ASSESSING THE COST AND OPERATIONAL FEASIBILITY OF "GREEN" HARDWOOD WINTER INVENTORY FOR SOUTHEASTERN PULP MILLS

by

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Abstract

Procuring hardwood pulpwood during the winter months for a pulp mill in the Southeast can be difficult. Saturated soils and low soil strength make logging difficult or impossible on many sites, forcing companies to store large volumes of hardwood pulpwood in woodyards for retrieval during wet weather. Hardwood fiber readily available in large volumes on ground that is operable during wet periods at a location near the pulp mill could provide a valuable alternative wood source. Thus, the objectives of this study are to 1) develop a decision model for a manager to use to determine the feasibility of strategically located, intensively-managed, short-rotation hardwood fiber farms as pulp mill furnish, 2) use the model to estimate wood costs for a hypothetical eastern cottonwood plantation, and 3) use the model to determine if a fiber farm grown on drier, upland sites ("green" inventory) could be used to reduce woodyard winter inventories and economically supply a nearby pulp mill during a wood shortage, thus reducing high cost, emergency "spot market" wood purchases. The decision model is incorporated in a spreadsheet and includes all the costs typical for a fiber farm. The model is tested using current establishment and management costs from the literature and

yields from an experimental fiber farm in the southeast. Under current yields, delivered costs from the fiber farm averages $71/ton. With potential increased yields that could occur with genetic improvements and operational optimizations, delivered cost for fiber farm wood could be reduced to $56/ton. In comparison, the highest cost wood purchased by the three cooperating pulp mills during the study period was $50.23/ton. The net present values of a fiber farm as "green" inventory were determined using actual wood cost and inventory levels from three cooperating southeastern pulp mills. For the "green" inventory analysis, all three pulp mills would have lowered their overall wood cost using a fiber farm (with higher yield) as "green" inventory, primarily by reducing the amount of wood required as dry inventory on woodyards. Savings accrued during "dry" years offset the higher cost of hardwood plantation deliveries. A sensitivity analysis was performed to determine the optimal size fiber farm for one of the cooperating pulp mills and indicated that 800 acres would be the most beneficial.

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CHAPTER I. INTRODUCTION

Hardwood Pulp Demand

Pulpwood consumption across the southeastern United States has increased steadily over the past decade as production has relocated from other parts of the country and market demand increased (American Pulpwood Association, 2000). This region now accounts for over 70% of the pulpwood consumption of the United States. The American Pulpwood Association also states that during the 1990s, hardwood usage in pulp mills has also increased as a percentage of raw material furnish, resulting in a 16% increase in total hardwood consumption. Many factors are behind this increase. In many localities, hardwood pulpwood may be cheaper than pine pulpwood (TimberMart, South 1999), and depending on the product output from the pulp mills, hardwood furnish may be more desirable for some mills because of paper qualities. Further still, some companies have developed a niche market by producing a hardwood pulp that is sold around the world where hardwood furnish may not be readily available.

Hardwood Supply Concerns in the Southeast

Throughout the southeastern United States, the hardwood resource is generally available at competitive prices, but during specific winter months it may be very difficult to procure, often causing seasonal increases of hardwood prices. These increases in price are commonly due to wet ground conditions, which may cause problems with in-wood's harvesting and truck transport. While the winter months may have less rainfall than the summer months, the reduced evapo-transpiration causes soils to remain wetter for longer periods. These wetter conditions constrain timber removal, since most companies are reluctant to continue harvesting operations when a threat exists to water quality. Also in the winter, rainfall tends to fall more slowly over a longer period, allowing it to soak into the soil (Frederick, 1979), which leads to difficult woods access as roads become saturated and impassable. As a result of the difficult winter season logging conditions, a seasonal increase in hardwood prices often results, which is particularly true since harvesting cost is often the largest component of delivered wood cost.

Additional concerns for hardwood supply arise from local availability. Many paper companies, in search of higher investment returns, have planted upland sites on company-owned (fee) lands with pine, converting thousands of acres from upland hardwoods to southern pine, a practice that has reduced hardwood supply on fee lands over time. Industry-owned hardwood can still be found growing on thousands of acres of bottomland sites in many regions of the Southeast, but access and availability may be a problem for many stands due to terrain, soil conditions, a high water table and other environmental concerns.

Most of the remaining hardwood stands are owned by private non-industrial landowners who control the decision whether to sell timber and who may be less interested in timber production. Also, timber availability from these sites may be constrained by steep slopes, swamps, limited road access and marginal volume per acre.

While most reports on region-wide timber resources conclude that large quantities of hardwood volumes are present, the availability of the resource for future harvest remains uncertain. Recent social issues have further complicated availability. In some instances companies have located chipmills in areas with abundant hardwood resources, but environmental organizations often express concern about timber harvesting. Foresters view clearcutting of high-graded stands in the mountain regions as being beneficial for regeneration of more desirable species; however, the public is often skeptical about the increase in clearcutting in a region where "selective" harvesting has historically been used. As a result of these environmental and social concerns, locating chipmills in areas with extensive hardwood resources may not be an available solution to the hardwood pulpwood demand in some areas.

The traditional solution to wet weather access problems and other raw material availability fluctuations is to increase pulp mill wood inventories during drier periods. In the southeastern United States, to ensure an adequate volume of hardwood furnish during the winter months (and throughout the year), pulp mills typically "inventory" hardwood pulpwood on company or supplier remote woodyards. Wood, bought and stacked for later retrieval when necessary, is inventoried for short periods (1-6 months), while some wood is inventoried under water sprinklers for longer periods (6-24 months).

Inventory increases typically begin in the fall and peak around the first of the year (beginning of winter) (International Woodfiber, 2000), and are utilized during the few months of the year when wood purchases are often reduced by difficult logging conditions (Figure I.1). The inventory is then further reduced in the spring to a more operational volume based on daily wood consumption. Pulpwood held in remote inventory has additional costs associated with it due to the extra unloading and loading, some deterioration while in storage, and the cost of the facility where it is stored. The additional costs associated with this wood storage are considered "insurance" against the pulp mill running out of wood. During a mild winter, this wood may not be needed but must be consumed because it will deteriorate. The stored wood is then supplied to the mill at an above-average cost. Purchasing and storing excess wood inventory is costly for pulp and paper companies, but is the traditional way to ensure a constant supply of wood for the pulp mill during the winter period.

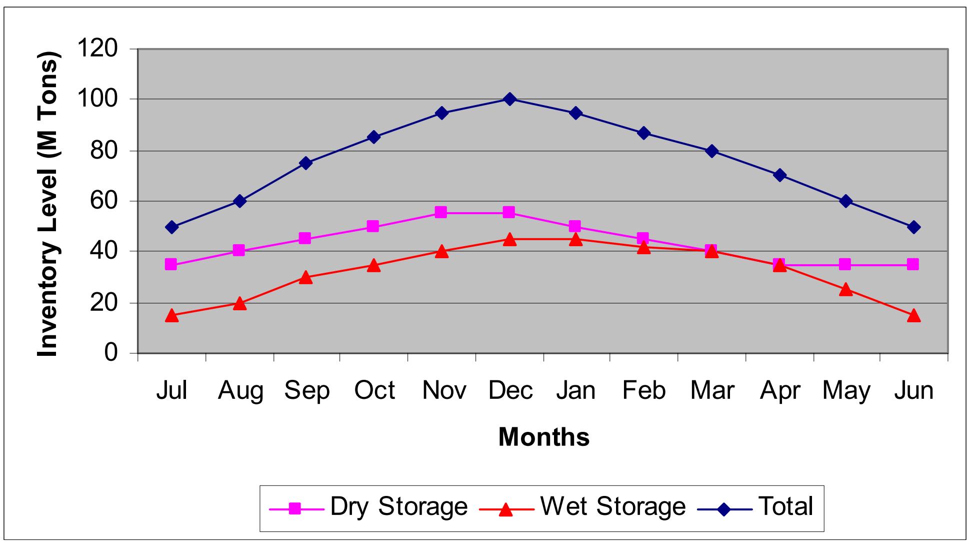


Figure I.1. Hardwood inventory levels for a southeastern pulp mill peak around the first of the year (International Woodfiber, 2000).

Green Storage

In the Pacific Northwest, wood procurement has become a year-round problem, due primarily to a massive reduction in the volume of timber harvested from national forests. In response, some companies have established intensively-managed, short-rotation, hardwood plantations to supply their mills with fiber (Kaiser et al., 1994) (Figure I.2). These plantations are intensively cultivated, irrigated, and fertilized. With this level of intensive management, it is possible to grow 90 Mg of dry hardwood fiber per hectare (40 tons/acre) on a planned rotation of 7 years (Withrow-Robinson, 1994). In this region, the high costs involved with intensive plantation management are necessary to ensure a raw material supply for pulp mills in the region. In the southeastern United

Figure I.2. Seven year-old hybrid poplar plantation in the Pacific Northwest.

