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Jamie L. Schuler
University of Arkansas at Monticello, schuler@uamont.edu

M. Pelkki
University of Arkansas at Monticello

Chris Stuhlinger
University of Arkansas at Monticello

Biological and Economic Considerations in Establishing a Short-Rotation Bioenergy Plantation

J. Schuler[1], M. Pelkki, and C. Stuhlinger

School of Forest Resources, University of Arkansas at Monticello, Monticello, AR 71656

[1]Corresponding author: schuler@uamont.edu

Abstract

The development of bio-fuel synthesis technologies has led to increased interest in woody crops grown specifically for energy production. These woody feedstocks typically involve fast-growing species (e.g., *Salix* spp., *Populus* spp.) planted at high densities using short rotations and intensive cultural practices like weed control and fertilization. Under ideal conditions, this type of system can produce 20 dry Mg/ha/yr, which is substantially higher than the 2.5-4 dry Mg/ha/yr produced by pine plantations in the southern U.S.

Many of these plantings are projected to be established on lower quality agricultural lands. Recent attempts at establishing these plantations have highlighted some of the challenges that landowners will need to overcome to achieve levels of production that are financially attractive. This paper will address some of the pitfalls and hurdles that need to be overcome before woody bio-fuel plantations will become widespread.

Introduction

The U.S. reliance on foreign sources of petroleum has increased every year since at least the 1980s. Currently, the U.S. petroleum and petroleum product imports account for over 60% of the total consumption (EIA 2008). Rising political instability among several of the major oil exporting countries coupled with a diminishing supply of global oil reserves has prompted the U.S. to re-evaluate the potential of developing liquid fuels from non-petroleum sources. The Advanced Energy Initiative proposed by President Bush in 2006 outlined goals to reduce the U.S. dependency on foreign oil. Since this initiative was proposed, a more ambitious goal of replacing 30% of the transportation fuel consumption by 2030 has been proposed. Ethanol derived from corn will likely replace less than 20 billion gallons. Ligno-cellulosic sources are expected to account for a significant amount of the remaining demand (Perlack et al. 2005).

These feedstocks will include agricultural residues (e.g., corn stover), wood residues from manufacturing, forest residues (e.g., slash) and dedicated woody crops. The low-hanging fruits are wood residues from manufacturing processes. However, much of the "waste" materials from sawmills and pulp mills is already being processed on site to generate electricity or converted into other marketable products (e.g., wood pellets, chips). Agricultural and forest residue feedstocks are abundant, but often regional. Additionally, many have short-term availability following harvesting, especially agricultural residues. Forest slash and non-merchantable materials have been explored as sources of feedstock (Earl 2006). However, the scattered distribution, collection, storage and transportation issues, as well as ecological concerns over long-term productivity, may limit the commercial availability of this feedstock.

Dedicated woody crops (i.e., short rotation plantations) are expected to be important sources of feedstock in the future for Arkansas (Potlatch Corporation 2006). Short rotation tree plantations are not new technology. These plantations have been established in the southern U.S. since the 1960s, with much of the early silvicultural and tree improvement work attributed to scientists working at the Southern Hardwoods Lab in Stoneville, MS (e.g., Krinard and Johnson 1980, Mohn and Randall 1969). These plantations have been developed using fast growing hardwood species such as cottonwood (*Populus deltoides*) and *Populus* hybrids, sweetgum (*Liquidambar styraciflua*), and sycamore (*Platanus occidentalis*), but have also included some trials using several pine (*Pinus* spp.) species. Many of these early efforts had limited success and relatively low yields due to poor establishment procedures and inappropriate species-site selections (Stanturf et al. 2004). When appropriate species were selected, the limited availability of genetically improved planting stock constrained productivity.

Under ideal conditions, short rotation plantations can produce exceptionally high yields. Some of the highest yielding plantations using *Populus*, *Salix*, and exotic *Eucalyptus* produce over 20 dry Mg/ha/yr (Perlack et al. 1995, Rockwood et al. 2006). These high yields have raised grower expectations, and in many cases, resulted in grower dissatisfaction when yields fell short. Typical yields for short rotation bio-energy plantations in the southern U.S. average roughly 10-11 Mg/ha/yr (Wright 1994). However, most bio-energy plantations far exceed the 2.5-4 dry Mg/ha/yr yields generated by intensively managed loblolly pine plantations in the South (Stanturf et al. 2003).

Despite the great potential productivity offered by bio-energy plantations, numerous pitfalls will likely keep many growers from achieving desirable yields.

