ROLES FOR AGROFORESTRY IN HARDWOOD REGENERATION AND NATURAL-STAND MANAGEMENT

H. E. 'Gene' Garrett[1]

ABSTRACT.—A convincing case can be made that current land-use patterns in the Central Hardwood region reflect a significant underutilization of our land-based resources. A land-use strategy is required that would allow landowners who are interested in converting marginal crop lands to forests, or unproductive woodlots to productive woodlots, to make the change without financial loss. Agroforestry has the potential to precisely do this. Agroforestry, an integrated land-use management approach for both production and conservation benefits has gained remarkable acceptance since the early 1990s. It provides the landowner the opportunity to develop a portfolio of short- and long-term investments and serves as a viable alternative to conventional forestry and agricultural practices.

Agroforestry, defined as "intensive land-use management that optimizes the benefits (physical, biological, ecological, economic, social) from biophysical interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock" (Gold and others 2000), has the potential to dramatically influence the acres of new hardwood plantings and unmanaged natural forest stands placed under management. This concept that had few supporters during the 1970s and 1980s suddenly became recognized as a highly specialized and successful technology in the 1990s. In contrast to the segregation-of-use philosophy that has dominated agriculture and forestry for decades, agroforestry advocates optimal integration of trees with crops for both production and conservation benefits and differs from conventional forestry in that it provides a cash flow that is derived from companion crops grown with the trees.

OPPORTUNITIES FOR HARDWOOD AGROFORESTRY

The demand for wood products within the U.S. is projected to increase significantly during the next few decades, perhaps as much as 38 percent by the year 2050 (Powell and others 1992). Coupled with a recent history of decreased harvesting on federal lands, a unique opportunity is unfolding for agroforestry in the Central Hardwood region. The increased demands will hopefully create new markets and improved prices for hardwoods (Wiedenbeck and Aramen 1993). Since the majority of timberland in the Central Hardwood region is under nonindustrial private ownership, if landowners could be convinced that putting their stands under management is financially rewarding, not only would we see vast acreages of unmanaged forests managed, but marketing of wood products could become a significant factor in the revitalization of the family farm and rural America in general.

In addition to forested land that is in need of being placed under management, the Central Hardwood region contains millions of acres of farmland, that is either lying idle or is being conventionally farmed, that has a high erodibility index (EI). Many of these lands would better serve the owner and society alike if they were under agroforestry management. Within the U.S., more than 90 percent of farm output is produced by our largest 600,000 plus farms leaving approximately 1.5 million farms fighting for less than 10 percent of the market. Within these 1.5 million farms are millions of acres of "under used" land ideally suited for tree planting. Many of these farms are located in the Central Hardwood region and are prime candidates for hardwood tree plantings (USDA 1994, Garrett 1995).

In the Midwest alone, where considerable agroforestry research has been conducted, the five states of Missouri, Illinois, Indiana, Iowa, and Ohio, have more than 19 million acres of cropland with

[1] Professor and Director (HEG), Center for Agroforestry, University of Missouri, Columbia, MO 65211-7270. HEG is corresponding author: to contact, call (573) 882-3647 or e-mail at garretth@missouri.edu.

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

an EI greater than 10, indicating very high erodibility (Noweg and Kurtz 1987, Garrett and others 1994). Approximately 9 million of these acres are recommended for forestry plantings and would be ideally suited for agroforestry. In the Plains States of Nebraska and Kansas, an additional 16 million acres of cropland are highly erodible (EI > 8) and would lend themselves well to agroforestry practices using either pure hardwoods or hardwood/conifer mixes. Within these same 7 states, there are 5 million acres of pasture land with high potential for conversion to agroforestry and more than 10 million with medium potential for conversion (Garrett and others 1994). Conversion would not only provide increased economic returns to the landowner but also many environmental benefits while helping our nation meet its future demand for wood products.

Agroforestry management incorporates intensive practices such as tree planting, annual cultivation, fertilization, irrigation, weed control, liming, grazing animals or combinations of these and other practices. Consequently, agroforestry manipulates the agroecosystem to achieve optimal benefits. These benefits may be combinations of economic, environmental, biological, or social (Udawatta and others, in press). Optimization implies that the various factors can be combined, through compromise, to best serve the interests of the user and society. Since each user may have different objectives – soil conservation, minimization of inputs, integrated pest management, profits, aesthetics, etc. – optimization of system components will vary. However, in most agroforestry designs, protective and productive benefits are realized. They are the products of biophysical interactions resulting from the proper mix of woody perennials, herbaceous species and/or livestock. These interactions directly affect soil, water, and air quality, biological diversity, wildlife habitat, aesthetics, economics and ultimately, even rural community development.