States, the cheaper cost of hardwood during much of the year makes short-rotation hardwood plantations more difficult to justify economically. In an analysis completed for the Southeast in 1998, Bar (1998) estimated current prices for fiber and projected costs for fertigated (fertilizer applied during the irrigation process) hardwood plantations. Those findings predicted that it would be several years before hardwood stumpage prices in the Southeast increase to the level necessary to justify intensive culture plantations as a daily source of fiber.

However, intensively-managed, short-rotation hardwood plantations located near the consuming mill could be economically and operationally feasible in the Southeast as a cost-effective alternative to the annual storage of large volumes of hardwood pulpwood inventory. For example, if the procurement organization for a pulp mill has determined that it requires 100,000 tons of hardwood fiber available to carry the mill through the winter months, potential savings could occur if alternatively, 90,000 tons were inventoried in conventional storage methods, and 10,000 tons were inventoried on hardwood plantations. During a mild winter, the plantation wood may not be utilized, allowing the trees to grow for another year. Thus, only 85,000 tons would need to be inventoried the next year before winter arrives, as the plantations would now make up the other 15,000 tons. While this inventory plan cannot go on indefinitely (there is an upper level to how much volume the plantations may replace), there could be potential savings from long-term plantation establishment versus using short-term wood storage methods.

Research Objectives

The objective of this study is to develop a methodology to analyze the cost feasibility of short-rotation, intensively-managed hardwood plantations in the Southeast and test whether they are cost effective for either direct pulp mill delivery or as "green" inventory in today's economy. The research project has the following specific tasks:

1. Develop a decision model for managers that includes the major cost components for establishing intensively-managed (fertigated) hardwood plantations in the southeastern Atlantic coastal plain.
2. Use this model and the best available component costs from literature to validate the decision model and estimate wood costs for eastern cottonwood plantations.
3. Use the wood cost estimates and actual hardwood cost data from three cooperating southeastern pulp mills to determine the cost feasibility of eastern cottonwood plantations for supplying emergency wood supplies or "green" inventory during wet weather conditions.

CHAPTER II. LITERATURE REVIEW

This literature review consists of two sections: information on hardwood silvicultural systems and information on wood inventory practices and systems.

Hardwood Silvicultural Systems

Natural Stands

Hardwood forest types occupy over half the timberland area in the South, totaling 38 million hectares (93 million acres) (USDA Forest Service, 1988). Two-thirds of this hardwood acreage are classified as upland hardwoods and one-third as bottomland; hardwood plantations make up an insignificant amount (less than 1%). A typical upland hardwood stand, which occurs throughout the South in the highland area, includes oaks (*Quercus spp*.) and hickories (*Carya spp*.), with some yellow-poplar (*Liriodendron tulipifera*), sweetgum (*Liquidambar styraciflua*) and maples (*Acer spp*.). Sites that occur in coves and moist flats may be very productive and contain commercially valuable species of northern red (*Quercus rubra*) and white oak (*Quercus alba*) and yellow-poplar.

Bottomland hardwoods are found in the coastal regions and along the alluvial floodplains of many major rivers across the South. Sweetgum is the dominant species with tupelos (*Nyssa spp*.), willows (*Salix spp*.) and some oaks. There are 12 million hectares (30 million acres) of bottomland hardwood in the South, about 17 percent of all timberland. Figure II.1 lists the distribution of growing stock among the hardwoods for both upland and bottomland sites.

The USDA report, “The South’s Fourth Forest” also indicates that a majority, 73%, of these hardwood stands are owned by the private non-industrial landowner with the remaining ownership evenly split between public and forest industry. The large hardwood acreage held in private ownership makes it questionable whether timber from these lands will be available for industry consumption. The majority of landowners in the South may be absentee landowners who are agreeable to harvest timber (Cordell et al., 1998), but a survey indicates only 3% of landowners listed selling timber as a reason for owning the land. In addition, accessibility to many upland stands is a problem due to steep slopes and rocky soils, and bottomland sites offer difficulties with moist soils and high water tables; therefore both sites may require specialized harvesting systems.

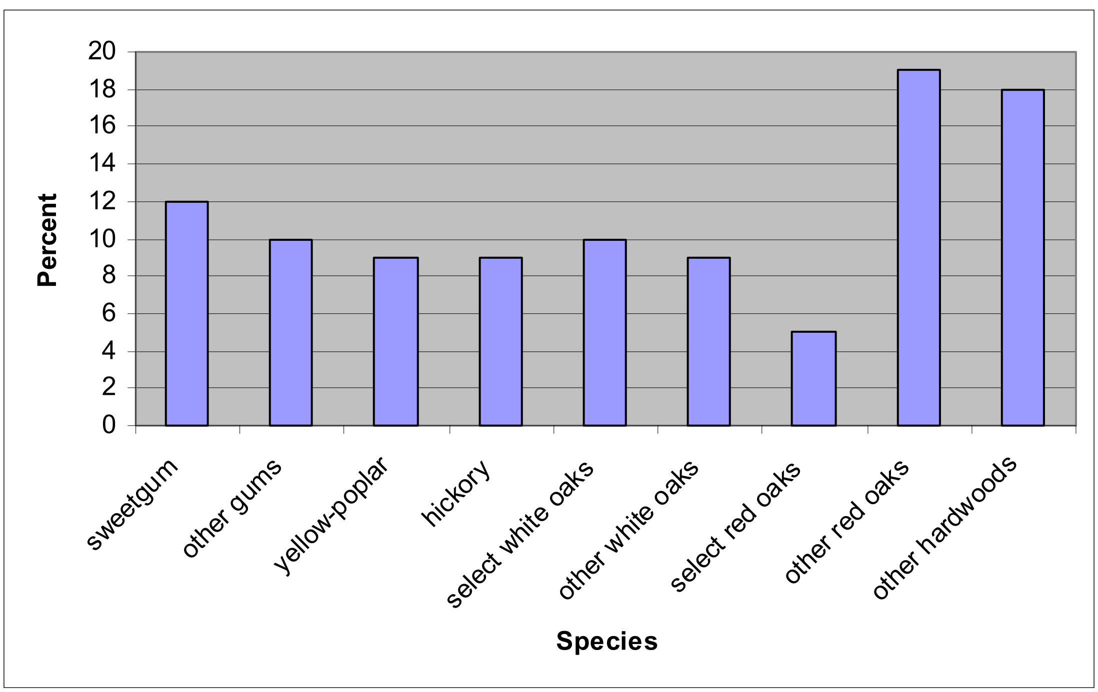


Figure II.1. Percent distribution of hardwood growing stock in Southern forests (USDA Forest Service, 1988).

The same USDA Forest Service report also indicated that a small amount of hardwood volume does occur as a component of natural pine forests, and this material may be available for industry consumption without some of the difficulties associated with the hardwood types mentioned above. But as intensively managed plantations become the norm for pine, this hardwood component may become scarce.

Hardwood Plantations

While hardwood plantations in the Southeast are uncommon, some do exist; in fact a few companies have been experimenting with hardwood plantations for 30 years or more.

Species selection. While many species have been evaluated for superior growth characteristics, most of the field trials have centered around four species: sweetgum (*Liquidambar styraciflua*), American sycamore (*Platanus occidentalis*), eastern cottonwood (*Populus deltoides*), and hybrid poplars (crosses of *Populus deltoides, P. trichocarpa* and *P. nigra*) (Steinbeck, 1999).

Sweetgum is a typical southern bottomland hardwood and, for the most part, occurs on rich, alluvial soils, but can adapt to many soil conditions. Sweetgum can be found in stands of mixed hardwood or as understory in a southern pine stand. Sweetgum may have fairly rapid growth depending on the site, it resists diseases and insects, and its long, straight bole is favorable for industry use (Hardin et al., 2000). In plantations, sweetgum begins growth relatively slowly, but accelerates during the second and third years (Steinbeck and Brown, 1976), and it tolerates changes in soil drainage better than many other species.

Sycamore can be one of the largest of eastern hardwoods and is very adaptable to site conditions, though it is found more in bottomlands. Growth tends to be fast, and is aided by its large leaves and spreading crown. Short-rotation managers like sycamore because it shades the ground very well and minimizes the need for weed control (Hardin et al., 2000). Sycamore plantations initiate rapid height growth during the first season, but growth rate typically declines in later years (Steinbeck and Brown, 1976).

Eastern cottonwood, a natural choice because it is potentially the fastest growing species in the South, is another bottomland species that thrives in moist, alluvial soils (Hardin et al., 2000). Even in natural conditions, young trees commonly grow 2 meters (6 feet) or more in height and 3 centimeters (>1 inch) in diameter yearly.

