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Enhancing Biodiversity With and Within Agroforestry Plantings[1]

Michele M. Schoeneberger[2]

Abstract.--Agroforestry is the deliberate introduction of multipurpose woody perennials (MWPs) into agroecosystems for the purpose of enhancing agricultural productivity, natural resource conservation, and human environments. This introduction promotes the biodiversity within the agroecosystem and thus its sustainability. This biodiversity is only a fraction of its potential due to the limited number and arrangement of the MWPs currently used in agroforestry plantings. An expanded effort in nursery and agroforestry research and development along with nursery production of diverse, adapted MWPs will need to be pursued to fully capitalize on the varied economic and ecological benefits of agroforestry.

INTRODUCTION

Agroforestry is being investigated as a way to couple ecological sustainability with economic stability within agricultural systems. The International Council for Research in Agroforestry (ICRAF) defines agroforestry as "a collective name for land use systems and technologies where woody perennials are deliberately used on the same management unit as agricultural crops and/or animals, either in some form of spatial arrangement or temporal sequence". The Center for Semiarid Agroforestry (CSA), established by the USDA-Forest Service with a focus on temperate, semiarid regions, has expanded this definition to "the use of conservation trees and shrubs in support of agricultural production, natural resource conservation and human environments".

The fundamental concept in agroforestry is "working" trees and shrubs that are planted in a particular place and configuration, and for a specific purpose in order to add value to the agroecosystem. Specific agroforestry practices in temperate regions include windbreaks for field, livestock, and farmstead protection; streamside buffer strips; living snowfences; wildlife habitat; fuelwood plantations; alley cropping; as well as specialty plantings for honey production or pisciculture.

The impacts from the introduction of MWPs into agroecosystems go beyond the benefits listed above. The multipurpose woody perennial plantings (e.g. trees and shrubs, MWPs) create shifts in crop patterns and management practices. Consequently, agroforestry plantings have profound ecological ramifications throughout the agroecosystem; the most obvious being enhanced biodiversity (fig. 1). The capability to integrate a wide array of MWPs and planting designs into agroforestry makes it a flexible and therefore powerful tool in providing multiple benefits to agroecosystems.

BIODIVERSITY: DEFINITION AND PERSPECTIVE

Biological diversity, or biodiversity, is the variety and complexity within all ecological systems that embodies ecosystem resiliency and thus sustainability. Biodiversity was defined in a recent Society of American Foresters report as "the variety and abundance of species, their genetic composition, and the communities, ecosystems, and landscapes in which they occur." (Society of American Foresters 1991). Biodiversity is comprised of the mosaic of ecological structures, functions and processes and their integration from molecular to global

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levels (Nigh et al. 1992). Biodiversity is conceptually broken down into an array of three levels and three components (table 1). Compositional diversity includes the species diversity (i.e. number of species present), the genetic diversity represented by these species, and the resulting net ecosystem diversity. Structural diversity pertains to the spatial arrangements of the compositional units. Functional diversity represents the variation in the net ecological processes at all scales. In reality, it is difficult to biologically separate and quantify the interactions among the many components in this matrix. Consequently, biodiversity is a concept more readily accepted than understood or measured.

Recent events, such as the 1992 Earth Summit in Rio de Janeiro, have put biodiversity in the public's eyes. The first image biodiversity engenders is the massive destruction of tropical rainforests. Here, the main thrust is to save or conserve diverse species, known or as yet unknown, by protecting the ecosystem. Biodiversity, however, is an ecological concern that encompasses more than just tropical rainforests or habitats for specific species, such as the spotted owl or red-cockaded woodpecker. Biodiversity is more than something to be protected in an ecosystem; it is also something that can be promoted to provide protection within an ecosystem.

Ecological theory states that ecosystem complexity and stability go hand-in-hand. It is the diversity of genes and species and their

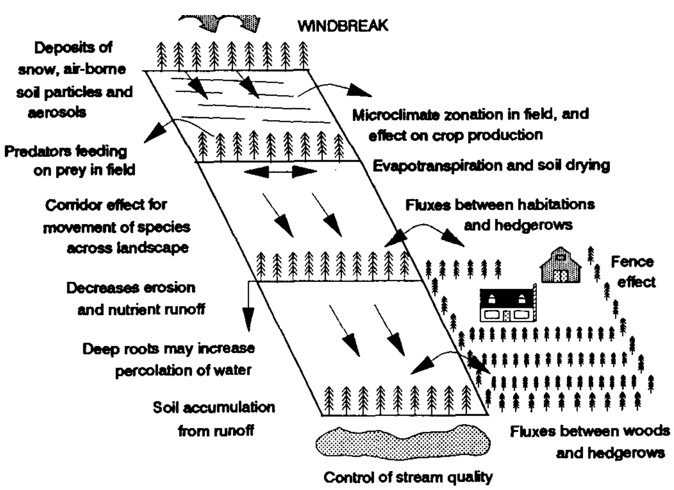

Figure 1.--Summary of major functions created by agroforestry plantings (modified from Forman and Baudry 1984).