The intentional combining of trees and/or shrubs with crops and/or livestock is an essential element of agroforestry. This aspect can create a multi-storied characteristic similar to that found in many natural ecosystems while providing a variety of marketable commercial products. Crops may include conventional agronomic commodities such as corn (*Zea mays* L.), wheat (*Triticum aestivum* L.) and soybeans (*Glycine max* (L.) Merr.); specialty commodities such as ginseng (*Panax quinquefolium* U.), mushrooms, honey and floral greens; warm- and cool-season pasture; woody biomass for energy, oriented strand board (OSB) and paper; trees of high-value timber/veneer, nut/fruit producing perennials, ornamentals and others.

AGROFORESTRY PRACTICES

Trees and crops can be arranged in numerous configurations providing five categories of agroforestry practices as recognized by the Association for Temperate Agroforestry (Merwin 1997). These practices are: Silvopasture, Forest Farming, Forested Riparian Buffers, Windbreaks, and Alley Cropping.

Agroforestry Practices For Native Stands

In the Central Hardwood region of the United States, nonindustrial private forest landowners own a high percentage of the commercial timberland. Much of this timberland is found on farms of 100 acres or less and is not under management. The reasons for lack of management are sometimes complex and highly variable. But with many, the lack of a short-term economic incentive serves as a major deterrent. In addition, forest land holdings are typically so small that, in the past, clearcutting has been perceived as one of the few viable options available to the owner to generate immediate income. With the downturn in farm economies during recent years, farm owners have become more receptive to trying agroforestry practices that allow them to conduct timber stand improvement, as a long-term investment, while creating microenvironments suitable to support forages for silvopasture or specialty crops in forest farming operations that provide an immediate cash flow.

Silvopasture

Silvopastoral practices are a form of agroforestry in which tree, forage and animal components simultaneously share a parcel of land. The forage component is typically an improved pasture of introduced grasses and/or legumes that is managed using conventional agronomic principles. Silvopasture may be simplistically described as “trees in pastures” and is the most common form of agroforestry practiced in developed countries (Sharrow 1999). It differs from forest grazing in which grazed forests or woodlands are *extensively* managed as pseudo-natural ecosystems. While they provide wood products and some forage for livestock, as is the case with silvopastures, the opportunity for maximizing economic gain is not realized and often decreases as a result of damage to the natural ecosystem that is trying to be maintained. Silvopasture is an artificial agroecosystem where each component (i.e., tree, forage, and animal) is emphasized and is maintained using *intensive* approaches such as annual inputs of nutrients, herbicides, and mechanical treatments (Clason and Sharrow 2000). One of the primary goals of silvopasture is to maximize economic gain on a per acre basis even though some sacrifice in wood, forage, or animal yields, from that of a pure practice, may occur.

While silvopasturing has been researched most extensively in the southern pine region, the practice has great potential within the Central Hardwood region. Even though density of shade is typically greater for hardwoods than pines, through the selection of forage species that will tolerate some shade and management of light regimes within a stand through well-timed thinnings and prunings, high quality pastures can be created and maintained under hardwood stands. Research within the Center for Agroforestry at the University of Missouri has clearly demonstrated that some forages possess the potential to grow as well in 50 percent shade as in full sun (table 1, Lin and others 1999, 2001).

Of 30 forage species and cultivars studied, 15 species/cultivars were found to be suitable based upon shade tolerance for use as a companion crop during the establishment or developmental stages of a silvopastoral practice. Those found to have slight to moderate shade tolerance such as Kentucky bluegrass (*Poa pratensis* L.), 'Benchmark' orchardgrass (*Dactylis glomerata* L.), 'Manhattan II' ryegrass

Table 1.— *Mean total above ground dry weight, acid detergent fiber (ADF), neutral detergent fiber (NDF) and crude protein (CP) percent of forages under three levels of shade during the 1994 and 1995 summer-fall growing season (Lin and others 1999, 2001)*

MEASURED PARAMETER AND SPECIES	Shade levels: Full sun	50% sun	20% sun
DRY WEIGHT	**- g -**	**- g -**	**- g -**
Kentucky bluegrass	12.45 a*	12.30 a	8.06 b
Orchardgrass 'Benchmark'	13.83 a	11.73 a	6.36 b
Ryegrass 'Manhattan II'	12.69 a	11.10 ab	8.59 b
Smooth bromegrass	9.61 b	11.95 a	9.54 b
Tall Fescue 'KY31'	13.28 a	16.24 a	7.96 b
Timothy	10.23 a	8.97 a	5.49 b
CRUDE PROTEIN	**- % -**	**- % -**	**- % -**
Kentucky bluegrass	20.3 b	20.7 b	22.7 a
Orchardgrass 'Benchmark'	12.6 c	15.7 b	19.6 a
Ryegrass 'Manhattan II'	15.3 b	16.0 b	18.8 a
Smooth bromegrass	16.7 c	18.1 b	20.2 a
Tall Fescue 'KY31'	14.0 b	15.0 b	18.1 a
Timothy	15.4 c	17.6 b	20.4 a
ACID DETERGENT FIBER	**- % -**	**- % -**	**- % -**
Kentucky bluegrass	33.0 b	35.3 a	33.9 ab
Orchard 'Benchmark'	35.2 a	35.8 a	31.5 b
Ryegrass 'Manhattan II'	31.5 a	32.5 a	32.3 a
Smooth bromegrass	33.0 a	34.0 a	34.2 a
Tall fescue 'KY31'	32.9 b	35.1 a	33.0 b
Timothy	32.4 b	34.1 ab	35.6 a
NEUTRAL DETERGENT FIBER	**- % -**	**- % -**	**- % -**
Kentucky bluegrass	60.9 a	64.1 a	62.7 a
Orchard 'Benchmark'	65.0 a	63.9 a	61.3 a
Ryegrass 'Manhattan II'	59.6 a	59.2 a	56.4 a
Smooth bromegrass	54.8 b	58.0 a	55.2 ab
Tall fescue 'KY31'	62.1 a	61.8 a	59.8 a
Timothy	58.6 a	60.7 a	58.4 a