Experimental cottonwood plantations were established in the 1940s in the Midsouth, and were followed by commercial-scale plantations in the 1960s (McKnight, 1970). Plantation research centered on site preparation requirements (Kaszhurewicz and White, 1976), cultivation (Kennedy and Henderson, 1976), spacing studies, and application of thinning and pruning (Gascon and Krinard, 1976).

Hybrid poplars are being grown in many regions of the country in short-rotation applications, though yields are greatly influenced by clone and site (Hansen et al., 1992). They have tremendous growth in height and diameter as long as they are kept in moist soils. Although they are capable of resprouting from their rootstock after a harvest, reestablishment is recommended to take advantage of the improved crosses (for insect and disease resistance) that are being developed each year (Tuskan, 2000).

While hybrid poplars are being used extensively and successfully in the West and Lake states' areas, the other three species are being tested in trials around the South. An ongoing study by Champion International compared the growth of these species in irrigated and non-irrigated conditions (Cox and Leach, 1999) and showed that all three species improved significantly in growth with water and nutrients added; cottonwood volume outperformed sycamore by 40% and sweetgum by more than double. It was this strong growth performance that convinced Westvaco Corp. to use it for small, operational hardwood plantations in South Carolina and Missouri. Cottonwood does have the shortcoming of being more susceptible to insects and disease, but both may be treated through the irrigation system.

Another consideration in species selection may be the potential yield from a selected species. The yield of pulp per unit volume of wood is usually directly related to density (Smook, 1992). The higher the density, the better the yield. Therefore an oak with an average density of 63 lbs/cu ft will yield more pulp than a cottonwood whose density averages 46 lbs/cu ft (Wenger, 1984). Hybrid poplars have further been studied to determine various pulping qualities. Goyal et al. (1999) found that plantations grown in drier, warmer climates had slightly longer fibers and higher specific gravities and pulp yields than similar plantations grown in cooler, wetter environments. Ideally, pulping characteristics for the chosen species can only be optimized with separate cooking environments, which is very unlikely in the high production pulp mills of the Southeast.

<u>Site selection and land value issues</u>. Land managers must understand site qualities to maximize the economic return of plantations, whether hardwood or softwood. Baker and Broadfoot's (1979) publication quantified site quality and tree growth based on four soil factors: 1) physical condition, 2) available moisture, 3) nutrient availability, and 4) aeration. Their study concentrated on 14 different hardwood species, producing

individual tables that quantified each of the 4 variables for each species. By comparing these 4 variables against the guide, site index may be estimated for a species on a given site. This system has been tested over the years on many sites (Groninger et al., 2000), and found to be an accurate indicator of site quality, especially in bottomlands.

Most hardwood plantations are placed on old fields or riparian zones where growth may be maximized with minimal silvicultural practices, but operability may be limited during certain times of the year when the ground is saturated. Operability for short-rotation hardwood plantations will have a high priority if they are to be available year round (Figure II.2). The four site variables specified by Baker and Broadfoot can be manipulated through silvicultural operations to maximize growth potential while still maintaining the operability characteristics needed to have the material available whenever necessary.

Figure II.2. Four year-old eastern cottonwood on a dry site, which allows for high operability, in South Carolina.

Placing the plantations on high, dry, sandy sites will allow for year-round access. In the Southeast, these dry, sandy sites also have the advantage of typically carrying lower land values if they are distant from urban sprawl; while agricultural lands may run $2500 to 4500/hectare ($1000 to 1750/acre) and good, plantable forestry sites cost $1000 to 1500/hectare ($400 to 600/acre), these sandy sites may be available for $600 to 900/hectare ($250 to 350/acre) (Bush, 2001).

Soil Properties. Soils supply essential nutrients and water to the trees if three conditions exist: 1) water and nutrients are in available forms in the soil, 2) roots are able to grow to where the water and nutrients are located, and 3) a transfer of the water and nutrients takes place from the soil to the roots (Morris and Campbell, 1991). Some of the several soil physical and chemical properties that influence water and nutrient availability are mechanical impedance, water storage, aeration, temperature, soil pH, and presence of certain nutrients.

Soil fertility will have to be closely monitored to maintain growth rates. The rate of nutrient removal through harvest will be highest in fast growing, short-rotation plantations that are harvested frequently (Nambiar, 1996). Nutrient deficiencies (especially for nitrogen, phosphorus and potassium) may be exasperated because of little accumulation of litter due to high rates of decomposition and the low rate of return of woody residue. Foliar analysis and/or soil testing will determine which nutrients are limiting growth and should be applied to enhance growth. Consideration could be given to ground water contamination to prevent long-term environmental problems, but recent studies indicate little effect on water quality from fertilization (Tolbert et al., 2000).

Regeneration source/establishment method. Short-rotation plantations are generally established using genetically superior seedlings from state and/or company-operated forest nurseries. Considerable research has been completed to determine which clones produce the greatest yields and are best for specific sites (Hansen et al., 1992). Clonal selection is usually based on rooting and survival of cuttings, rapid growth, disease resistance, and pulp quality. Hybrid poplar is the species receiving the most attention for short-rotation plantations. Studies are being conducted in most regions of the country where short-rotation plantations are being investigated.

Coppicing is being used in plantations of woody species whose main product is biomass for energy. In fuel plantations, volume is the most important criteria, and generating many sprouts from a single stump will enhance yield. Species with good coppicing ability are found in *Salix, Populus, Eucalyptus, Alnus* and *Betula* genera (Sennerby-Forsse et al., 1992). Plantations of these species will provide three to five harvests before the site must be re-prepared and planted with new seedlings.

For short-rotation plantations whose purpose is pulping, seedlings will be planted for each rotation. This is because a single uniform bole is desired to maximize yield of pulp quality chips from the plantation and so improvements in genetic stock during the 6 – 10 year rotation can be taken advantage of. Also, most sites require minimal site preparation for the second rotation to be established (Figure II.3).

Site preparation and planting methods. Intensive forest management involves manipulating soil and stand conditions to ameliorate factors that limit tree growth (Fox, 2000). Intensive site preparation is critical for the successful establishment of a plantation (Kaiser et al., 1994). Depending on site preparation, the resulting growth rates

Figure II.3. One-year old second rotation hybrid poplar planted between first rotation rows in eastern Oregon. These trees are grown for seven years and then harvested for pulpwood.

may vary greatly over the stand rotation. Several operations are available to maximize hardwood plantation growth.

<u>Chopping</u> – Chopping involves pulling a large drum across the site to break up the residual slash and to crush the natural regeneration. While it has little value for improving soil conditions, this treatment is based on its value for reducing slash and improving conditions for subsequent operations, such as burning (Morris and Lowery, 1988).

Disking – Soil disking, or tilling, involves pulling a series of large diameter, saucer-shaped steel blades across the site (Figure II.4). Disks may be pulled by either a crawler tractor or a large 4-wheel drive agricultural tractor. The purpose of disking is to ameliorate soil compaction in the upper 30 cm (12 inches) and to incorporate organic surface layers into the underlying mineral soils; another benefit is to minimize weed re-sprouting. Disking also improves the soil for increased rooting by the seedlings because of better aeration and moisture movement (Morris and Lowery, 1988), and if done during the summer, may reduce hardwood sprouting because the residual root system is severed.

Figure II.4. Example of a disking plow for soil tillage.

Planting – Hand planting is commonly used for short-rotation establishment because with hand planting the seedling can be inserted in the ground directly under the drip tube release point to allow for maximum water and nutrient supply to the seedling. A good hand planting crew can plant 600 to 1500 trees per man-day if the site and seedlings are good (Smith et al., 1997). The crucial quality for hardwood planting is getting good soil contact with the seedling root system.

Spacing - Spacing of trees will vary somewhat by region and species, but is most affected by product objectives (Netzer and Hansen, 1994). Short-rotation plantations for fuel typically have a close spacing: 1.2 meters between rows and 0.3 meters between trees (4 feet by 1 foot). However, a larger stem is required for a pulpwood product, so spacing is extended to 3 meters between rows and 2.4 meters between trees (10 feet by 8 feet). Recent plantations on the West Coast with a building product objective were planted on a 3.7 x 3.7 meter spacing (12 feet by 12 feet) (Stanton et al., 2002).

Weed Control - Most agronomic strategies for controlling weeds begin at site preparation and continue during the first two years of plantation establishment (Schuette and Kaiser, 1996). Continued weed control is important for hardwood plantation success, especially for Eucalyptus (McNabb, 1994). Weed control begins immediately after planting with an over-the-top application of various pre- and post-emergent herbicides. Tilling between rows can be used during early tree development. Later, shading will prevent most herbaceous weed growth after crown closure; typically shading will occur by the end of the second growing season. Some companies will apply herbicides during the last year of growth to provide advanced weed control for the next rotation.

