PERENNIAL CROPS FOR BIO-FUELS AND CONSERVATION

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Abstract: Perennial woody crops have the potential to contribute significantly to the production of bio-fuels while simultaneously helping to provide a wide range of conservation benefits. Among these benefits are increased biological diversity in the landscape, conservation of soil and water resources, maintenance of forest ecosystem productivity and health, contribution to the global carbon cycle, and provision of socioeconomic benefits. Short rotation woody crops, like hybrid poplar and willow, grow rapidly and can reach 15-25 feet in height after only three years. Currently, non-irrigated yields can be sustained at about 5 dry tons/acre/year and are increasing as plant breeding, nutrient management, and weed control advances are made. The high hemi-cellulose and cellulose content of woody biomass result in favorable net energy conversion ratios of 1:11 when co-fired with coal and 1:16 when undergoing gasification. Directing this wood fiber into bio-fuels would benefit both the energy sector and forest and farm landowners, while providing an array of conservation benefits and ecological services. The amount of bio-fuel that can be sustainably produced each year from perennial crops is potentially very large. The next Farm Bill affords an opportunity to insure that this potential can be more fully realized.

Sustainable Land Management

In the United States, forestry and agriculture are both faced with the challenge of meeting an increasing demand for goods, as well as for an expanding array of ecological services, like clean water, soil conservation, and wildlife habitat, often from the same lands. With the nation's population expanding by more than three million annually, all this will need to occur on a fixed or shrinking land base.

An emerging critical challenge is the need to develop sustainable approaches to producing renewable biomass crops to help meet our nation's energy needs. In this regard, perennial plants like trees and shrubs have the potential to provide large quantities of biofuel feedstock, while also providing a wide array of ecological services and revitalizing declining rural economies. Biomass currently provides about 10 percent of the global primary energy supply (IEA 2002). Projections are that this proportion will need to increase dramatically to meet growing energy demand. Given a relatively fixed land base, the production of energy crops will compete with traditional agricultural and forestry uses of land. Clearly, it is essential that agriculture and forestry work together to create integrated biomass production systems that landowners can use to help meet our nation's growing energy demands. Producing fast-growing short rotation woody crops (SRWC) on agricultural lands is one such approach that shows considerable promise. When produced in integrated systems, SRWCs combine the goals of sustainable forestry with those of sustainable agriculture at multiple temporal and spatial scales (Ruark 1999).

In addition to using woody biomass for energy for power and heat generation via cofiring and gasification, woody crops with their high hemicellulose and cellulose content are well suited for biorefining to yield liquid fuels like ethanol, methanol, biooil, and other bioproducts, such as biodegradable plastics and specialty chemicals. Studies on willow (*Salix spp*) have documented highly favorable net energy ratios of 1:11 when willow biomass is co-fired with coal and 1:16 when it undergoes gasification (Heller et al. 2003). The ratios for wood contrast well with the net energy ratio of 1:1.3 observed for ethanol produced from corn (Shapouri et al. 2002) and the net energy ratio of 1:0.4 associated with the generation of electricity from coal (Mann and Spath 1999).

Agriculture Today – Agriculture in the United States is highly mechanized and uses considerable inputs of fertilizer and pesticides. The agricultural sector is increasingly vertically integrated and in any given year only a few varieties of corn or soybean are planted. In the central part of the country corn and soybean dominate the landscape for as far as the eye can see. With the exception of narrow patches of trees along stream corridors and grass contour strips in fields and along roads, the rural landscape often lacks any perennial vegetation. In fact, for 6-7 months each year most fields lie bare after the fall harvest until the newly planted crops begin to emerge in mid-spring. This approach to agriculture has proven to be highly productive, evidenced in most years by a surplus of grain. However, the downside of our industrial agriculture approach has been the loss of most ecological services across the landscape. The massive spatial scale for cropping and the uniform vegetation of corn and soybean provides little opportunity for species diversity and only minimal structural diversity across the landscape. Conservation challenges include managing soil erosion, concentrated livestock waste, runoff of fertilizers and pesticides into surface water and groundwater with substantial downstream impacts.