* Means followed by the same letter within a row do not differ significantly from each other at the 5 percent level of probability using Tukey's studentized range test.

(*Lolium perenne* L.), and timothy (*Phileum pretense* L.) are recommended for use during tree establishment, under conditions of low density tree arrangements, or with tree species having open canopy structures at maturity. Because of the competitive nature of fescue (*Festuca arundinacea* Schreb.), it is recommended only for well-established stands. Others that demonstrated high shade tolerance, such as smooth bromegrass (*Bromus inermis* Leyss.) are recommended for incorporation into silvopastures containing tree species with more dense canopies or into mature silvopastures (Lin and others 1999). Even with the more shade tolerant forages, yields will be a product of shade levels. Therefore, canopy management through appropriately timed thinnings and prunings is always important.

More recent work within the University of Missouri's Center for Agroforestry has demonstrated that while percent acid detergent fiber (ADF) and neutral detergent fiber (NDF) are either not affected or only slightly increased by shade, overall forage quality for some species is increased (Lin and others 2001, Huck and others 2002). This is in part attributed to shade creating a concentration of nitrogenous compounds in the foliage. In Lin and Huck's work, crude protein was found to increase in shade tolerant forages when grown under light shade. Furthermore, Huck and others (2002) found increased digestibility of some forages when they were grown in partial shade. Grazing trials in Missouri using mixtures of these forages and others have proven successful (Lehmkuhler and others 1999).

Forest Farming

Forested areas also provide opportunities for the production of specialty crops that are sold for ornamental, culinary, or medicinal uses. Forest landowners not interested in livestock grazing may choose to develop enterprises such as the production of food items (mushrooms, maple products), medicinal plants (ginseng, goldenseal (*Hydrastis canadensis* L.)) or even shade-tolerant ornamental plants. Forest farming requires thinning of natural stands to create suitable microenvironments for growing specialty crops such as shade-tolerant botanicals. Specialty crops serve to provide a cash-flow while the released trees (the long-term investment) are growing to a commercial size. The sale of medicinal botanicals (just one of many options available) has reached the 4 billion dollar mark in the United States and represents one of the fastest growing segments of mass marketing (supermarket, drug, and natural food stores—Brun 1999).

For landowners who feel they must have short-term economic justification for placing their stands under management, forest farming provides this justification. By carefully matching a commercially valuable companion crop to the site and microenvironment created, the landowner can realize significantly greater economic gain than is possible from conventional forestry practices alone.

In the hardwood region of the central and eastern United States, forest farming first took on prominence in the northeastern and Appalachian States but more recently has attracted interest in the Corn Belt region. Its popularity is rapidly growing as woodland owners become more aware of the economic aspects of special forest products. Naturally forested areas throughout the hardwood region provide excellent opportunities for the production of specialty crops. Even though currently most forest specialty crop production is passive (i.e., harvested as a wild crop) and does not qualify as agroforestry using the strict definition, the potential for increasing the economic gain through intensive management is rapidly becoming recognized as markets develop for plants common to understories.

Agroforestry and Tree Plantings

Many landowners with underutilized acreage are expressing interest in planting single or multiple rows of trees in agroforestry configurations to provide production and environmental enhancement benefits. Agroforestry provides opportunities through the application of silvopasture, alley cropping, windbreaks, and forested riparian buffer practices.

Properly designed agroforestry practices, regardless of the one chosen, can yield many benefits but their success requires proper selection and active manipulation of the vegetation. While the potential for agroforestry varies by regions, reflecting the diverse landscapes, values, and regional/local economies, the ultimate success of an agroforestry program depends upon the nature of the biological interactions created and the value of the benefits (economic, environmental, etc.) produced.

In agroforestry practices started from planting, selection of the proper tree species is of paramount importance. In addition to being adapted to the site and producing high-value products (i.e., wood, fruit, specialty products etc.), the trees must create suitable microenvironments to accommodate the needs of companion crops while satisfying special needs such as controlling erosion, improving wildlife habitat, or buffering our waterways from excess nutrients and pesticides. While the emphasis on desirable characteristics of hardwood trees used in agroforestry will vary to some degree with management objectives, there is a consensus that certain characteristics are generally desirable. Desirable characteristics might include the production of multiple high-value products (i.e., wood, fruit, specialty products, etc.); generation of light shade; deep-rootedness with minimal surface roots (except where erosion control is a priority); rapidly decomposing foliage; foliage that minimizes acid-generating potential; a lack of allelochemicals; a short growing season; and, good wildlife food and/or habitat production potential. Tree spacing and the most effective design will vary depending on the management practice and purpose of the planting, light requirements of the species used (including companion crops), and even personal preferences of the landowner.