Fertilization – The correct fertilization regime, with respect to timing and rates, can be one of the simplest ways to improve crop production (Mitchell and Ford-Robinson, 1992). For short-rotation crops, fertilization is required and will vary with different regions: some areas may need a light application, which can be accomplished with a four-wheel ATV and spreader. Helicopters with cyclone-type spreaders may provide a more uniform fertilizer application if cost is not a limiting factor.

For irrigated plantations, fertilization is often accomplished using liquid fertilizer administered through the irrigation system (fertigation). Daily applications of fertigation, primarily of nitrogen and water, occur during the growing season.

Irrigation - The plantations with the highest yield are those with irrigation systems supplying water to the trees and the irrigation system should be designed specifically for the tree crop. While drip technology is relatively new to forestry, it has been used successfully in agriculture for many years (Bar, 1996). Because irrigation should enhance tree growth rather than merely enhancing survival, providing the correct amount of water available daily is crucial to maximize potential of the plantation. Drip irrigation supplies a continuous wetted strip along the tree line for the first two years (Figure II.5), then, as root systems spread, the irrigation lines may be moved between the rows which makes water available to the tree while maintaining good soil aeration.

While many factors are involved in determining the amount of flow through the irrigation system, the type of soil and the age of the plantation are the two main factors affecting application rates. Local rainfall may also vary the watering schedule, which typically calls for water every other day. Mature plantations require much more water than young plantations.

Figure II.5. With a typical fertigation system, twenty-millimeter drip tube provides water and fertilizer to trees.

Drip tube maintenance is a continuous process (Wierman, 1994): lines must be flushed regularly, animal damage may occur and require immediate attention, and finally, the drip tubes must also be lifted and removed before a harvesting operation, then re-laid for the next rotation.

As mentioned, an added benefit of a drip irrigation system is the ability to apply liquid fertilizer during regular intervals in a cost effective manner (Figure II.6). Reduced labor costs, no soil compaction or stand damage during application, and accurate and uniform distribution are among the advantages associated with fertigation. Also, various insecticides may be added to control some insect problems, if needed.

Figure II.6. Tanks store fertilizer for daily applications through the irrigation system.

Another added benefit of a drip irrigation system is the ability to use outside sources of water (Madison and Brubaker, 1996), including mill effluent, domestic wastewater, or other industrial wastewater. While using any of these sources may have multiple advantages (the plantation gets water and the supplier disposes of wastes), the amount of dissolved solids in the water must be minimized to prevent drip line blockages. Therefore, a good filtering system must also be used during application of these sources of water.

The disadvantages of a drip irrigation system include the high initial capital cost for purchase and installation, as well as the annual maintenance costs to keep the system operating to its potential. While this cost component is a large percentage of plantation establishment and management, a drip irrigation system will often be required for a successful short-rotation hardwood program.

Intermediate operations. For most short-rotation hardwood plantations, there will be few intermediate operations other than adding water and fertilizer. As discussed, rapid crown closure minimizes the need for competition control by the third year. Also, the dense canopy will prevent most woody plants and weeds from sprouting.

Pre-commercial thinnings or intermediate cuttings are unnecessary for a pulpwood objective. A study completed in Georgia (Steinbeck, 1998) measured total volume removed from a site using different cutting cycles. While the harvest regime using multiple cuts over 15 years had larger diameter trees at the final cut, the stand with only one harvest at the end produced greater total volume than the multiple harvests. For a pulpwood objective, intermediate cuttings would likely result in reduced total volume.

Nutrient availability and uptake are important to maintain rapid growth in short-rotation hardwood plantations. There are two conflicting approaches to nutrient management in short-rotation plantations (Heilman, 1992). The conservative approach, which calls for adding fertilizer to a site only when the diminished supply begins to affect growth, uses minimum amounts of fertilizer and therefore reduces some annual investment in the plantation, but may not assure maximum growth.

The contrasting approach (from the same report) is to keep fertility at a high, steady state to assure optimal nutritional value in the plantation. This process has been used for a long time in higher value agricultural crops, but is now being proposed for short-rotation plantations. Most companies are practicing nutrient management at an intermediate level to these two approaches to minimize costs and potential leaching. Concerns about nutrients in the water supply from fertilization have been addressed in recent studies. While Tolbert et al. (2000) and Binkley et al. (1999) found little impact in stream runoff, they did acknowledge that there were major limitations in current knowledge on the effects of repeated fertilization in short-rotation plantations.

Knowledge of soil fertility is essential for appropriate fertility management. Foliar analysis and soil testing can be used to determine what nutrients may be in short supply, though a significant amount of annual nutrient demands can be met from internal cycling and litter decomposition. As nitrogen is the main nutrient restricting growth of forest trees, annual applications of 30 – 80 kg per hectare may be needed (Ericsson et al., 1992), and can be easily applied through the drip irrigation system.

<u>Rotation lengths</u>. For short-rotation hardwood plantations, rotation lengths will vary depending on region and plantation objectives. Boise Cascade and Fort James in Oregon are managing strictly for pulpwood material, and rotations are six to eight years (Wierman, 1999). In that of time, they are growing trees to an average of 18 centimeters dbh and 26 meters in total height (7 inches and 85 feet). The objective of Potlach Corp. in Oregon is to produce a 7 meter (21 feet) peeler log from the base of their trees. They

are managing their plantations on a 10 year cycle and doing some intermediate pruning to enhance the quality of that first log.

Harvesting. Depending on the intensity of management, the stand will normally be available for harvest around year seven. Currently, two equipment systems are being used to harvest these stands where a pulp mill is the primary market (Hartsough et al., 1996):

1. Feller/buncher - grapple skidder – chain flail delimber/debarker – mobile chipper – chip vans.
2. Feller/buncher – grapple skidder – mechanized delimbing - log loader – tree length trucking.

In both cases, the feller/buncher may be a small machine as the diameter of the trees rarely exceeds 25 centimeters (10 inches). For example, a Hydro-Ax 411 is a 120 HP four-wheel feller/buncher capable of a small sawhead for high speed felling. The high number of stems per acre offers advantages to a limited-area type machine. Its ability to minimize movement within the stand and fell multiple stems quickly allows high production while also reducing soil disturbance (Greene and Reisinger, 1999) (Figure II.7).

Both systems perform well with the end market (chips or roundwood) determining which is more viable. The chipping system has been used where harvesting is performed on a more scheduled regime, with a set amount of volume harvested each week. This system delivers clean chips into the pulp mill, with the residuals (bark, limbs and foliage) from the chipping operation usually processed in the field and sent to a market as fuel. This system will include one or two feller/bunchers, three skidders, a

Figure II.7. Limited-area feller-buncher harvesting a seven year-old hybrid poplar stand in eastern Oregon.

hydraulic knuckleboom loader, a chain flail debarking chipper and numerous trucks and chip vans. Capital costs for an operation of this size may exceed $3 million. The large capital investment in this system requires that it be run on a weekly basis, necessitating a continual market for the plantation material.

The second system, a more conventional longwood system, may consist of one feller/buncher, two skidders, a loader and a few treelength trucks. Capital cost will usually remain around $1 million. This flexible system may be employed harvesting traditional plantations and natural stands in the area, and be called on to harvest a short-rotation hardwood plantation only when the pulp mill needs additional volume. Here the residuals are typically left in the woods to decay and supply additional nutrients to the next rotation. The treelength material from this operation is delivered to the pulp mill woodyard for debarking and chipping. This system allows the procurement personnel to wait and harvest the short-rotation hardwood plantation only when it is necessary to meet a raw material shortage.

Costs and Returns of Short-Rotation Plantations

The costs versus returns of short-rotation hardwood plantations were first studied in the late 1970s and early 1980s as a consequence of the energy shortages of the 1970s. Researchers believed that short-rotation plantations could fill an energy demand for fuel by substituting wood biomass for oil or coal.

Bowersox and Ward (1976) evaluated the cost portion of producing and harvesting fiber for three hybrid poplar clones planted on abandoned fields in central Pennsylvania. They looked at yields from first and second rotation crops grown for two to four years in each rotation, and evaluated tree spacing. Yield ranged from a low of 0.0 to a high of 5.0 oven-dried tons/acre/year for their fiber fuel plantations. They also estimated costs for land rent, site preparation, annual maintenance and harvesting. The lowest production and harvest cost for one clone was $8.24 per oven-dried ton grown on a three-year first rotation followed by a four-year second rotation. While this was not an attractive price for many investors, a landowner with marginal producing farmland or a fiber industry in need of inventory insurance may have found it feasible.

Rose and DeBell (1978) followed with a similar study that expanded the analysis to include wider spacing and longer rotations than did Bowersox and Ward. They also added fertilization to the management practices. Using a set product price of $35 per oven dry ton, they found that very short rotations (2 years) were not feasible, but longer rotations of 10 years could provide a positive internal rate of return on investment. Wider spacing of trees (2.4 meter by 2.4 meter) along with annual fertilizer applications yielded better returns.

