Bentrup, G. and T. Kellerman. 2003. **Agroforestry and GIS: achieving land productivity and environmental protection.** In: *Proc. of the 8th North American Agroforestry Conference*. 23-25 June 2003. Corvallis, OR. pp. 15-25.

Agroforestry and GIS: Achieving Land Productivity and Environmental Protection

Gary Bentrup*
Todd Kellerman

USDA National Agroforestry Center
East Campus – UNL
Lincoln, NE, USA 68583-0822
**Corresponding Author: gbentrup@fs.fed.us*

ABSTRACT

Agroforestry, the deliberate integration of trees into crop and livestock operations, has the potential to achieve many of the environmental, economic, and social objectives being demanded from working landscapes by landowners and society. To simultaneously address these diverse landowner and societal goals, a multi-scale planning process must be utilized. This planning process can be expedited using a geographic information system (GIS), a collection of computer hardware and software used to analyze and display geographically referenced information. Data layers like soil type, slope, and land cover can be used to identify suitable locations for agroforestry practices that address community issues, such as water quality and wildlife habitat. These same data layers can be used to identify promising locations for growing agroforestry specialty products that can be harvested and marketed for a variety of uses. By combining these suitability assessments, locations where multiple objectives might be achieved can be determined. A case study from the Western Corn Belt Ecoregion illustrates the role of GIS in helping to address and balance land productivity and environmental protection goals.

Keyword: Geographic information systems (GIS), Agroforestry, Planning, Suitability assessment

Introduction

Agroforestry is the intentional combination of agriculture and forestry technologies to create integrated, diverse, productive, profitable, and sustainable land-use systems (Rietveld 1995). Examples of agroforestry practices that are focused on meeting the environmental, social, and economic needs of people on private lands include alley cropping, forest farming, riparian forest buffers, silvopasture, and windbreaks. Environmentally, agroforestry practices can reduce erosion, improve water infiltration and quality, moderate microclimates, enhance nutrient cycling, and provide wildlife habitat (Sanchez 1995). Socially, communities may be revitalized through partnerships that implement publicly owned agroforestry projects like community shelterbelts or ecobelts (Josiah et al. 1999, Bentrup et al. 2001). Lal (2000) recently cited agroforestry as one of the future technological innovations that will be needed to meet the food demands for the global increase in population.

Economically, agroforestry practices can reduce production costs by lowering the need for chemical, water, energy, and/or labor inputs while increasing overall agricultural output (Lassoie and Buck 2000, Olson et al. 2000). Another financial benefit for landowners is the potential to grow and sell specialty products like ginseng, mushrooms, and black walnut for lumber, nuts, and hulls (Rietveld and Francis 2000). Through careful management, agroforestry systems can be harvested sustainably for products including edible foods like berries and nuts, medicinal products like goldenseal and ginkgo, and horticultural materials like evergreens for floral wreaths, Christmas trees, or colorful woody stems (Hill and Buck 2000). When these agroforestry species or products are combined, a synergistic system can be created that maximizes landowner benefits, while providing environmental services to all.

Achieving Multiple Goals with GIS-guided Planning

The goals and objectives that agroforestry systems can achieve partially depend on the spatial scale at which they are planned and designed. Landowner goals, like minimizing soil erosion and providing crop production, can often be accomplished by just focusing on the site conditions within the property boundaries. However, a larger scale perspective is often required for community-driven goals, like water quality and wildlife habitat. For instance, water quality issues need to be studied and addressed at a landscape or watershed level to determine spatial distribution of pollutant sources, hydrological pathways, and opportunities and constraints for best management practices. To integrate these different concerns and goals within agroforestry systems, a multi-scale planning process needs to be used (Rietveld and Francis 2000).

Use of geographic information systems (GIS), a collection of computer hardware and software used to analyze and display geographically referenced information, can facilitate this planning process. Spatial data layers like soil type, slope, and land cover can be used to develop suitability assessments that can identify optimal locations for agroforestry practices to solve landowner and community concerns. A simple overview of the GIS-guided suitability assessment process is illustrated in Figure 1. By selecting data with the appropriate spatial resolution, this assessment process can be used at any scale for planning agroforestry practices. The most significant benefit of using GIS-guided suitability assessments is the ability to combine different assessments to determine locations where multiple objectives can be achieved.