Silvopasture

While silvopasture can serve to get unmanaged native stands under management, it is also a viable option for new plantings. In recently established and young open-grown stands, light is abundant and most grasses and legumes will produce high quality forage for pasture. However, to be successful, a landowner must provide some form of protection for the trees. Placement of a wire cage around each seedling is effective but expensive. An equally effective and more preferred practice uses a single strand of electric wire down both sides of a row of trees. Lehmkuhler and others (2002) found no damage to four hardwood species planted directly into pastures when protected by electric fencing. A landowner might also choose to allow the planted trees to reach a suitable size before pasturing the area, thus saving the cost of protecting the trees.

To avoid the negative effects of grazing cattle, including compaction, rotational rather than continuous grazing is recommended in silvopastures. Lehmkuhler and others (1999), found that 20-year-old black walnut (*Juglans nigra* L.) plantations placed under silvopastoral management, produced adequate quantities of forage to maintain cattle during the spring and early summer months utilizing cool-season grasses and legumes (table 2). Rotationally grazing the plantations, compared with continuous grazing, provided increased forage production and quality, higher calf gains and less soil disturbance without negatively affecting tree growth.

Alley Cropping

Alley cropping is broadly defined as the planting of rows of trees at wide spacings that create alleyways within which agricultural or horticultural crops are grown (Garrett and McGraw 2000). In the Midwest where this practice is most popular, high-value hardwoods are often used to create alleys that support conventional row, forage, or horticultural crops. Within- and between-row spacings vary with the tree and intercrop species planted, management objectives (i.e., emphasis on wood versus fruit production) and even the availability of farming equipment (width of headers, etc.).

Table 2.—*Weekly and overall average total and live forage dry matter (DM) availability from silvopastures in southwest Missouri, USA (Lehmkuhler and others 1999)*

Week	Total DM (lb acre^{-1})			Live DM (lb acre^{-1})		
	Continuous	Rotation	SEM	Continuous	Rotation	SEM
1	1,668[a]	2,581[b]	160	1,632[a]	2,513[b]	149
2	1,042	1,398	160	1,026	1,386	149
3	933	1,491	160	796	1,341	149
4	424	760	160	279	533	149
5	513	808	160	246	505	149
6	598	614	160	218	376	149
7	217	363	160	93	190	149
8	125	469	160	24	355	149
Overall mean	698[a]	1,060[b]	56	539[a]	900[b]	53

[a,b] Treatment means within a row with unlike superscripts differ significantly ($P < 0.05$).

While few reports are available on the effects of the open conditions in alley cropping on tree growth and wood quality, those available are favorable. Cutter and Garrett (1993) found that height, diameter, and specific gravity were equal to or better for alley-cropped walnut trees than for trees grown under woodlot conditions. Furthermore, based upon early growth of alley-cropped walnuts, 50- to 60-year veneer and saw log rotations were projected compared with more standard 80- to 100-year rotations for more conventionally grown trees of higher density (Garrett and others 1995). Assuming equal quality, the shorter the rotation, the greater the return on the investment. Although published information is limited, that which is currently available suggests that if properly managed, the quality of hardwood trees grown under alley-cropping, will not vary significantly from that of forest-grown trees but the time required to grow them to a marketable size will be greatly reduced. Greater management (i.e., pruning, etc.), however, is required to guarantee high quality logs with alley-cropped trees than with trees grown at higher densities.

Various economic analyses have been conducted on walnut alley cropping in Missouri (Garrett and others 1994; Kurtz and others 1984, 1996). Depending upon the combination of crops studied, internal rates of return (IRR) for walnut alley cropping have been found to range from 4 to 11 percent. In general, returns tend to increase with management complexity and site quality. However, obvious factors such as market value of crops grown, cash-flow relationships and even risk taking, influence profitability. With black walnut, early returns from planted intercrops coupled with nut production revenue are very important factors in creating high financial yields (Garrett and Harper 1999, Kurtz and others 1996). Because of this and the uncertainty of good nut production resulting from wild, genetically unknown walnut seedlings (Garrett and others 1995, Jones and others 1994), the planting of grafted walnut cultivars with known genetic histories is strongly encouraged. Similarly, if individuals are interested in using pecan (*Carya illinoensis* (Wanyenh.) K. Koch), Chinese chestnut (*Castanea mollissima* Bl.) or some other nut or fruit-bearing species in alley cropping or other agroforestry practices, they should give serious consideration to using reliable grafted selections.