In 1981, Lothner et al. (1981) undertook a study to help bridge a gap between theory and practice and looked at the economics of short-rotation plantations in the Lake States. Along with the standard intensive practices of short-rotation management, irrigation was added to the operation. The study evaluated two spacings: 1.2 meter by 1.2 meter and 2.4 meter by 2.4 meter (4 feet by 4 feet and 8 feet by 8 feet), and three rotations: 5, 10, and 15 years. Irrigation and fertilization were treated as optional operations, while site preparation and weed control were assumed the same for all alternatives. The study estimated costs for all the silvicultural practices associated with short-rotation management. Using current market prices for whole-tree chips, they determined the internal rate of return and the net present worth (10% discount rate) for several alternatives. They concluded that none of the alternatives had a positive net present worth under their cost estimates. Longer rotations did have the better investment performance, and the product may have more uses to a pulping operation, but they also offer a higher risk component.

An energy and financial analysis using short-rotation hybrid poplar for biomass production was completed in 1984 at The Pennsylvania State University (Strauss et al., 1984). All aspects of plantation establishment and maintenance were cost analyzed on a commercial scale basis, with the major product being biomass for energy. A linear programming model of a working unit determined the most financial and energy efficient approach among various strategies. Irrigation, fertilization, and land rent were found to be the major costs for short-rotation plantations. While substantial net energy gains were recorded, their financial profiles displayed mild to modest limits. The basic problem was that costs were too high relative to the product output.

A 1986 study looked at short-rotation hybrid poplar investments using stochastic simulation (Lothner et al., 1986). It used standard discounted cash flows for the analysis, but added stochastic simulation to provide a mean estimate of financial performance. Land purchase, site preparation, planting, maintenance, and administrative costs were estimated along with product yield and value. Results indicated that the net present value per acre could range from a negative $310 to a positive $1010 with a mean value of about $140, using a 4% discount rate. Product price was found to be the major cause of uncertainty surrounding the financial returns for the 30-year study that included two 15-year rotations.

Golob (1986) extensively analyzed short-rotation plantations that included costs for all the various operations. He included equipment purchases and production rates for many of the operations such as site preparation and harvesting. He did not include irrigation costs, but found that short-rotation fiber plantations could provide biomass for energy and fiber applications for 5- and 10-year rotations and the final costs for these plantations make them competitive with fuel oil and natural gas.

A more recent study looked at the economic potential of short-rotation, hybrid poplar plantations on agricultural land for pulp fiber (Alig et al., 2000). This study used a model to determine what impact 600,000 – 1.1 million hectares (1.5 – 2.8 million acres) of plantations could have on the forest industry and agricultural markets. Using given cost and yield data, various amounts of short-rotation woody crops were deemed feasible for the Pacific Northwest and the Lake States' regions. Plantations in the South and Corn Belt both resulted in less potential, but for different reasons. The Corn Belt results were driven by the high value of agricultural land. In the South, projected large investments in southern softwood production along with the relative availability of smaller trees for pulp fiber on the larger timberland base reduced the financial attractiveness of short-rotation plantations.

With over 20,000 hectares (50,000 acres) currently in production, hybrid poplar is a new addition to the Northwest's agricultural economy (Stanton et al., 2002). While these plantations were developed primarily as a raw material for the paper business, falling prices for hardwood wood chips are driving the market toward solid wood products. The future of these plantations will depend largely on projected shortages of alder (*Alnus rubra*) sawtimber, the impact of imported fiber from plantations in the Southern Hemisphere, and the possible development of a market for tradable carbon credits.

Storage – Wood Inventory Systems

Why Keep Inventory?

Due to the uncertainty of wood flow into the pulp mill, companies have traditionally maintained an inventory of wood. The independent logging contractor force in the Southeast tends to work on a five-day/week schedule and only during the daylight hours (for safety reasons). However, because the pulp mill consumption is 24 hours, 7 days per week, inventory is essential. Attention must be given to inventory management to ensure that adequate quantities of wood are available when needed (Deal, 1981), as wood from logging operations cannot be expected to be received evenly throughout the year.

Managers want to keep the wood supply rotated to minimize aging of the inventory, so this inventory is generally stored using a first in, first out method (FIFO). Storing inventory is costly; most companies estimate that 20% or more of inventory costs are spent on carrying costs (Siedlecki, 2001). Carrying costs include the monetary costs of financing; inventory takes up space and requires storage areas; it ties up money resulting in an opportunity cost; it may need to be insured, and can possibly be taxed; it needs to be managed (which involves more personnel); and most inventory has a limited shelf life. All these carrying costs added together may easily exceed 20% of total costs for inventory.

Just-In-Time Inventory Management

A method to minimize the costs associated with keeping inventory is "just-in-time" (JIT) inventory management. The main goals of JIT are to reduce inventory and its associated carrying costs (Beard and Butler, 2000), and to minimize the time the inventory is stored before processing. Estimates suggest that JIT has saved the automotive industry more than $1 billion per year in inventory carrying costs over the past decade (Mercer, 2002). JIT is also used extensively by the food service industry, where minimal shelf life is important to food quality.

Adopting a JIT philosophy for inventory requires the strong support of suppliers, because they bear much of the responsibility for deliveries. A company decision to minimize inventories has many benefits to the company such as less space, fewer personnel, and fresher raw materials. But the supplier must now take additional steps to ensure continuous deliveries, which, according to Mercer (2002), most suppliers expect to be compensated for. While this additional compensation will reduce some of the savings JIT will bring to a company, the potential benefits of JIT can still far outweigh storing large quantities of raw materials. Even with JIT in place, however, inventory planning is still about uncertainty, as supply chain disruptions and economic hardships can put it to the test (Aichlmayr, 2001). This is especially true for the wood business, where varied weather and markets affect deliveries.

Concern remains that any disruptions in transportation flow or the inability of suppliers to meet their contracted terms put the company at risk of mill curtailments (Nesbitt, 2001). Because of these concerns, wood procurement organizations have not yet adopted the JIT philosophy because of the high cost that occurs if a pulp mill needs to stop a production line due to lack of furnish. While the wood industry may never be able to reach full compliance with JIT principles because of the schedule conflict between logging and pulp mill production and the operational difficulties in the woods, adopting any JIT practices may be beneficial for reducing inventory costs

Inventorying a raw material is not unique to the forest products' industry. The farming industry inventories much of its products during the year, but for different reasons. In farming, harvest must occur within a short time as crops mature, but consumption is evenly spaced throughout the year (Benirschka and Binkley, 1995). Farmers will hold their product, which involves more cost, in hopes of capitalizing on a better market price. But they can only hold their product until it's needed in the marketplace if the product is held in a quality storage facility (Derickson et al., 1991). Forestry is similar in that the industry faces possible uneven production from the woods (caused by independent contractor work schedule and bad weather impacting operations), yet consumption is evenly spaced throughout the week and year.

Because of these different production and consumption levels, some inventory is required because companies do not want to run the risk of curtailments (Winer, 1982). As noted earlier, the quantity in storage will vary with the season. How much inventory should be stored has been debated for many years. Reports by Beckett and Associates (1966) and Turner (1972) concluded the Canadian woods industry was carrying excessive amounts of inventory at a cost of $6 to $9 million annually.

A stochastic simulation model developed by Galbraith and Meng (1981) as a tool to assist managers in developing inventory strategies used probability distributions for both roundwood demand and deliveries to determine inventory levels for an existing mill in New Brunswick, Canada. By setting rates for cost of capital, handling inventory and running out of inventory, a safe operating inventory level was developed.

In a follow-up comment to the Galbraith and Meng publication, Winer (1982), a manager for Mead Corporation, validated their methodology. Winer independently developed a similar model to optimize inventory levels for a mill at Kingsport, Tennessee. He observed most locations were not using any inventory model applications because companies failed to recognize the stochastic nature of both wood supply and consumption. Also, many managers were unwilling to consider the marginal cost of running out of wood. Winer states that most wood procurement managers will prevent a wood shortage at any cost and therefore go into a winter with a wood pile so large that running out of wood is inconceivable.

Determining optimum inventory levels was revisited in 1997 when LeBel and Carruth developed a spreadsheet for industry use. They used similar probability distributions for deliveries and consumption, but went into more detail on the supply capabilities of the contractor force. Specifically, production and capacity utilization for both harvesting and trucking, mill demands, inventory levels, and weather impacts were all designed into the model. Trial runs indicated that keeping a small buffer in the woods significantly reduced the number of days the paper mill would experience low inventories. While determining optimal inventory levels is best approached by running a probabilistic model, where and how to keep that inventory is another challenge.