Suitability assessments have been used for several decades to identify locations for different land uses such as landfills, wildlife reserves, and residential development (McHarg 1995). Some of the first examples of suitability assessments in the United States were prepared by the Natural Resources Conservation Service (previously the Soil Conservation Service), which ranked soil types based on suitability for different engineering and agricultural functions (Soil Survey 1993). Although GIS and the suitability process has been used for many environmental protection applications, this technology has yet to be used extensively in agroforestry (Ellis et al. 2000, Bentrup and Leininger 2002).

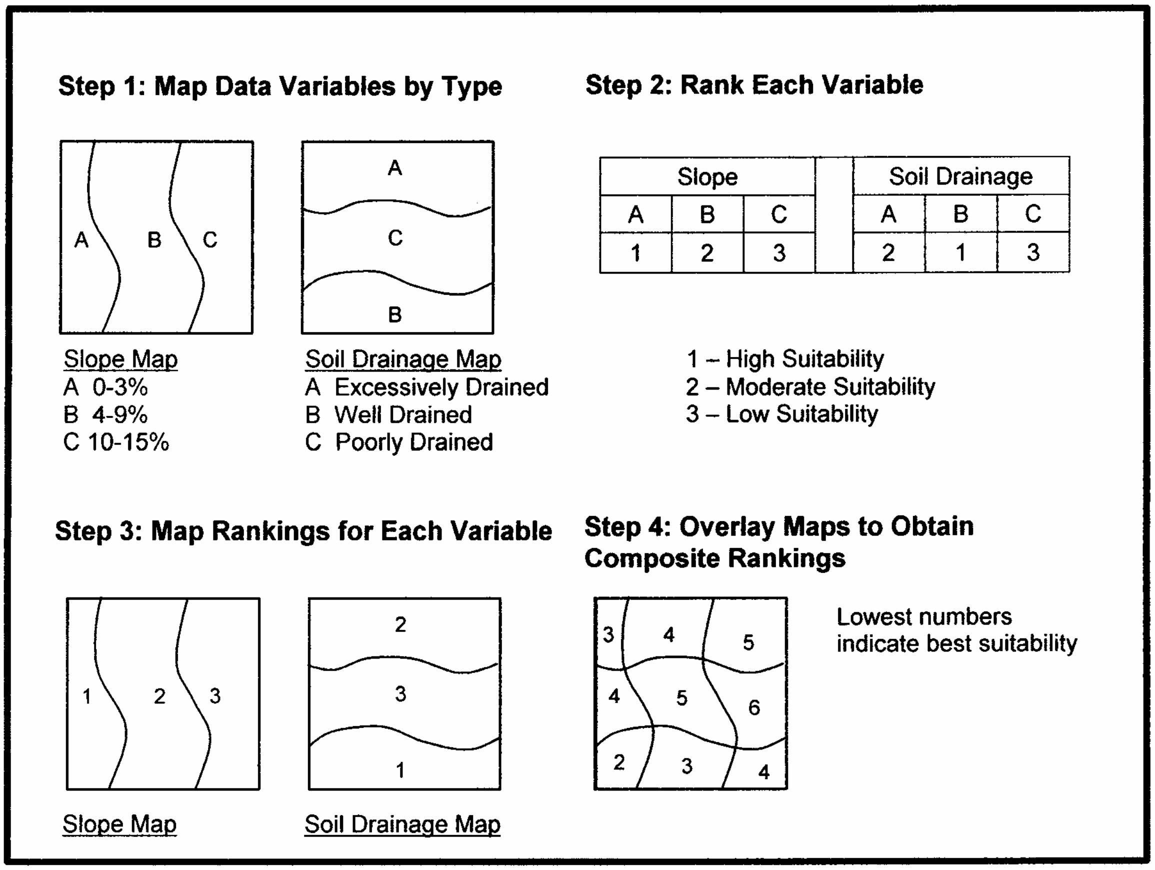

Figure 1. A diagram illustrating the suitability assessment process (Adapted from Steiner 1991).