Windbreaks

Windbreaks are of noted importance in the Plains States for protecting and enhancing production of crops (Brandle and others 1988). However, with our increased knowledge of their value, has come increased adoption and use in other areas of the Central Hardwood region. When properly designed, woody/herbaceous windbreaks can be used to protect soil, conserve moisture and improve crop and animal production. They also provide benefits to wildlife by protecting them from wind and adverse weather, and provide escape or refuge cover, food and foraging sites, reproductive habitat and travel areas (Pierce and others in press, Johnson and others 1993).

Windbreaks also provide diversity that supports natural enemies of crop pests and are finding increased use around animal confinements for odor regulation. Twenty-year-old windbreaks in which trees and shrubs occupied only 6 percent of the land unit have been shown to provide adequate crop protection in Nebraska (Brandle and others 1988). Increases in yields from windbreaks vary with the crop and year (weather). However, increases in winter wheat will typically be in the 20+ percent range and some crops like millet (*Tennisetum glaucum* L.) may yield 40 or more percent higher behind windbreaks than in the open (table 3, Brandle and others 2000).

Windbreaks can also be beneficial for livestock in the more northern areas of the Central Hardwood region. Properly positioned hardwoods or conifers combined with hardwoods can provide much needed protection for pastures, feedlots, and calving areas. Reducing wind speed lowers animal stress, improves animal health, and increases feeding efficiency of livestock (Brandle and others 2000). Canadian researchers have demonstrated that cattle on winter range require an additional 20 percent increase in feed energy, above maintenance, to

Table 3.—*Crop response to shelter (Brandle and others 2000)*

Crop	Number of field years	Weighted mean yield increase
	- no. -	- % -
Winter wheat	131	23
Barley	30	25
Oat	48	6
Millet	18	44
Corn	209	12
Soybean	17	15

offset the direct effects of exposure to a combination of cold temperatures and wind. Adequate wind protection has been found to reduce the direct effects of cold by more than half (Webster 1970). Similar findings have been reported for other animals such as dairy cows and sheep (Brandle and others 2000).

While some negative effects of windbreaks exist, most can be mitigated through proper species selection, corridor design, and management. Effects perceived as being negative by landowners include a reduction in available land for planting, the potential for increased wind turbulence, competition for soil moisture and nutrients, allelopathy, and shading. All of these potentially negative effects occur in immediate proximity to the woody windbreak and are manageable.

The economic benefits of windbreaks are quite variable and location specific due to the indirect nature of windbreak contributions. While numerous studies have been published describing the specific gains in increased crop and livestock yields, few financial evaluations of the costs associated with generating the gains are available. However, a detailed examination of the financial aspects of several field windbreak practices over a range of crops, yields, prices, discount rates, and windbreak establishment costs has been conducted for eastern Nebraska. Three practices utilizing windbreaks at spacings of 635, 420, and 218 feet were evaluated in fields planted to soybeans, corn, or winter wheat. All three designs were found to yield positive net benefits over an estimated 50-year life span. The lowest return was from the widest spacing, although a positive present net worth (PNW) at an 11 percent discount rate was still realized. Positive PNW's were yielded by the other designs at discount rates as high as 17 percent (Brandle and others 1992). Similarly, positive economic returns have been reported for windbreaks designed to protect animals (Quam and others 1994).

Forested Riparian Buffers

An agroforestry practice of enormous potential in the Central Hardwood region and in need of immediate broadscale adoption is the forested riparian buffer. This practice typically consists of a combination of herbaceous and woody species established on stream and river banks and is designed to help control water quality, flow regime, physical habitat, and energy inputs in streams, while producing wood and other products of commercial value.

Agriculture-derived contaminants such as sediment, nutrients, and pesticides, constitute the largest diffuse source of water-quality degradation in the Central Hardwood region. Surface runoff and subsurface flow from pastures, crop fields, and animal confinements can cause significant nutrient loading to downslope water sources unless appropriate management techniques are applied. Bioassimilative strategies using properly designed forested riparian buffers are often advocated. Research has demonstrated that inclusion of trees and shrubs with grasses can be an effective tool in countering water pollution problems especially when they are established along smaller headwater streams (Osborne and Wiley 1988).

Woody/herbaceous riparian buffers function as bioassimilative transformers, changing the chemical composition of compounds (Lowrance 1992, Lin and others 2002). Under oxygenated soil conditions, resident bacteria and fungi mineralize runoff-derived nitrogen and other compounds that are then available for uptake by soil bacteria and plants. In addition, greater infiltration of contaminant-transporting water occurs within the forested riparian strip than in cultivated fields and pastures (Schultz and others 2000). Planting or retaining forested riparian buffers are effective and economically feasible procedures for reducing chemical contaminants. Established forested riparian buffers 90- to 150-feet in width have been shown to reduce nitrogen in ground water by 68- to 100-percent and in surface runoff by 78- to 98-percent. Buffers 50- to 150-feet wide reduce phosphorus concentrations in surface waters by 50- to 85-percent (Osborne and Wiley 1988).