Dry Storage

Pulp and paper mills typically store large volumes of wood to prevent wood shortages during the winter when logging is difficult due to wet conditions. Wood is stored at the mill woodyard, although mill space is often limited. Companies will store as much wood as feasible in the pulp mill woodyard so that wood is available as needed. This may be as little as four days to as many as seven days of daily wood demand, depending on space limitations. Most, if not all, of this material will be stored in chip form, so it is readily available for the digesters. The remaining volume will be in roundwood form and very accessible. Over time, the size of pulp mill woodyards have generally been reduced as companies either expanded or upgraded pulp and paper making operations and used the valuable real estate assigned as wood storage areas.

Additional volume is inventoried at “remote” woodyards, located in the surrounding areas. Remote woodyards are opened to increase the procurement zone from which wood purchases are made, and to allow for additional volume to be stored. These dry storage sites keep wood on the ground for as short a time as a few days to as much as six months. During cooler times of the year, wood degradation is minimized and can be stored for a longer period of time. Additional costs are associated with this material inventoried on remote woodyards including wood deterioration, handling, and transportation.

Wood deterioration affects this supply by reducing volume (USDA Forest Service, 1999). Several studies have shown that changes in specific gravity cause losses in pulp yield from wood stored for a prolonged period. Losses in specific gravity of green pine pulpwood in the southern region ranged from two to ten percent for wood stored two to six months (Lindgren, 1953). Similar studies done on hardwood species confirmed a loss in tearing strength from wood stored six months (Ference and Gilles, 1956). Other problems associated with dry storage of pulpwood occur during processing, where the wood may break up during debarking, grinding and chipping (Turner, 1950).

Older material tends to break more readily during processing, causing debris to fall through or plug the system, and older material tends to chip into smaller pieces, possibly causing excessive pins (undersized chips).

Handling costs are incurred as the material is unloaded from the logging trucks and placed in inventory on the ground at the remote woodyard. This cost occurs again when the material is later retrieved and loaded on either trucks or railcars for delivery to the pulp mill. Finally, there is the associated transportation cost of getting the wood to the mill, which may be somewhat offset by the reduced cost of hauling the pulpwood a shorter distance from the woods to the remote woodyard than a longer distance to the pulp mill.

Operationally, the most important practice for dry storage is wood rotation. To prevent deterioration from impacting the wood too much, it is very important to work on a first in, first out flow. In this system, wood is typically piled in different areas (called bins) and arrival dates are recorded (Figure II.8). Most dry storage yards are spread out, so wood can be stored in different rows. As the time arrives for reloading the wood onto trucks (in three to six months depending on the time of the year), the oldest wood is loaded out first. Some companies are replacing traditional remote woodyards with temporary "surge" woodyards, where wood is bought and stored beginning in September or October, then loaded out in the winter as needed. If demand does not materialize during the winter, the wood is shipped to the pulp mill during the spring because it has reached its storage life. The "surge" woodyard then remains closed until the following September when it is time to build inventory levels again.

Figure II.8. Wood is stored in bins for later shipment to the pulp mill.

Dry storage of wood inventory may take place as roundwood or chips. Advantages to storing as roundwood include ease of material rotation (because of the many bins that are used); the need for less expensive equipment for unloading and loading (a simple hydraulic log loader is sufficient); and ease with which the remote woodyard location can be changed, as wood purchases from a specific area will vary over time due to stumpage availability.

A disadvantage is that transportation can be a problem. A truckload of roundwood is visually unappealing, and with numerous, highly visible loads of woods moving down the highway, public pressure may become a problem. Rail woodyards escape this concern, but deliveries may be a larger problem due to unreliable train arrivals.

The advantages of dry storing chips are that the material is in the form the pulp mill needs and transportation tends to be easier and cheaper (Martin, 2000). While a truckload of roundwood is very visible and may be messy (with dirt and bark falling on the highway), a truckload of chips tends to be anonymous and clean. Also, lightweight trailers and evenly distributed loads allow most chip trucks to haul higher volumes than roundwood trucks, thereby reducing costs. Disadvantages include the additional equipment needed to unload and load the material (expensive truck dumps and conveying systems), and the difficulty associated with ensuring rotation. Most companies use roundwood storage on remote woodyards, but will have chip storage at the mill facilities. Some mills will keep an inventory of both forms.

The characteristics of the woodyard have changed over time. During the 1940s and 1950s when pulp mills were establishing across the Southeast, many woodyards were located in remote locations (Bush, 1986). They were typically small and were nearly always located on a rail line, as that was the main mode of transportation for any distant shipments. Wood was received at these woodyards in shortwood form on small "bobtail" trucks, which was very labor-intensive. Over time, as trucking capabilities improved, companies combined some of these remote woodyards into larger storage facilities. For the remote woodyards closer than 160 kilometers (100 miles) or so, trucking became more cost-effective and allowed for greater flexibility in shipments to the mill. Eventually, some of these large woodyards were converted to chipmills, again changing wood flow patterns.

Recently, many companies have gone to one large woodyard located near the mill for inventory of roundwood and have eliminated remote woodyards. This allows the procurement organization to run the woodyard more as a "surge" yard that will unload wood only when the pulp mill is receiving more trucks than they can handle. Under these circumstances, the additional trucks are diverted to this surge yard and unloaded. When wood deliveries slow (typically due to weather problems), the surge yard reloads the material onto trucks and deliver it to the mill. There is the associated cost for additional wood handling, but loggers are able to get better turnaround time on their trucks and the mill is given additional inventory at a local site.

Mills still rely on dry storage primarily to manage weekly fluctuations of pulpwood deliveries and as a place to store winter inventory. But as economic conditions continue to tighten, companies are looking for ways to minimize all costs associated with raw material procurement.

Wet Storage

As noted, most difficulties associated with dry storage center around wood deterioration from decay that reduces yield. Various techniques for reducing wood losses during storage have been tested. Storing logs in ponds has been used for years as an effective way to maintain an even moisture content throughout the logs; however, storing pulpwood underwater involves expensive retrieval facilities and special equipment that would be impractical for the large volume of material maintained by today's typical pulp mill (Chesley et al., 1956). In addition, today's high volume pulp mills would need such a large body of water the practice is not feasible.

On the other hand, putting wood under water sprinklers has proven to be feasible. The first report of this technique in the literature was at a hardwood sawmill in Louisiana (Vick, 1964), where cypress and oak were stored under sprinklers during the summer months with no increase in defects over green logs. During the early 1960s, a few pulp companies decided to try this to store their wood. Hiwassee Land Co. experimented using banded bundles of pulpwood stacked two high on a woodyard (Mason et al., 1963). Using various pumps, sprinklers, and water directly from a river, they kept wood under spray for up to six months. Results indicated no deterioration of wood as long as adequate water was kept on the wood.

International Paper Co. ran similar test in 1964 for their southern pulp mills (Volkman, 1966). Wood was stored for up to 12 months under various levels of water spray and tested for pulp yields at different intervals; no significant losses in yield were reported. However, one disadvantage was that the bark from the trees tended to fall in large chunks, making it difficult to process through the debarking system (Djerf and Volkman, 1969). Since most of the bark was saturated, it did not burn well in their boilers and had to be hauled to the landfill. More important though, were the results that wood could be stored for long periods, as long as adequate water was distributed across the piles.

The long-term effects of keeping wood under sprinklers was revisited after Hurricane Hugo in 1989. Due to the large amount of downed timber, large quantities were put under sprinklers to extend their useful life. Syme (1994) determined that water had to be put on the material as quickly as possible to attain 100% moisture content (a rule-of-thumb is a minimum of one-half inch of water per day per foot of decked wood height). Continuous sprinkling also gave better results than intermittent, though it may have been more water volume that gave better results.

While wet storage woodyards offer many advantages, building a wet storage yard is no easy task. Permits are required from several state and federal agencies, and the yard design must be fully approved by all entities. Modern wet storage yards are built as closed systems, meaning that the water sprayed onto the trees will eventually drain back into the storage pond, which minimizes concern about local ground water contamination. A storage pond is built to maintain ample water supply as the flow from wells may not be sufficient to supply adequate water to the wood. Most sprinkler systems are run 24 hours a day to keep wood wet.

Operationally, a wet storage yard does not have the same rotation constraints as a dry storage yard. When the material is generally worked on a first-in, first-out flow, as long as it stays under water, deterioration problems are minimized. Thus, it is not unusual for some wood to be in storage for up to a year, sometimes 20 months if the area experiences a dry winter and the stored wood is not in demand. The wood is usually put down in rows, also called bins, and the pile is watered immediately (Figure II.9). Then

Figure II.9. Wood is stored under sprinklers to extend its useful life.

the water is sprayed daily until the inventory levels at the mill require shipments, at which point the water is turned off, and the wood is ready for immediate shipment.