Using GIS in agroforestry applications

To illustrate the potential of using GIS in agroforestry applications, a case study example is provided from the Midwest region of the United States. The study was conducted in the Nemaha Natural Resource District (NRD) in southeast Nebraska, a 7200 km^2 region located within the Western Corn Belt Ecoregion (WCBE)(Figure 2). Once covered with a mosaic of tallgrass, prairie, and riparian woodlands, over 90% of the ecoregion is now used for cropland and the remainder is in forage for livestock. A combination of nearly level to gently rolling glaciated till plains and hilly loess plains, ample precipitation, and warm, fertile soils make this one of the most productive areas of corn and soybeans in the world. The intensive cropping in this area has resulted in a highly fragmented riparian corridor system with remnant patches of riparian vegetation being separated by areas cropped to the edge of the stream bank. Project goals were to identify locations for agroforestry buffers to improve riparian connectivity for wildlife movement while providing a marketable product that could be harvested sustainably from the buffer, in this case, woody species used in the decorative floral industry.

Woody Floral Suitability

Willow and dogwood species, like curly willow (*Salix matsudana* "Tortuosa") known for its curly stems, the French pussy willow (*Salix caprea*) with red stems and flowers, the black pussy willow (*Salix melanostachys*) with black flowers, and the yellowtwig dogwood (*Cornus sericea* "Yellowtwig") with bright yellow stems, are some of the woody species used in the decorative floral industry (Dirr 1983, Yoder and Moser 1993). The demand for these unique stems and flowers in floral arrangements, wreaths, and baskets has been increasing and estimates suggest that floral products grown in agroforestry buffers can offer potential annual net returns of up to $13,590 per ha (Miller et al. 1994). The use of woody florals within riparian buffers will often be restricted to a single row, allowing other native species to be integrated in the buffer for wildlife value. Even as a limited component in a riparian buffer, the woody florals can offer potentially significant economic returns for innovative landowners in a short production timeframe. Recent work by Josiah and Skelton (2003) in southeast Nebraska on woody florals has shown potential annual net returns ranging from $400-$3500 per 333 m at a 1.2-1.9 m plant spacing.

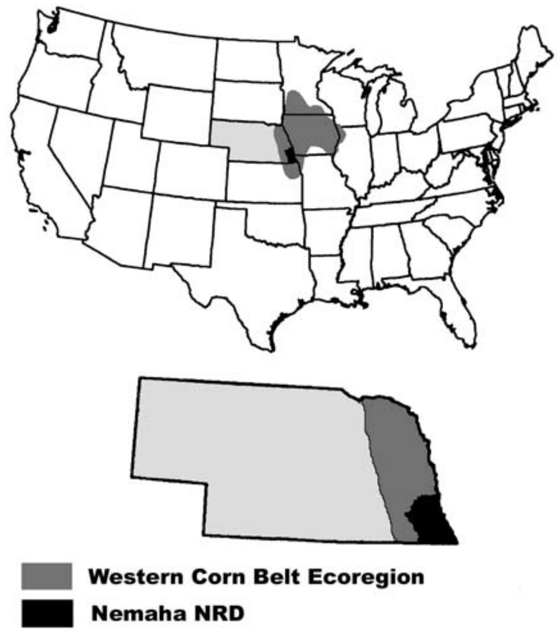

Figure 2. Study area within the Western Corn Belt Ecoregion.

Woody floral species are tolerant to most soil and climate conditions found in the study area but do require the presence of seasonally flooded or moist soils (Dirr 1983). Although these species can be grown on dry soils with irrigation, the assessment focused on areas requiring no irrigation. Using the Natural Resources Conservation Service's (NRCS) State Soil Geographic Soil Database (STATSGO), the assessment was based on selecting soils that have an occasional to high frequency of annual flooding or that have shallow water tables ($\leq$ 1.8 m). To refine the assessment, land use/cover data from the United States Geologic Survey (USGS) National Land Cover Characterization Dataset, a 21-division land cover classification scheme derived from Landsat Thematic Mapper satellite data (30 m resolution) taken during the early 1990's, was incorporated into the analysis. Land uses like commercial, industrial, and residential areas were considered unfavorable due to having been developed while agricultural lands were rated suitable because they could easily be converted to woody floral production. Where suitable land uses coincided with the required soils, these areas were considered favorable for cultivation of woody florals (Figure 3).