Sediment loading of streams can also be a problem but is even easier to address with forest/grass buffers than is nutrient loading. Narrow buffers—30- to 90-feet wide—that augment shallow sheet flows provide excellent protection from sediments entering streams (Osborne and Kovacic 1993). While stiff, dense grass is an important component of the buffer to drop-out sediment contained in runoff, the woody component is necessary to stabilize streambanks. Sloughing streambanks are one of the greatest sources for sediment found in our streams (Erman and others 1977).

Narrow wooded buffers have also been shown to have a significant effect on reducing solar radiation inputs and effectively moderating stream water temperatures. Feller (1981) demonstrated that 30- to 90-feet wide buffers improved habitat for many aquatic insects via reduced stream water temperature, higher dissolved oxygen and reduced denitrification rates. Partial shade is required when attempting to maximize both the overall ecological health of the riparian environment and control specific submerged and emergent aquatic plants.

Little information exists related to the time required, or the specific composition of forest riparian buffers needed, to restore farm streams to their former undegraded condition. However, the requirement and time may be less than previously thought. In 1985, a woody riparian buffer was established in southern Ontario using hardwood species common to the Central Hardwood region including cottonwood (*Populus deltoides* Bartr.) and river birch (*Betula nigra* L.). A 1.2-mile section of a small degraded stream was planted on both sides with 6,500 trees. After only 4 years, the plantings averaged 8 dried tons of biomass per acre and radiation loading to the middle of the stream was reduced by almost 40 percent (Gordon and others 1992).

In recent work within the Center for Agroforestry at the University of Missouri, Udawatta and others (in press), found that after only 3 years grass buffers planted with single rows of oak (*Quercus* spp.) and integrated into an upland site, reduced total phosphorus in runoff by 17 percent based on calibration relationships. In view of the miles of unprotected stream and river banks in the Central Hardwood region—the states of Illinois, Indiana, Iowa, Missouri, and Ohio have 85,000 miles (Garrett and others 1994)—there are many opportunities for planting of hardwoods for both environmental and economic benefits. Economic gain from riparian buffers varies with design. Revenues are associated with marketable products such as forage, fiber, specialty crops, and timber produced within the buffer (Schultz and others 2000).

CONCLUDING REMARKS

Never in history has global concern for the consequences of human land use been more widely shared. Soil erosion adds to food, energy, and transportation costs and threatens future food production capacity. Nonpoint source pollution from forest and agricultural lands restricts access to safe water. Loss of vegetation from land development and site degradation affects our aesthetic environment, global climate patterns, and the quality of the air we breathe. Such problems are often the legacy of our success in maximizing production of one or more agricultural products in a financially optimal fashion without sufficient knowledge of, or regard for, impacts on future productivity and the environment. This was a rational economic choice when long-term consequences were unknown, when resources appeared to be relatively unlimited, and when technology promised means for further intensifying production.

Now that we are discovering undesirable longer-term consequences of current land-use systems, alternatives must be sought. One alternative is to model managed ecosystems after the structure and functions of naturally occurring ecosystems by re-establishing complexity in time, space, and biodiversity. This would lead to a shift away from separating land uses on discrete parcels to integrating them on a landscape level. Agroforestry, which exploits the interactions between trees and crops (including livestock) when they are grown together, bridges the gap between production agriculture and natural resource management. This provides opportunities to integrate land uses on a landscape level. Furthermore, properly designed agroforestry practices provide environmentally and economically sound alternatives to many unsustainable production systems in use today.

Agroforestry seeks to optimize production of multiple products and benefits by manipulating the interactions between components. It requires shifting our thinking in both spatial and temporal domains, and demands skills in managing, rather than reducing complexity. Traditional disciplinary approaches to problem-solving are no longer sufficient. Agroforestry challenges land managers to transcend disciplinary boundaries and explore the potential synergism between production agriculture and natural resource management. Essential to this is an understanding of hierarchical scalar relationships within ecosystems and recognition that defined ecosystem “boundaries” exist primarily for managerial convenience.

Two decades of observational data and applied research suggest that agroforestry should be vigorously explored as a possible component of improved land-use strategies in the Central Hardwood region and throughout the United States. Current interest in ecosystem management strongly suggests that we should embrace the complexity inherent to agroforestry and apply agroforestry principles, where appropriate, to better meet our current and future needs for the products and services of the land.

ACKNOWLEDGMENT

The US Environmental Protection Agency and the USDA Agricultural Research Service, Dale Bumpers Small Farms Research Center, Booneville, AR, funded this work. The results presented are the sole responsibility of the Principal Investigator and may not represent the policies or positions of the funding agencies.

LITERATURE CITED

Brandle, J.R.; Hintz, D.L.; Sturrock, J.W., eds. 1988. Windbreak technology. Amsterdam: Elsevier Science Publishers. 598 p.

Brandle, J.R.; Hodges, L.; Wight, B. 2000. Windbreak practices. In: Garrett, H.E.; Rietveld, W.J.; Fisher, R.F., eds. North American agroforesty: an integrated science and practice. Madison, WI: American Society of Agronomy, Inc.: 79-118.