Conservation Benefits of Trees on Agricultural Land

Agroforestry practices (windbreaks, riparian buffers, alley cropping) that incorporate trees into working agricultural lands have been used in the United States since the time when windbreaks were employed to abate soil erosion in the “dust bowl” of the 1930s. In the past 15 years the interest in and adoption of agroforestry practices have been increasing dramatically. The primary reasons for this expanded interest have been for economic diversification and conservation benefits. Trees have been shown to provide a variety of conservation benefits when they are purposefully integrated into agricultural operations (Ruark et al. 2003). Designed windbreak systems strategically located in fields protect soils, livestock, and a variety of wind-sensitive crops. Typically, crop yields are improved due to lowered plant evaporation and transpiration stress. In fact, on a field basis, increases in corn and soybean yields as a result of wind protection have been estimated to average 12 percent, based on crop yield assessments of hundreds of field years of data derived worldwide (Baldwin 1988, Kort 1988). The area of cropland afforded significant wind protection has been shown to extend for up to 15 times the height of the windbreak (Brandle 1992). In regions where drifting snow can block roadways and increase safety risks, living snow fences configured with planted trees and shrubs have been shown to control snow drifting, and reduce road maintenance costs and accidents (Brandle and Nickerson 1996). Windbreaks have also been shown to protect livestock during winter storms.

Trees introduce both vertical and horizontal structural variation in agricultural landscapes. Where croplands occupy most of the landscape, linear riparian forest buffers and field shelterbelts can be essential for maintaining plant and animal biodiversity, especially under a changing climate scenario. Agroforestry adds plant and animal biodiversity to landscapes that might otherwise contain only monocultures of agricultural crops (Noble and Dirzo 1997, Guo 2000). Agroforestry plantings can be used to connect forest fragments and other critical habitats in the landscape (Freemark et al. 2002).

Streams that course through agricultural lands are often devoid of vegetation in their riparian zones. As a result, runoff containing excess fertilizers, pesticides, animal wastes, and soil sediments enter surface waters unabated. Agroforestry technologies such as riparian forest buffers have been shown to be effective in reducing water pollution from agricultural activities when they are well designed and properly located in a watershed (Dosskey 2002). These buffers can stabilize stream channels and slow and reduce the transport of runoff to streams. This allows more time for infiltration of water and contaminants into the soil and increases the ability of the environment to degrade pesticides and animal waste products. Linked systems of upland and riparian tree-based buffer systems, when integrated with other landscape practices and features, can optimize soil and water conservation in the watershed.

Perennial Systems for Biofuel Production and Their Conservation Benefits

Several woody perennial plants can be grown for bio-fuels, while at the same time provide conservation benefits and ecological services that markedly exceed those associated with conventional annual crops like corn. In the United States most research has focused willow shrubs (*Salix spp*) and hybrid poplar (*Populus spp*) production systems.

Hybrid Poplar - Hybrid poplars used in this country are predominantly cottonwoods and interspecific hybrids that have been selected and breed for fast growth. Sustained yields of 5 dry tons/acre/year have been documented in the north central United States and have reached 7 dry tons/acre/year on high productivity sites (Riemenschneider et al. 2001). A 5 dry tons/acre/year yield represents a reasonable national average, assuming a supportive R&D program along with appropriate technology transfer is maintained through time.

To gauge the potential of this species, let’s examine it in the context of the approximately 38 million acres of Conservation Reserve Program (CRP) lands. If these acres were planted to hybrid poplar annual production would approximate 190 million dry tons of wood/year for use as bioenergy. At 16 million BTUs per dry ton/year, that is equivalent to 3,040 trillion BTUs (3 quads)/year, or about double that which is potentially available from utilizing all annual logging residue from forest lands (FIA 2002). The Energy Information Administration predicts gasoline consumption in the U.S. will reach 24 quads of BTU by 2025. Thus, short rotation woody crops can contribute significantly to transportation fuels. An added benefit would be the reinvigoration of rural economies, while producing substantial levels of ecological services.

Another potentially large source of cellulose is agricultural residues, such as corn stalks. However, the extent to which these can be sustainably removed from crop land each year without significantly lowering soil organic matter and overall soil quality is unknown.