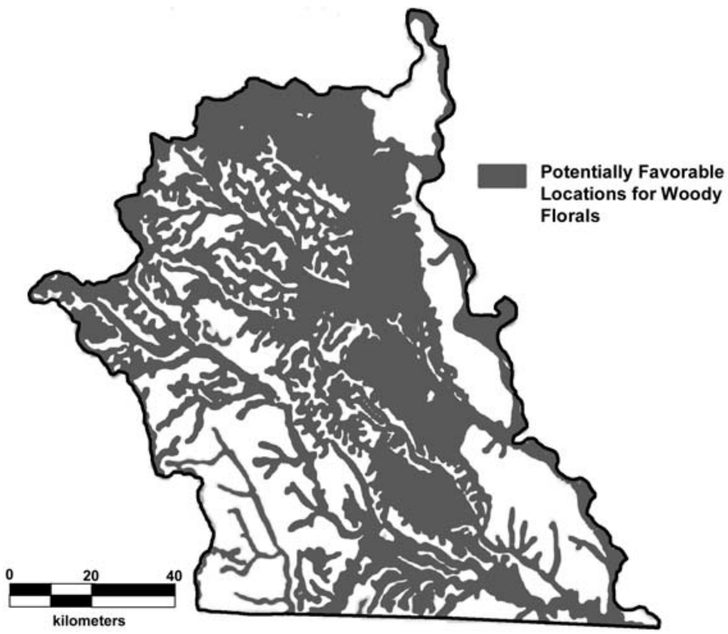

Figure 3. A landscape-scale assessment illustrating potentially suitable areas for growing woody florals in the Nemaha NRD.

Riparian Connectivity

Research suggests that the most effective approach to riparian restoration for aquatic and terrestrial wildlife is to protect the remaining habitat areas and to restore structural connectivity in the gaps between these remnant areas (Niemi et al. 1990). By reestablishing riparian vegetation in these gaps, restoration can be accelerated through enhanced dispersal and colonization of faunal species (Frissell 1997). Using this strategy, an individual wildlife species can be used to identify significant riparian remnants and serve as an indicator of connectivity. The remnant patches must be large enough to maintain a stable core population while being close enough to other patches to allow exchange of individuals. This approach has been used in other landscape settings (Brooker et al. 1999).

We selected the meadow jumping mouse (*Zapus hudsonius*) as our indicator species because this species: (1) is found in the mixed riparian communities in the ecoregion; (2) does not utilize cropland habitats; (3) has relatively low dispersal capability, providing a conservative estimate of connectivity; and (4) is documented to use riparian corridors for dispersal (Baker 1983, Choate et al. 1991). In addition, the species is non-controversial with the agricultural community since it does not cause crop damage (NatureServe 2003). Empirical research suggests that this species requires riparian patches that are a minimum of 1.5 ha in size and has the capability of dispersing 0.4 km (Quimby 1951, Baker 1983). If connectivity is achieved for the mouse, it is assumed that connectivity will be achieved for species with similar or greater dispersal capabilities.

Data from the USGS digital line graphs (DLG) provided the stream network while the USGS National Land Characterization Dataset was used to determine riparian vegetation remnants along the streams in the study area. Land cover was clipped out along the streams in the Nemaha NRD using variable width buffers based on Horton-Strahler stream orders (Horton 1945, Strahler 1957). Higher order streams had a wider buffer since they typically have a more extensive floodplain and larger spatial extent of riparian vegetation (Dunne and Leopold 1978). Although riparian corridors are not a fixed width, this method allows for a straightforward, approximate delineation of the riparian corridor for the connectivity analysis. Pre-settlement riparian vegetation in this ecoregion was a mosaic of vegetation types including woodland, wetland, and grassland communities (Robertson et al. 1997). Within the clipped land cover, we regrouped these vegetation communities into a single classification called "riparian vegetation" while other cover types were classified as "non-riparian".

Since the meadow jumping mouse has been documented to require a minimum patch size of 1.5 ha, riparian remnants smaller than 1.5 ha were not considered in the analysis. Each riparian remnant that was equal to or larger than 1.5 ha in size was buffered by ½ the species dispersal distance (0.2 km). Where the dispersal distances touch or overlap, the gap between the remnants is theoretically close enough for successful movement between the riparian remnants for the meadow jumping mouse and is delineated as a connectivity zone (Figure 4). Areas that exceed the connectivity threshold are delineated as "critical gaps" that would benefit from being reconnected with riparian buffers.