Soil and Site Conditions

The majority of these plantations will likely occur on marginal agricultural lands and pastures. Establishment on cutover forestland will be limited due to high site preparation costs. Site preparation is probably the single most important factor in determining plantation success. Abandoned agriculture and pasturelands often have soil limitations and established vegetation that are sometimes difficult, and often expensive, to ameliorate and control.

In Arkansas, marginal crop and pasturelands are usually characterized by poorly drained soil conditions and reduced fertility, and contain root-restricting layers (e.g., plow pans). Many of these lands were formerly candidates for the Conservation Reserve Program and Wetlands Reserve Program. Intensive soil management practices using tillage and fertilization treatments can reconcile many of these issues. Subsoiling and/or deep disking can ameliorate root-restricting layers, while repeated nutrient additions, commonly nitrogen, reduce fertility limitations. Many of these sites also have well-established competing vegetation that will significantly reduce growth and survival of any plantation. A sustained and integrated effort must be made to control this existing vegetation plus any subsequent germination. Some initial control can be achieved during soil preparation (i.e., disking). However, almost no long-term control is afforded by soil preparation. A combination of pre- and post-planting herbicide applications will usually be required to achieve adequate vegetation control (Nelson 1985, Zutter et al. 1987). While these practices are commonplace in forestry and agriculture, they are expensive. Cost-cutting at this step will likely reduce survival and productivity. One of the most difficult situations to overcome is the case where grass, herbaceous and semi-woody vegetation is aggressively competing with hardwood seedlings. Almost no herbicide options exist that will control all of the competing vegetation without harming the seedlings. This underscores the importance of initial vegetation control.

Species Selections and Planting Stock

The site and soil characteristics will dictate the appropriate species. Guidelines for choosing a species based on tolerances to flooding, soil depth, and soil texture are available for many of the more commonly grown plantation species (Baker and Broadfoot 1979, Allen et al. 2001). Even so, many sites have a range of soil and site conditions. For example, sites that have not been leveled are not uniform, and often have undulating topography. Under such circumstances, more than one species may be needed to account for micro-site differences with a site. Generally, species that tolerate poorly drained conditions will also grow reasonably well on better drained areas. The opposite, however, is rarely true. With variable soil conditions, the grower can (1) plant the entire area with species that tolerate the most restrictive site condition, (2) group similar areas into manageable sized blocks and plant species that are best suited for the sites, (3) plant just the most productive areas (usually the better drained) and leave the remainder unplanted. Mixing species within a site can improve diversity. However, as a caution, individual species/clones usually grow better and are easier to manage when planted in single species/clone blocks. If species and/or clones are mixed throughout an area, the manger must make sure prescriptions are acceptable for all (e.g., herbicide and fertilization rates).

Selecting the source and type of planting stock can also be challenging. Some species have been included in breeding/tree improvement programs, which has led to improved genetic material. Unfortunately, most nurseries will only have improved genotypes for pine and cottonwood, and currently, sources for large quantities of clonal cottonwood are limited in the South. Hardwood seedlings sold by most nurseries are "woods-run", meaning non-improved genotypes. If known, seedlings should be selected from sources that have similar seed zones. Seed moved from north to south generally leaf out later and are less susceptible to frost than seed moved south to north (Schmidtling 2001). However, as a trade-off, southern sources generally have higher growth rates.

Generally speaking, a grower should obtain the best genotypes that he/she can afford. Additionally, advancements in clonal propagation methods have resulted in improved availability of advanced genotypes and the development of site-specific clonal selections that are more refined than the species-site guidelines mentioned above. Individual nurseries and experienced growers will often assist potential buyers in making selections. For cottonwood, clone assessment trials have identified several best-performing genotypes (e.g., S7C8, ST66, ST124) (ca. Cooper and Ferguson 1979, Jeffreys 2006).

Other Events

Despite our best efforts, unplanned and unforeseen events can cause significant reductions in productivity, and even complete failure. Arkansas, like many areas in the southern U.S., has recently experienced a range of weather conditions that has affected tree plantations. A late April frost in 2007 caused significant damage throughout the state. Many trees had succulent foliage and stems that were either killed or severely damaged. Vigorous established trees were able to re-flush without serious damages, except for a loss in fruit production. Many young seedlings and unhealthy trees that were unable to overcome a complete loss of foliage subsequently died. Spring droughts have delayed planting operations later into the spring than desired. Summer droughts have resulted in numerous plantation failures.