Four forest products companies that operate multiple remote woodyards were contacted in 2001 to estimate the cost of operating woodyards in the southeastern United States (Table II.1). Small woodyards are characterized as the remote woodyards that added area to the pulp mill procurement zone. Large woodyards are the overflow yards some mills have begun using to handle surges at the pulp mill. The function of wet storage woodyards is to keep wood for a longer period, but these have higher costs due to maintenance on watering systems. When trucking is added to the cost of this material, remote woodyard wood typically delivers to the pulp mill at a $10/ton premium (Martin, 2001).

Table II.1. Operating costs for various company woodyards located in the southeastern United States in 2000.

	Volume /year (thousand tons)	Operating Cost ($/ton)
Small woodyard – dry storage	40-80	3.22
Large woodyard – dry storage	250-300	2.06
Wet storage woodyard	60-90	6.14

The "Green" Hardwood Inventory Concept

Hardwood plantations have been established around the country for many years. Under an intensive management, plantations can show tremendous productivity (Stanturf et al., 2003). Most are experimental, with the end product being either fuel or pulp mill furnish. Most of the operational short-rotation plantations are on the West Coast, while a few others are located across the forested regions of North America. The first plantations were established during the 1970s, primarily for energy use. The Department of Energy (DOE) began crop research in 1978 with the establishment of the Biofuels Feedstock Development Program (Tuskan et al., 1994). Its mission was to provide leadership in the development, demonstration, and implementation of environmentally acceptable and commercially viable biomass supply systems. During the first 15 years, their primary emphasis was on species selection for plantation establishment. While more than 150 woody plant species were evaluated, hybrid poplar emerged as the tree with the most advantages. Factors used to determine the most desirable tree included: straightness of the tree stem, annual growth rate, wood density, disease and insect resistance, crown structure, and ease of conversion to the final end product (pulp yield and paper quality) (Arnold, 1996). Sycamore and sweetgum continue to be evaluated, but the industry has focused on hybrid poplar or eastern cottonwood as the most desirable species.

As the energy crunch of the 1970s subsided, so did interest in short-rotation plantations. Later, as the need for fiber increased, various paper companies began to look again at the viability of these plantations. In the mid-1980s, Scott Paper in Alabama, which used short-rotation hardwood plantations for energy, tested the chips from these plantations as a possible fiber source for the pulp mill (Morgan, 1994). In 1988, Scott paper began installing operational plantations. Around the same time, Simpson Timber Company was establishing plantations of eucalyptus for their pulp mill near Anderson, California (Rydelius, 1994). Other West Coast companies, such as Boise Cascade (Pottle, 1996); Potlach (Eaton and Finley, 1996); and James River all began their programs in the early 1990s. All of these companies were driven by high fiber costs and a dwindling supply of stumpage, a situation that has not yet occurred in the Southeast to justify consideration of this alternative.

Economic studies on short-rotation hardwood plantations have been done specifically for the Northwest and the Southeast. For the Norhtwest, a *USDA Pacific Northwest Experiment Station Bulletin* (PNW 356, 1995) details many of the operational and silvicultural steps needed for a successful hybrid poplar short-rotation plantation. It covers the necessary site preparation functions, where to find planting material, weed control, fertilization, and some of the possible insects and diseases the manager of the plantation needs to be aware of. The bulletin is written for the small, private landowner to pique interest in short-rotation plantations and it provides an economic analysis that indicates the breakeven point to be approximately $21 per ton for stumpage, assuming a yield of 91 tons/acre at age 7. This analysis does not include irrigation costs.

A similar study for the Southeast (Bar, 1998) includes irrigation costs and a six-year rotation. Bar's breakeven point was a delivered cost of $75.00/cord (approximately 27.80/ton), which is $4-5/ton higher than current market prices for delivered hardwood in the southeast region (International Woodfiber Report, 2001). While hardwood price trends have been inching higher, it may take a few years to reach this level. However, at specific times of the year (winter), prices often peak at or near this level, and having short-rotation plantations in the ground may prove cost-effective during those periods.

Figure II.10 graphically indicates how “green” inventory would fit into the wood market. The left side of the graph indicates the cost relationship between the different sources of wood for a southeastern pulp mill. The right side indicates inventory levels and when these different sources may be required. Direct truckwood is considered the cheapest source of wood and a southeastern pulp mill will want deliveries all the time. To minimize the impact of seasonal fluctuations in direct truckwood deliveries, most pulp mills inventory wood in remote woodyards. Storage and handling costs make this a higher cost of wood, but a pulp mill continues to take deliveries until inventory returns to a satisfactory level. If inclement weather continues to cause inventory to decline, many companies will look to the spot market for wood purchases. This wood from the spot market is typically outside the normal pulp mill procurement zone and high transportation costs and short-term demand puts this category higher on the wood cost scale. “Green” inventory will be the most expensive wood on the market and will be in demand only when pulp mill inventory hits a critical level.

While a percent scale for inventory level is indicated on the graph and indicates when these different sources may be required, determining when each source is actually used will vary with time of year and a procurement manager’s decision as when inventory is “critical.” While a level of 50% of inventory goal may be deemed critical in January (early in the wet season), that same level in March may not constitute the demand for “green” inventory. So exactly when “green” inventory is required will vary for each pulp mill depending on inventory level and time of year.

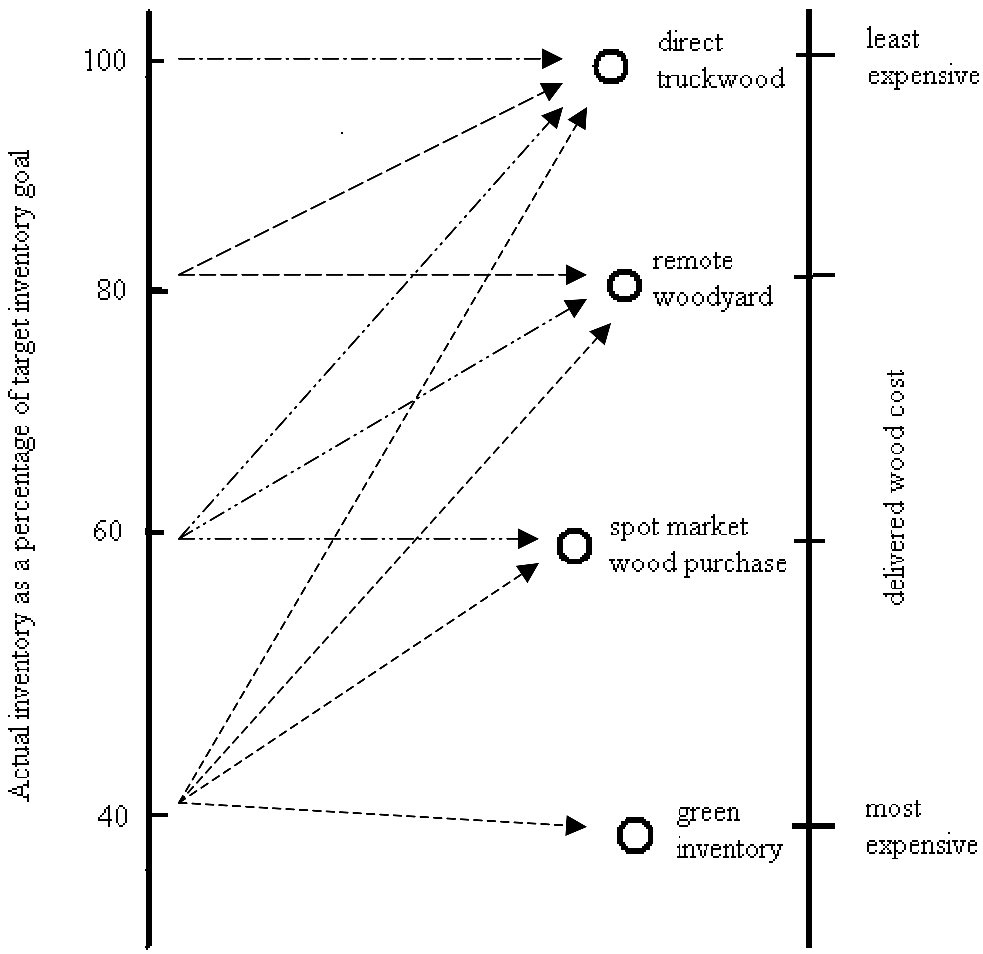


Figure II.10. A conceptual model of the cost relationship of "green" inventory to other wood sources for a southeastern pulp mill. As actual inventory level drops from the target level (likely caused by weather impacting in-woods operations), procurement personnel will look at increasingly expensive alternative sources of wood. The arrows indicate at what inventory level each source may hypothetically be required to prevent a curtailment in pulp mill production due to wood outage.