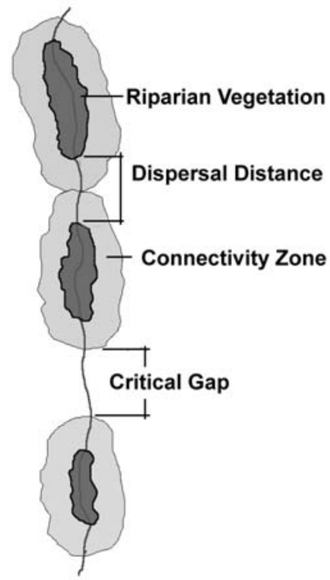

Figure 4. The riparian connectivity concept based on dispersal distance and remnant riparian patches.

Results

By combining the results from the riparian connectivity and agroforestry product assessments, areas were identified where riparian buffers could be located to improve habitat connectivity while offering landowners the option to grow woody florals for profit (Figure 5). This integrated assessment provides a starting point for natural resource managers to begin to develop a more strategic landscape plan and to determine where greater effort may need to be allocated. It should be noted that species used in the riparian buffer should not be invasive. Since willows are dioecious, planting only the male plants (which are the ones with the most showy flowers) can ensure the introduced species do not spread by seed and out compete native species in the riparian corridor.

Additional concerns, such as water and soil quality issues can also be addressed by GIS-guided suitability assessments and overlaid on this integrated assessment, further enhancing the ability of these systems to meet multiple goals. GIS-guided suitability assessments can also be used for finer scale planning by incorporating data with higher spatial resolution. For instance, the woody floral assessment could be completed for a county by using the NRCS Soil Survey Geographic Database (SSURGO) mapped at 1:24,000 scale in place of the STATSGO database mapped at 1:250,000 scale.

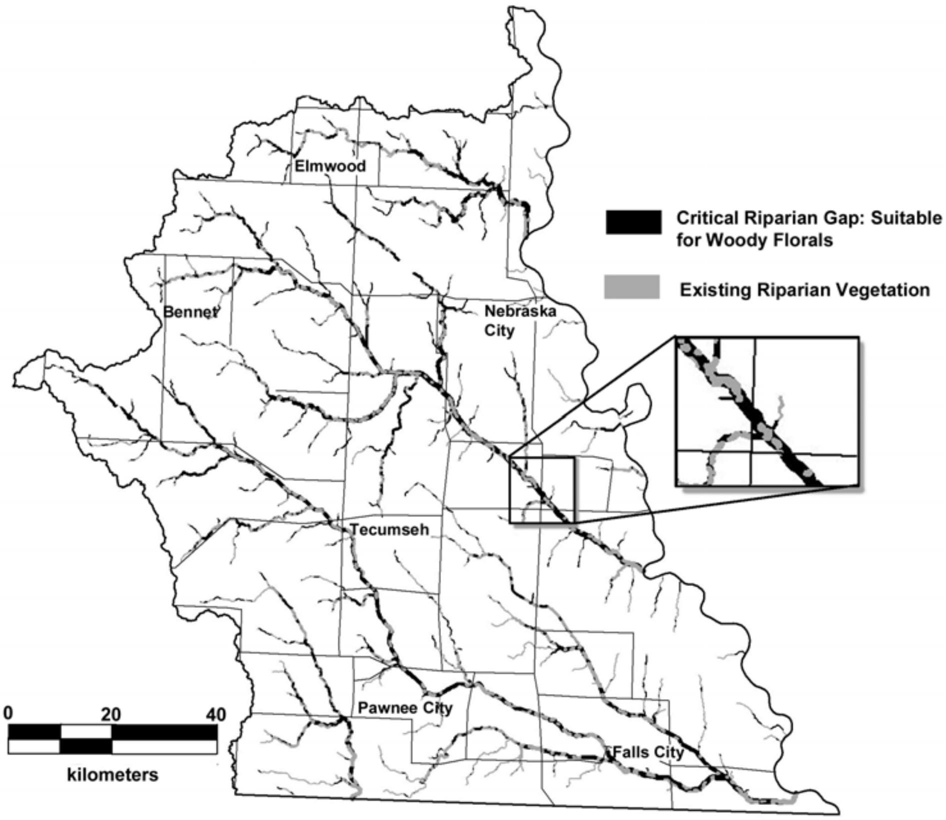

Figure 5. A landscape assessment indicating critical gaps in riparian corridors that could be restored with a mixture of native riparian species and woody florals.