Droughty conditions during the growing season are fairly common in Arkansas. Irrigation is rarely an option, not to mention expensive. Good weed control will reduce water loss by removing competing vegetation. Tillage treatments can also improve water availability by improving the rooting environment and rooting depth. On the other extreme, flooding is also common in Arkansas during the spring. It is almost impossible to physically guard against the effects of flooding. However, diversifying species selections by putting the most flood tolerant species in areas most susceptible to flooding will improve chances of survival.

Pests are often not considered until after a problem has manifested. A diligent monitoring program coupled with a predesigned management plan will minimize risks associated with pests. Common types of pests are insect defoliators and borers, rodents, and browsing animals.

Economic Considerations

One of the challenges associated with perennial crops is that costs are compounded over the rotation. Traditional forestry rotations can be 25-35 years for pine and 40-70 years for hardwoods. Short rotation bio-energy plantations, by contrast, are 5-10 years. Despite the short period of investment, initial establishment costs are often very high. There is a concern that the need for cellulosic feedstocks will compete with traditional forestry pulpwood markets and drive their prices up due to increased demand. This was one of the unintended consequences of the ethanol boom, where the price of corn-derived products skyrocketed. An objective of short rotation bio-energy plantations is to produce biomass at a cost that will be competitive with pulpwood (currently $8-10/green metric ton), and therefore not necessarily compete with the pulp and paper industry.

One production system that substantially reduces the costs is the coppice system. This system uses species that are capable of sprouting after harvesting, thereby eliminating replant costs. Many hardwood species have this capability, whereas most conifer species do not. Table 1 describes the costs associated with the initial establishment of a coppice system over a five year rotation. Values were derived from local sources (Eric Myers, AFC forester, pers. commun.) and our experiences, but may not reflect costs throughout the state. The costs compounded over five years ranged from approximately $2,700 - 3,500/ha.

Table 2 illustrates the advantage of the coppice system using values presented in Table 1 and the importance of the cost of capital. Coppice systems can have increased production for several harvests after the first rotation, but the stools (stumps supporting the sprouting stems) will eventually die and reduce overall production. For the sake of simplicity, we have elected to model an average productivity of 22 Mg/ha/yr (~10 dry Mg/ha/yr) over five 5-year rotations. The 1.5 x 1.5 m spacing used for these calculations represents a spacing that will allow the trees to quickly capture a site, which is key for short rotations, and also aid weed control efforts by suppressing competing vegetation. Also, fertilization and herbicide treatments were included after each coppice cycle.

The data show that the short rotation coppice system can provide a woody feedstock product at a cost that is comparable to pulpwood prices. One metric ton (equivalent to 1 Mg) of biomass can be produced under our scenario after three coppice rotations using a low guiding rate of return. Short rotation grown biomass can be produced at pulpwood prices after four rotations across the guiding rates tested.

Table 1. Estimated costs for establishing a short rotation bio-energy plantation at 1.5 x 1.5 m spacing.

			Future Value ($ after 5 yr)			
Project Year	Activity	Cash Flow ($/ha)	4%	6%	8%	10%
0	Ripping	99	121	133	146	158
0	Pre-planting herbicide	99	121	133	146	158
0	Seedling ($0.25/tree) + Planting ($0.10/tree)	1507	1833	2016	2214	2427
0	Post-planting herbicide	173	210	232	255	279
1	Weed control	173	203	217	235	252
1	Fertilizer	161	114	203	217	235
2			0	0	0	0
3			0	0	0	0
4			0	0	0	0
5			0	0	0	0
		Total Cost ($)	2,602	2,934	3,213	3,509

Table 2. Estimated costs (US$) for producing 1 metric ton of biomass grown on 1 to 5-five yr coppice rotations for various guiding rates of return.

	Guiding Rate of Return			
No. of Coppice Rotations	4%	6%	8%	10%
5	6.90	7.50	8.41	8.82
4	7.82	8.51	9.25	10.04
3	9.36	10.21	11.11	12.09
2	12.43	13.59	14.84	16.17
1	21.65	23.75	26.01	28.43

* Assumes yields equivalent to 22 green Mg/ha/yr

Summary

Given the current low conversion efficiencies of corn and other crops, the limited acreage of agricultural land, and the limited availability of other sources of feedstock, short rotation bio-energy plantations are expected to increase in the future. Compared to our existing fast growing pine plantations, the production potential of certain species and clones grown using short rotation culture techniques is impressive. However, these systems require significant investments and are riddled with pitfalls that can make these investments unprofitable. Careful attention to site and soil characteristics, species selections, and intensive vegetation control will increase the probability of success. Fast-growing plantations grown under intensive culture and using well-tested genotypes can provide a cellulosic feedstock at prices that are comparable or more favorable than pulpwood prices.

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