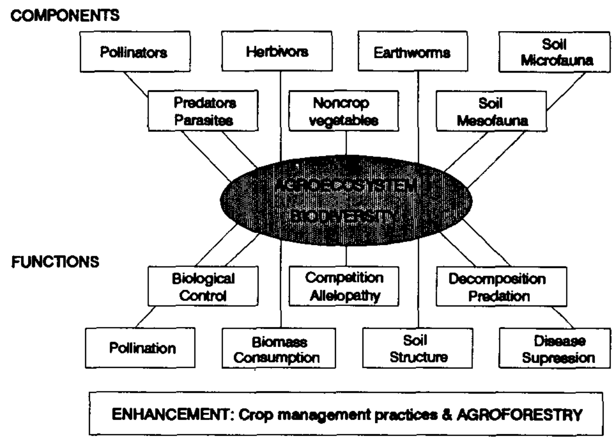

Figure 2.--Components and functions within agroecosystem biodiversity that play a role in sustainability (modified from Altieri 1991).

functions and interactions within a system that provides the "redundancies" that serve as the natural stabilizing mechanisms for that system (Perry and Borchers 1990), e.g. a niche vacated within an ecosystem is soon filled from within thereby maintaining ecosystem integrity. Longterm soil productivity, water quality and quantity, and other biogeochemical cycles within a system are dependent on the system having a healthy level of diversity and therefore an adequate level of natural stabilizing mechanisms. Practices that enhance biodiversity in ecologically barren systems can be used to build more ecologically-balanced systems.

BIO-SIMPLICITY OF MODERN DAY, INTENSIVE AGRICULTURAL SYSTEMS

Agriculture has been extremely successful in producing high quality and reasonably priced food for consumers. But we must now examine the consequences of the massive and intensive practices utilized to attain this goal.

The quest for maximum crop yields has resulted in the "bio-simplification" of agroecosystems. Today's large scale agriculture is basically a series of monocultures comprised of a limited species and genetic base. Monoculture production (e.g. corn in the midwest or grapes in California), has resulted in the net reduction in ecosystem diversity at many levels. For example, monoculture production has been shown to severely reduce earthworm numbers and species. Soil management practices, such as plowing and pesticide application, have also been shown to significantly reduce soil invertebrate diversity and numbers (Paoletti et al. 1992).

Table 1.--Examples of levels and components of biodiversity.

Levels of Biodiversity	Components of Biodiversity		
	Compositional	Structural	Functional
Genetic	number of genes, alleles	genetic structure	recombination, evolution
Species	number of species	species distribution and abundance	trophic levels, life histories
Community or Ecosystem	number of communities, ecosystems	habitat structure, community distribution and abundance	ecosystem processes

Source: Nigh et al. (1992)

Each reduction in diversity further uncouples ecosystem processes and, with it, sustainability (fig. 2). Continuous and intensive inputs of pesticides, cultivation and fertilization are required to maintain these uncoupled agroecosystems resulting in persistent soil erosion, contamination of surface and subsurface waters, growing resistance to pesticides by insects and other pests, and loss of fish and wildlife habitat. There may be many other impacts to long-term productivity as yet unidentified but occurring none-the-less. The need is now for exploring new alternatives that can "balance demands on agricultural resources for food production with ecological concerns for surface and ground water quality, wildlife, and wetlands, as well as human health" (Department of Agriculture 1991).

ENHANCING BIODIVERSITY WITH AGROFORESTRY PLANTINGS

Pimentel et al. (1992) and Altieri (1991) emphasize that productive agricultural and forestry systems can not function successfully without the vital activities of the diversity of the natural biota. Given that temperate agroforestry is the deliberate addition of trees and shrubs to agroecosystems that are deficient in these components, two things become obvious. One, agroforestry systems, by definition, will have greater structural and functional diversity than the "monoculture" representative of modern intensive agriculture. Two, through the choice of species and their spatial arrangement, the functional and structural biodiversity created within an agroecosystem can intentionally be directed and enhanced (fig. 1).

At present, each agroforestry planting is generally targeted for a single, primary benefit. The primary benefit of shelterbelts or windbelts is the modification of microclimate for the protection of crops, livestock, farmlots and homesteads. The primary benefit of waterway buffer strips is in "filtering" out sediments and agrichemicals and thus in maintaining water quality. The primary benefit of living snow fences is in road protection.