Brandle, J.R.; Johnson, B.B.; Akeson, T. 1992. Field windbreaks: are they economical? Journal of Production Agriculture. 5: 393-398.

Brun, C. 1999. Growth of medicinal herb industry in the Pacific Northwest. In: Proceedings, 2nd National small farm conference. Sedalia, MO: Interstate Printing: 155.

Clason, T.R.; Sharrow, S.H. 2000. Silvopastoral practices. In: Garrett, H.E.; Rietveld, W.J.; Fisher, R.F., eds. North American agroforesty: an integrated science and practice. Madison, WI: American Society of Agronomy, Inc.: 119-147.

Cutter, B.E.; Garrett, H.E. 1993. Wood quality in alleycropped eastern black walnut. Agroforestry Systems. 22: 25-32.

Erman, D.C.; Newbold, J.D.; Roby, K.B. 1977. Evaluation of streamside buffer strips for protecting aquatic organisms. California Water Resour. Center Tech. Rep. Davis, CA: University of California.

Feller, M.C. 1981. Effects of clear-cutting and slash-burning on stream temperature in southwestern British Columbia. Water Resources Bulletin. 17: 863-867.

Garrett, H.E. 1995. Temperate-zone agroforestry opportunities for the 21st century and beyond. In: Ehrenreich, J.H.; Ehrenreich, D.L.; Lee, H.W., eds. Proceedings, 4th North American agroforestry conference. Moscow, ID: University of Idaho: 3-4.

Garrett, H.E.; Buck, L.E.; Gold, M.A.; Hardesty, L.H.; Kurtz, W.B.; Lassoie, J.P.; Pearson, H.A.; Slusher, J.P. 1994. Agroforestry: an integrated land-use management system for production and farmland conservation. Resource Conservation Act (RCA) Appraisal Document. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 58 p.

Garrett, H.E.; Harper, L.S. 1999. The science and practice of black walnut agroforestry in Missouri, USA: a temperate zone assessment. In: Buck, L.E.; Lassoie, J.P.; Fernandes, E.C.M., eds. Agroforestry in sustainable agriculture systems. New York, NY: CRC Press: 97-110.

Garrett, H.E.; Loewenstein, E.F.; Jones, J.E.; Rink, G. 1995. The importance of selection gain in walnut agroforestry management. In: Edwards, M.B., ed. Proceedings, 8th Biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 364.

Garrett, H.E.; McGraw, R.L. 2000. Alley cropping. In: Garrett, H.E.; Rietveld, W.J.; Fisher, R.F., eds. North American agroforesty: an integrated science and practice. Madison, WI: American Society of Agronomy, Inc.: 149-188.

Gold, M.A.; Rietveld, W.J.; Garrett, H.E.; Fisher, R.F. 2000. Agroforestry concepts and nomenclature in the United States. In: Garrett, H.E.; Rietveld, W.J.; Fisher, R.F., eds. North American agroforesty: an integrated science and practice. Madison, WI: American Society of Agronomy, Inc.: 63-77.

Gordon, A.; Williams, P.; Kaushik, N.K. 1992. Advances in agroforestry: crops, livestock and fish have it made in the shade. Highlights of Agricultural and Food Research in Ontario. 15(3): 2-7.

Huck, M.B.; Kerley, M.S.; Garrett, H.E.; McGraw, R.L.; Van Sambeek, J.W.; Navarrete-Tindall, N.E. 2002. Effects of shade on forage quality. In: Schroeder, W.; Kort, J., eds. Temporate agroforestry: adapive and mitigative roles in a changing physical and socio-economic climate, proceedings of the 7th biennial conference on agroforestry in North America: 6th annual conference of the Plains and Prairie Forestry Association; 2001 August 12-15; Regina, Saskatchewan, Canada. [City, Province of publisher unknown: Association for Temperate Agroforestry: 125-134.

Johnson, R.J.; Brandle, J.R.; Fitzmaurice, R.L.; Poague, K.L. 1993. Vertebrates for biological control of insects in agroforestry systems, symposium on biological control of forest pests in the Great Plains: status and Needs. Publ. 145. Fargo, ND: Great Plains Agriculture Council: 77-84.

Jones, J.E.; Haines, J.; Garrett, H.E.; Loewenstein, E.F. 1994. Genetic selection and fertilization provide increased nut production under walnut-agroforestry management. In: Schultz, R.C.; Colletti, J.P., eds. Proceedings, 3rd North American agroforestry conference. Ames, IA: Iowa State University: 39-42.

Kurtz, W.B.; Garrett, H.E.; Kincaid, W.H. 1984. Investment alternatives in black walnut plantation management. Journal of Forestry. 82(10): 604-608.

Kurtz, W.B.; Garrett, H.E.; Slusher, J.P.; Osburn, D.B. 1996. Economics of agroforestry. MU Guide G5021. Columbia, MO: University of Missouri Extension. 2 p.