> Agroforestry Timberbelts - Recently, a new concept called a “*timberbelt*” has been introduced. These are multiple row field windbreaks that are planted with commercially

> valuable, fast-growing trees (such as hybrid poplar or hybrid willow) to provide conservation benefits, improve adjacent crop yields, diversify on-farm income sources, and produce commercially valuable wood products. Various planting configurations have been developed that provide wind protection for soils and crops, and yield sufficient biomass to make wood harvest economical. Tree rows are oriented perpendicular to the prevailing wind to reduce wind velocity and improve the microclimate within the sheltered zone to enhance production of adjacent crops. Because of their rapid growth and range of marketable products, hybrid poplars fit well into the timberbelt concept. The strategy is to harvest half of the rows in a timberbelt at age 7-12, while the other half are left to provide continued wind protection. Within a few years after the stumps have sprouted and re-established sufficient wind protection the remaining rows are harvested. In this way continuous wind protection and associated economic benefits to adjacent crops can be achieved.

<u>Willow</u>- Willow has several characteristics that make it ideal for woody crop systems, including high yields, ease of propagation, a broad genetic base, a short breeding cycle, and the ability to resprout after multiple harvests. (Volk et al. 2004). A sustainable system has been devised for willow biomass production by planting unrooted stem cuttings at a density of 4,000-8,000 plants per acre. Willow can achieve high yields, typically reaching 15-25 feet in height in three years, at which time they can be harvested using modified agricultural equipment that cuts and chips the biomass in one operation. They resprout vigorously from their stumps (coppice) following harvest, with 7-8 harvesting cycles possible from an initial planting (Volk et al. 2004). To date, trials with willows shrubs in this production system have been conducted in nine states throughout the Northeast and Midwest.

Yields of fertilized and irrigated willow grown in three-year rotations have exceeded 10.8 dry tons/ac/yr in North America and 12.0 dry tons/ac/yr in Europe (Volk et al., in press). Due to economic limitations, irrigation will probably not be used for most large-scale production operations. However, this work sets a benchmark for the potential of willow shrubs grown in this type of system. First-rotation, non-irrigated research-scale trials in central New York state have produced yields of 3.4 to 4.6 dry tons/ac/yr. Second rotation yields of the five best producing clones increased by 18-62 percent compared to the first-rotation. Breeding of willows for biomass production is in its infancy in North America. Field trials of new varieties produced in 1998 and 1999 in New York indicate that the yield of some varieties is 140 percent of the standard operational variety of *Salix dasyclados* (SV1) currently used in large-scale field demonstrations. More than 20 of these new varieties are currently being scaled-up for regional clone-site trials, larger yield trials, and eventual deployment in commercial plantings. These efforts could yield new, improved varieties within six to eight years. Improvements in other aspects of the production system, ranging from improved weed control, matching planting density with crown architecture, and optimizing nutrient management, will help realize the production potential of this crop.

A common misconception is that monocultures of willow are planted across the landscape creating biological deserts. In fact, a mixture of different species and hybrids are established by planting blocks of different varieties across a field or random mixtures of varieties within rows. These mixtures enhance structural and functional diversity greater than that of conventional agricultural row crops and reduce the threat of pests and diseases (McCracken and Dawson 2001). The resultant landscape has about one third of its area harvested annually, while the remaining area contains a mixture of one-, two-, and three-year-old willow. Research has documented that between 24 and 41 species of birds regularly use woody crops (Sage 1998, Dhondt and Wrege 2003). Similarly, four years after the initial planting soil microarthropods under willows were found to reach the levels of those associated with undisturbed, fallow fields (Minor et al 2004).

Research Needs

Although several production systems have already been devised for hybrid poplar and willows, continued and consistent investment in research is needed to improve the efficiencies and sustainability of these perennial systems. Additional knowledge is required to determine how to best manage short rotation woody crops in plantations, as well as those deployed in integrated agroforestry systems like timberbelts. A better understanding is needed of how to manipulate the plant's natural production of specific components already found in the crop, such as cellulose, hemicellulose, and lignin to increase energy yields and reduce conversion costs. More information is needed on the feedstock production stage of the biomass life cycle to better understand and evaluate the economics of producing biomass, biomass carbon cycles and carbon sequestration, quantification of economic benefits and ecological services generated. These efforts will need to be jointly pursued by the forestry and agricultural sectors with an understanding of the barriers and challenges impacting land availability, producer adoption, and key issues surrounding soil sustainability.

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