However, once a planting is established, a new "community" evolves comprised of numerous easily observed (e.g. birds, mammals) and not so readily observed (e.g. microflora and fauna) components (Forman and Baudry 1984). Enhanced wildlife habitat is a readily recognized and appreciated "by-product" of agroforestry plantings, particularly windbelts (Schroeder 1986). Along with providing the habitat needs for ring-necked pheasant, gray partridge, fox squirrel and white-tailed deer, agroforestry plantings also serve as critical oases for numerous grassland and woodland birds, as well as migratory populations.

The type of community created and the resulting ecological interactions within an agroforestry planting will be a function of the species composition and arrangement. MWPs introduce a compositional, structural and functional diversity into the agroecosystem that will produce numerous interactions (fig. 1). The interactions between tree/crop systems can range from positive to negative (Vandenbelt et al. 1990) making it critical for us to have a detailed understanding of them if we are to capitalize on them.

Riparian areas, in general, have been found to be among the richest in biological diversity. The tendency in modern agricultural systems is to farm or graze up to the water's edge. These practices generally results in vegetation, soil and water degradation. Establishment of woody perennials along perennial and even intermittent waterways can provide substantial soil conservation and water quality benefits while creating ideal habitats for numerous species of flora and fauna.

Biological Control Through Biodiversity

Biological control, also referred to as biocontrol, of important crop and tree pests is another potential by-product from agroforestry plantings, particularly crop buffer strips (Altieri 1991). Polycultures, such as those created by agroforestry plantings, can indirectly control insect pests by offering improved habitat for their predators. Studies have shown that the habitats created by agroforestry plantings support a larger and more diverse population of natural enemies, such as birds and predatory arthropods (spiders) than monocultures. The effects of these "non-crop" edges may range from providing food for pest predators during low infestation periods; providing breeding habitat, to modifying wind speeds and patterns (Heisler and Dix 1991). They have been found to serve as important reservoirs of predatory arthropod species that feed on crop pests such as cereal aphids. In one study, predator numbers decreased with increasing distance from the non-crop edge and were inversely correlated with numbers of aphids (Dennis and Fry 1992). A specific example of biocontrol through agroforestry is in the establishment of blackberry bushes or prune trees along the edges of vineyards. These plantings serve as winter refugia for the parasitic wasp responsible for biological control of the grape leafhopper, an economically important pest of grapes (Altieri 1991).

These findings challenge arguments for the maximal field size currently considered to be efficient for crop production and provide support for the belief that "fragmentation" of the agroecosystem which would produce pockets of enhanced diversity, as a more sustainable approach (Thomas et al. 1992). Integrated pest management of shelterbelts and other agroforestry practices will necessarily have to be based on an understanding of the trees and their development, the crop and its development, the natural enemies and pests of both crops, and the interactions among all these components (fig. 1). It offers much promise in providing an improved control technology that would be ecologically sound and environmentally and economically acceptable.

ENHANCING BIODIVERSITY IN AGROFORESTRY PLANTINGS

Management of the agroecosystem includes management of the "non-crop" edges" in addition to crop management for enhanced production (Dennis and Fry 1992, Forman and Baudry 1984, Thomas et al. 1992)(fig. 1). Current conservation tree/crop systems which typically utilize only a few species, encompass only a fraction of the potential biodiversity. Biodiversity of non-crop edges could be greatly enhanced by incorporation of numerous and diverse MWP or more structurally-diverse planting designs. This flexibility offers a tremendous tool to expand the quality and quantity of benefits from agroecosystems. Field and farmstead windbreaks, living snow fences, and multistrata waterway buffer systems are three examples of agroforestry practices whose ecological benefits can be significantly increased through directed selection and planting design of MWPs.

The criteria for species selection in windbreaks traditionally focus on structural aspects needed to alter microclimate for crop and farmstead protection. These criteria can also incorporate functional attributes, such as habitat and forage suitability to promote wildlife and/or natural pest-predator populations. The current trend of planting only small and single-row windbelts may contribute to substantial reductions in some Great Plains bird species (Martin and Vohs 1978). The "Habitat Suitability Index" model created by Shroeder (1986) for determining wildlife species richness in shelterbelts utilizes six variables: average height of the two tallest rows, percent tree/shrub canopy closure, number of rows, number of woody perennial species, configuration and size. Such a model can provide direction in designing windbelts for wildlife purposes through the manipulation of the above listed variables.

Plant selections, such as big sagebrush, for living snow fences can serve in providing road protection and winter forage for mule deer and sage grouse. Depending on the type and number of MWPs selected, the living snow fence can provide additional benefits that range from enhanced wildlife habitat and soil conservation to landscape beautification and biocontrol.