Lehmkuhler, J.W.; Felton, E.E.D.; Schmidt, D.A.; Bader, K.J.; Moore, A.; Huck, M.B.; Garrett, H.E.; Kerley, M.S. 2002. Grazing during the establishment period: methods of tree protection and impact of grazing on tree and animal performance. In: Schroeder, W.; Kort, J., eds. Temporate agroforestry: adapive and mitigative roles in a changing physical and socio-economic climate, proceedings of the 7th biennial conference on agroforestry in North America: 6th annual conference of the Plains and Prairie Forestry Association; 2001 August 12-15; Regina, Saskatchewan, Canada. [City, Province of publisher unknown: Association for Temperate Agroforestry: 135-143.

Lehmkuhler, J.W.; Kerley, M.S.; Garrett, H.E.; Cutter, B.E.; McGraw, R.L. 1999. Comparison of continuous and rotational silvopastoral systems for established walnut plantations in southwest Missouri, USA. Agroforestry Systems. 2-3: 267-279.

Lin, C.H.; Lerch, R.N.; Garrett, H.E.; George, M.F. 2002. Incorporation of selected forage grasses in riparian buffers designed for the bioremediation of Atrazine, balance (isoxaflutole) and nitrate. In: Schroeder, W.; Kort, J., eds. Temporate agroforestry: adapive and mitigative roles in a changing physical and socio-economic climate, proceedings of the 7th biennial conference on agroforestry in North America: 6th annual conference of the Plains and Prairie Forestry Association; 2001 August 12-15; Regina, Saskatchewan, Canada. [City, Province of publisher unknown: Association for Temperate Agroforestry: 256-265.

Lin, C.H.; McGraw, R.L.; George, M.F.; Garrett, H.E. 1999. Shade effects on forage crops with potential in temperate agroforestry practices. Agroforestry Systems. 44: 109-119.

Lin, C.H.; McGraw, R.L.; George, M.F.; Garrett, H.E. 2001. Nutritive quality and morphological development under partial shade of some forage species with agroforestry potential. Agroforestry Systems. 53: 1-13.

Lowrance, R.R. 1992. Groundwater nitrate and denitrification in a coastal plain riparian forest. Journal of Environmental Quality. 21: 401-405.

Merwin, M.L. 1997. The status, opportunities and needs for agroforestry in the United States: a national report. Association for Temperate Agroforestry. Columbia, MO: University of Missouri, Center for Agroforestry. 41 p.

Noweg, T.A.; Kurtz, W.B. 1987. Eastern black walnut plantations: an economically viable option for Conservation Reserve lands within the Corn Belt. Northern Journal of Applied Forestry. 4: 158-160.

Osborne, L.L.; Kovacic, D.A. 1993. Riparian vegetated buffer strips in water quality restoration and stream management. Freshwater Biology. 29: 243-258.

Osborne, L.L.; Wiley, M.J. 1988. Empirical relationships between land use/cover and stream water quality in an agricultural watershed. Journal of Environmental Management. 26: 9-27.

Pierce, R.A.; Ferrand, D.T.; Kurtz, W.B. 2003. Projecting the bird community response resulting from the adoption of shelterbelt agroforestry practices in eastern Nebraska. Agroforestry Systems. 53: 333-350.

Powell, D.S.; Faulkner, J.L.; Darr, D.R.; Zhu, Z.; MacCleery, D. 1992. Forest resources of the United States. Gen. Tech. Rep. RM-234. Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Quam, V.C.; Johnson, L.; Wight, B.; Brandle, J.R. 1994. Windbreaks for livestock production. EC 94-1766-X. Lincoln, NE: University of Nebraska, Cooperative Extension.

Schultz, R.C.; Colletti, J.P.; Isenhart, T.M.; Marquez, C.O.; Simkins, W.W.; Ball, C.J. 2000. Riparian forest buffer practices. In: Garrett, H.E.; Rietveld, W.J.; Fisher, R.F., eds. North American agroforestry: an integrated science and practice. Madison, WI: American Society of Agronomy, Inc.: 189-281.

Sharrow, S.H. 1999. Silvopastoralism: competition and facilitation between trees, livestock and improved grass-clover pastures on temperate rainfed lands. In: Buck, L.E.; Lassoie, J.P.; Fernandes, E.C.M., eds. Agroforestry in sustainable agricultural systems. New York, NY: CRC Press: 111-130.

Udawatta, R.P.; Krstansky, J.J.; Henderson, G.S.; Garrett, H.E. 2002. Agroforestry practices, runoff, and nutrient loss: a paired watershed comparison. Journal of Environmental Quality. 31: 1214-1225.

USDA. 1994. Census data. Washington, DC: USDA Census Bureau, Heritage Foundation.

Webster, A.J.F. 1970. Direct effects of cold weather on the energetic efficiency of beef production in different regions of Canada. Canadian Journal of Animal Science. 50: 563-573.

Wiedenbeck, J.K.; Araman, P.A. 1993. Possible demands for eastern hardwoods resulting from harvest restrictions in the Pacific Northwest. Forest Products Journal. 43: 51-57.