Conclusions

For agroforestry to achieve its full potential in the United States, it must simultaneously satisfy a range of environmental, social, and economic goals. Depending upon the scale of analysis, GIS-based assessments can serve a variety of uses in the promotion, adoption, planning, and design of agroforestry systems. Assessments conducted at a national or multi-state scale can be useful for influencing federal policy programs such as the Continuous Conservation Reserve Program (CCRP) or the Forest Land Enhancement Program (FLEP) to incorporate agroforestry practices that address multiple issues (Kurtz 2000). By illustrating the range of alternative agroforestry products that can be grown in a region, cost-share and other assistance programs can be developed to encourage appropriate crop diversification and integration. Support for these assistance programs can be generated when the public can clearly see the community benefits of implementing agroforestry systems on private lands.

Assessments developed at a state or multi-county level can be valuable in developing technology transfer programs such as publications and landowner workshops on agroforestry. Suitability assessments for agroforestry specialty products can assist landowners and communities in species selection, providing guidance not only where the plants can be grown but also on the feasibility of establishing processing facilities or co-ops to promote the marketing and distribution of specialty products. The results from the assessments may also provide direction for research at universities and institutes dedicated to finding viable alternatives for agricultural producers.

The assessment process can also serve as a valuable catalyst to pull together and organize stakeholders who have varied interests and goals. Using a collaboration-based approach with the assessments, stakeholders can articulate and design the desired future conditions for their planning area and can prioritize agroforestry projects that achieve production and environmental protection goals.

Acknowledgments

Funding and support for this project was provided through the USDA National Agroforestry Center, which is part of the U.S. Forest Service Rocky Mountain Research Station, and the University of Missouri Center for Agroforestry under cooperative agreements AG-02100251 with the Agricultural Research Service (ARS) and CR 826704-01-0 with the U.S. Environmental Protection Agency (EPA). The results presented are the sole responsibility of the authors and may not represent the policies or positions of the EPA or ARS. The authors would like to thank Michele Schoeneberger and Richard Carman for their helpful input on this project.

References

Baker, R. H. 1983. Michigan Mammals. Michigan State University Press, Detroit, MI, pp. 642.

Bentrup, G., Schoeneberger, M.M., Josiah, S. and Francis, C. 2001. Ecobelts: reconnecting agriculture and communities - case studies. In: Steward W.C. and Lisec, A. (eds), Proceedings of the Ecospheres Conference. University of Nebraska, Lincoln, NE. June 10-12.

Bentrup, G. and Leininger, T. 2002. Agroforestry: mapping the way with GIS. Journal of Soil and Water Conservation 57(6):148a-152a.

Brooker, L., Brooker, M. and Cale, P. 1999. Animal dispersal in fragmented habitat: measuring habitat connectivity, corridor use, and dispersal mortality. Conservation Ecology. [online] 3(1). Available from the Internet URL: http://www.consecol.org/vol3/iss1/art4/index.html Verified: 05/29/03.

Choate, J.R., Moore, D.W., and Frey, J.K. 1991. Dispersal of the meadow jumping mouse in Northern Kansas. Prairie Naturalist 23:127-130.

Dirr, M.A. 1983. Manual of Woody Landscape Plants. Stipes Publishing Company, Champaign, IL, 826 pp.

Dunne, T., and Leopold, L.B. 1978. Water in Environmental Planning. W.H. Freeman and Company, New York, NY, 818 pp.

Ellis, E.A., Nair, P.K., Linehan, P.E., Beck, H.W. and Blanche, C.A. 2000. A GIS-based database management application for agroforestry planning and tree selection. Computers and Electronics in Agriculture 27:41-55.

Frissell, C.A. 1997. Ecological principles. In: Williams, J., Wood, C.A., and Dombeck, M.P. (eds), Watershed Restoration: Principles and Practices. American Fisheries Society, Bethesda, MD, pp. 96-115.