Waterway buffer strips, also referred to as filterstrips, have tremendous potential to be manipulated for biodiversity enhancement along with water quality protection. Multistrata waterway buffer systems that incorporate forage, shrub and tree layers are being promoted not only for their greater efficacy in trapping sediment and chemical runoff from agricultural lands, but also for multiple other purposes (i.e. stream bank stabilization, wildlife, recreation). Plant selection criteria for the primary benefit of water quality focusses on both the structural and functional attributes that enable agrichemicals and sediments to be trapped and either sequestered or degraded within the strip. This design adds diversity both aboveground and belowground. Rooting depth and pattern play a significant role in agrichemical entrapment as does the soil microbial component. Microflora quantity and diversity, as well as enzyme and nutrient activity, were found to be increased under coconut-based multicropped systems rather than under monocropped systems (Bopaiah and Shetty 1991). The efficacy of the waterway buffer system can therefore be increased through knowledgeable manipulation of species selection that promote rhizosphere populations. As we gain a better understanding of the role belowground biodiversity plays in ecological sustainability, we may find it plays an even more important role in determining ecosystem resiliency to disturbance than aboveground diversity (Fitter et al. 1985).

MWPs FOR AGROFORESTRY PLANTINGS: OBSTACLES AND OPPORTUNITIES

Design of Agroforestry Plantings

> "Agroforestry is still emerging as a science but has been an art form in many parts of the world for centuries."
> (Vergara and MacDicken 1990)

Enhancing the biodiversity with and within agroforestry plantings consists of more that just adding a greater number of species. It also includes the directed selection (i.e. species, genotype) and arrangement of diverse MWPs to attain multiple benefits. Currently, agroforestry knowledge is based more on demonstration than on hard science making it difficult to design plantings with highly predictable outcomes, e.g. biocontrol. Models that have been developed for agroforestry plantings are few and are generally limited to single benefit/single agroforestry practice, such as wildlife enhancement in shelterbelts (Schroeder 1986). Work is ongoing to understand this broader context but much is yet needed in developing the fundamental principles to fully understand and capitalize on the ecological complexity of agroforestry plantings.

Availability and Development of Diverse Adapted MWPs

Before we can have successful agroforestry plantings, we must have access to diverse, adapted MWPs that will flourish in the stressful environments in which they are planted. Tree improvement efforts for selection of stress- and pest-resistance conservation trees is underway at the Center for Semiarid Agroforestry. An expanded effort will be needed, particularly in the selection of diverse, native MWPs.

Availability of diverse MWP planting stock is limited. In the SCS publication "Conservation Tree and Shrub Cultivars in the U.S." (Carlson et al. 1991), availability of many cultivars is listed as "limited supply", "limited nursery stock" to "very limited supply", "not yet available" or "none". Some MWP material is available only as seed rather than as plantable stock. Selection of stress- and pest-resistant MWP species and genotypes will need to be coupled with a strong program in nursery research and development that will provide the information necessary for commercial production, e.g. propagation, seed collection and handling, seedling production (Landis, 1992).

Agroforestry UAS

Integration of agroforestry in sustainable land-use will require cultivating landowners UAS - understanding, acceptance and support. A "short-term production economic ethic" has resulted in farming up to the stream's edge, in removing trees and shrubs to maximize field size and in grazing riparian areas. A new public ethic needs to evolve focussing on the benefits through agroforestry. Agroforestry will need to be appreciated for both its short-term economic value as well as for the long-term ecological concerns it tackles. Therefore, agroforestry must take into account both social, economic, as well as ecological impacts to the agroecosystem.

The need for a longer-term ecological perspective will necessitate shifts in environmental perception. A major objective of the Center for Semiarid Agroforestry is in providing a clear model of agroforestry as an agrarian alternative through technology transfer, demonstration and information and education programs. Programs, such as "Conservation Trees for Your Farm, Family and Future" by the National Arbor Day Foundation and "Conservation Trees in Communities" by CSA have been established to increase the public's awareness of the multiple values created by MWP plantings.

SUMMARY

The importance of the biodiversity created by agroforestry can best be summed up by paraphrasing Forman and Baudry (1984): the clearest way to pinpoint the roles and values of agroforestry plantings is to visualize a suitable agricultural landscape without them. The biodiversity created by agroforestry plantings can provide a useful tool to strengthen natural control mechanisms that have been disrupted by intensive farming practices (Mader 1988). This, along with the other benefits afforded by agroforestry, should far outweigh the land utilized for the MWP plantings.

Much of the potential in agroforestry lies in the versatility of diverse MWP selection and arrangement to provide these multiple benefits. Both agroforestry and nursery research, development and application programs need to be accelerated, if agroforestry is to be a viable strategy in promoting agroecosystem biodiversity and sustainability.

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