also need further investigation given the wide array of products and services that may be supplied by different tree species.

Management is integral to the success of silvopastures, but producers currently lack the information and decision support systems needed to implement the practices. Guidelines are especially needed to help producers manage competition for light, water, and nutrients (58). In this context, livestock should be viewed as both a product and a management tool, particularly where competition between trees and grass can be reduced by grazing (15).

Summary

- Silvopastoral management offers great potential for increasing system productivity through intentional integration of trees, forages, and livestock.
- Trees selected for silvopastures should be compatible with forages and livestock and provide several products and services.
- Several tree protection methods are available; choice will depend upon management objectives.
- Spatial arrangement should be designed to optimize benefits to trees, forages, and livestock while meeting management needs.
- Animal production typically is increased in silvopastures when forage production is not limited.
- Timber production and quality can be as good or better in silvopastures with appropriate management.
- Much research is needed to provide critical management and decision support information for successful implementation of silvopastoral practices.

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