Hill, D.B. and Buck, L.E. 2000. Forest farming practices. In: Garrett, H.E., Rietveld, W.J., and Fisher, R.F. (eds.) North American Agroforestry: An Integrated Science and Practice. American Society of Agronomy, Madison, WI, pp. 283-320.

Horton, R.E. 1945. Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. Geological Society of America Bulletin 56:275-370.

Josiah, S.J., Gordon, L.J., Streed, E. and Joannides, J. 1999. Agroforestry in Minnesota: A Guide to Resources and Demonstration Sites. University of Minnesota Extension Service, St. Paul, MN.

Josiah, S.J. and Skelton, P. 2003. Productive conservation: diversifying farm enterprises by producing woody decorative florals in agroforestry systems. Proceedings of the 8th North American Agroforestry Conference. American Association of Temperate Agroforestry, Corvallis, OR. June 22-25.

Kurtz, W. 2000. Economics and policy of agroforestry. In: Garrett, H.E., Rietveld, W.J., and Fisher, R.F. (eds.) North American Agroforestry: An Integrated Science and Practice. American Society of Agronomy, Madison, WI, pp. 321-360.

Lal, R. 2000. A modest proposal for the year 2001: we can control greenhouse gases and feed the world…with proper soil management. Journal of Soil and Water Conservation 55(4):429-433.

Lassoie, J.P. and Buck, L.E. 2000. Development of agroforestry as an integrated land use management strategy. In: Garrett, H.E., Rietveld, W.J., and Fisher, R.F. (eds.) North American Agroforestry: An Integrated Science and Practice. American Society of Agronomy, Madison, WI, pp. 1-29.

McHarg, I. 1995. Design with Nature. John Wiley and Sons, New York, NY, pp. 208.

Miller, B.K., Moser, B.C., Johnson, K.D. and Swihart, R.K. 1994. Increase wildlife habitat and provide income. In: Campbell, K.L., Graham, W.D. and Bottcher, A.B. (eds.) Environmentally Sound Agriculture: Proceedings of the Second Conference. Orlando, FL.

NatureServe. 2003. An Online Encyclopedia of Life. 2000. Version 1.1. Arlington, Virginia, USA: Association for Biodiversity Information. [online] URL: http://www.natureserve.org/explorer/index.htm Verified: 05/29/03.

Niemi, G.J. and seven coauthors. 1990. Overview of case studies on recovery of aquatic systems from disturbance. Environmental Management 14:571-587.

Olson, R.K., Schoeneberger, M.M. and Aschmann, S.G. 2000. An ecological foundation for temperate agroforestry. In: Garrett, H.E., Rietveld, W.J., and Fisher, R.F. (eds.) North American Agroforestry: An Integrated Science and Practice. American Society of Agronomy, Madison, WI, pp. 31-61.

Quimby, D.C., 1951. Life history and ecology of the jumping mouse, Zapus hudsonius. Ecological Monographs 21: 61-95.

Rietveld, W.J. and Francis, C.A. 2000. The future of agroforestry in the USA. In: Garrett, H.E., Rietveld, W.J., and Fisher, R.F. (eds.) North American Agroforestry: An Integrated Science and Practice. American Society of Agronomy, Madison, WI, pp. 387-402.

Rietveld, W.J. 1995. Agroforestry: a maverick science and practice. In: Rietveld, W.J. (ed.) Proceedings of Agroforestry and Sustainable Systems Symposium, August 7-10, 1994, Fort Collins, CO. General Technical Report RM-GTR-261. USDA, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Robertson, K.R., Anderson, R.C., and Schwartz, M.W. 1997. The tallgrass prairie mosaic. In: Schwartz, M.W. (ed.) Conservation in Highly Fragmented Landscapes. Chapman and Hall, New York, NY, 448 pp.

Sanchez, P.A. 1995. Science in agroforestry. Agroforestry Systems 30:5-55.

Soil Survey. 1993. Soil Survey Manual. Natural Resources Conservation Service. U.S. Department of Agriculture Handbook 18.

Steiner, F. 1991. The Living Landscape: An Ecological Approach to Landscape Planning. McGraw-Hill, New York, NY, 356 pp.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. American Geophysical Union Transactions 38:913-920.

Yoder, K.S. and Moser, B.C. 1993. Pussy willow branches – a new crop for sustainable agriculture. Horticulture Science 28(5): 191.