Short-rotation, intensively-managed hardwood plantations have been studied for many years. Researchers have determined costs and yield for plantations that can be used either as fuel or as fiber for a pulp mill. They are currently an integral part of the normal wood supply for pulp mills in the Pacific Northwest. They have not, however, been established on an operational level in the Southeast, primarily due to their high delivered cost to a pulp mill relative to other wood sources. However, using short-rotation, intensively-managed hardwood plantations as "green" inventory to offset costs of traditional woodyard inventory winter build-up and expensive "spot market" purchases may prove to be a feasible alternative (Figure II.11). Development of a decision model will allow a wood procurement manager to determine if replacing a portion of woodyard inventory with short-rotation, intensively-managed plantations is feasible for his/her operation.

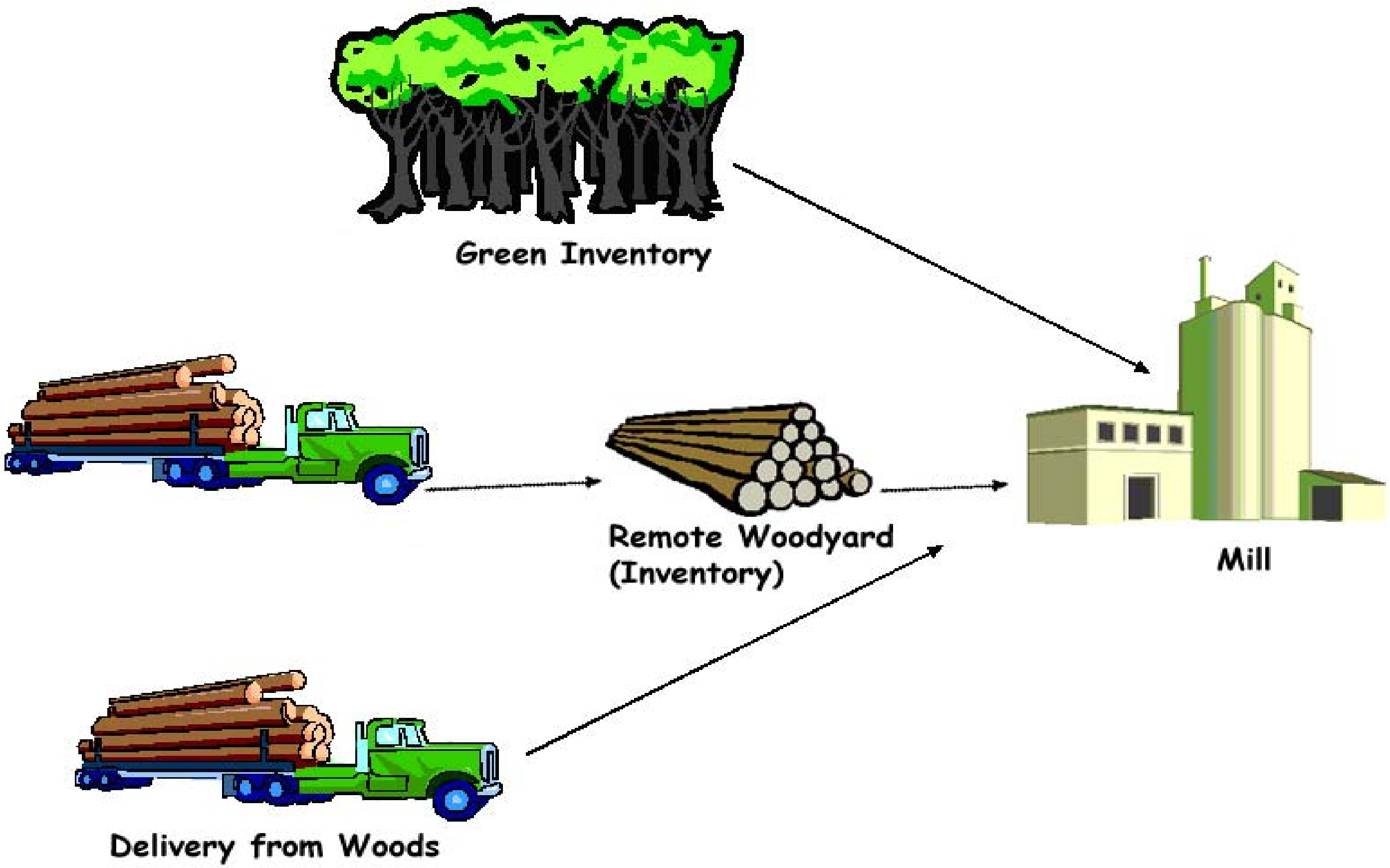


Figure II.11. Potential sources of wood for a southeastern pulp mill if “green” inventory hardwood plantations were available.

CHAPTER III. DEVELOPMENT OF A DECISION MODEL TO DETERMINE THE COST FEASIBILITY OF SHORT-ROTATION HARDWOOD PLANTATIONS ON THE SOUTHEASTERN COASTAL PLAIN

ABSTRACT

While intensively-managed, short-rotations fiber farms are found in the Northwest U. S., few have been established in the Southeast. This study's objective was to develop a decision model that could determine if a hardwood fiber farm would be a cost effective source of furnish for a southeastern pulp mill or as "green " inventory to replace storage of wood on remote woodyards. The decision model requires inputs that include initial costs such as land, irrigation and site preparation and annual costs such as fertilization, herbicides and insecticides. The model then summarizes these costs into a delivered cost for wood from a fiber farm that a manager can evaluate. An Excel spreadsheet is used for the decision model to facilitate a sensitivity analysis of operational costs. A net present value analysis of the fiber farm as a possible wood inventory tool is the primary output of the model. Understanding all the costs of a fiber farm from the decision model analysis should help determine whether they are feasible for individual company operations.

INTRODUCTION

Short-rotation, intensively–managed hardwood plantations are an established method of producing wood fiber for pulp mills in the Northwest (Stanton et al., 2002). In the southeastern United States, few intensively-managed plantations have been established, in part due to the abundant availability of hardwood resources throughout much of the year (USDA Forest Service, 1988). However, during rainy winter months, hardwood is often difficult to procure, and substantial seasonal increases in hardwood prices are common.

In addition to seasonal fluctuations in the operability and cost of the hardwood resource, the future long-term availability of the resource also remains uncertain. Recent social issues have further complicated availability. Some companies have located chipmills in areas with abundant hardwood resources, only to find that environmental organizations generate public concern about over-cutting. Foresters view clearcutting of high-graded stands in the mountain regions as beneficial for regeneration of more desirable species; however, the public is often skeptical about the increase in clearcutting in a region where "selective" harvesting has historically been used. As a result of these environmental and political concerns, locating chipmills in areas with extensive hardwood resources may not be an attractive solution to meet the hardwood pulpwood supply problem in some areas.

In the southeastern United States, the relatively low cost of hardwood during the spring and summer makes short-rotation hardwood plantations more difficult to justify economically. In an analysis completed for the southeast in 1998, Bar (1998) estimated current prices for fiber and projected costs for fertigated (fertilizer applied during the irrigation process) hardwood plantations. Bar's findings predicted that it would be several years before hardwood stumpage prices in the South increase to the level necessary to justify intensive culture plantations as a traditional source of fiber. However, he did not examine them in the context of high cost "spot market" wood purchased during a winter wood shortage period.

There have been several studies that have estimated the costs of short-rotation, intensively-managed hardwood plantations (Bowersox and Ward, 1976; Rose and DeBell. 1978; Lothner et al., 1981; Bar, 1998). All of these studies have included some but not all the various costs such as land purchase, site preparation and planting, irrigation and fertilization. Some determined the stumpage cost for the plantations while others did a net present value analysis. Most determined the cost for short-rotation, intensively-managed hardwood plantations were not quite yet economically feasible. None of the studies compared the cost of this material in conjunction with the cost of delivered wood for a pulp mill operation, mainly because of the confidentiality that most pulp mills place on their wood costs made these costs unavailable to the researchers.

Developing a decision model to summarize all the costs associated with short-rotation, intensively-managed hardwood plantations would allow a manager to determine if they are feasible for a southeastern pulp mill operation. A model in spreadsheet form will allow for the inclusion of only those costs a specific site might require, and also allow for the user to do a sensitivity analysis to determine what level of inputs are needed.

The model will consist of two sections: the first section will classify the costs associated with stand establishment, annual costs for fertilizer, herbicides and insecticides, all capital costs (for land and irrigation) and supervision. Output from this section will be a cost for intensively-managed, short-rotation hardwood delivered to the pulp mill. The second section will look at using these plantations as part of a "green" inventory system, to reduce wood cost at a pulp mill. Inputs will be hardwood inventory levels for the pulp mill, and delivered costs for past alternative sources of wood will be necessary for the financial analysis.

This paper will build upon Bar's study by developing a decision model to estimate the costs to establish short-rotation, intensively-managed hardwood plantations. A manager can then use the pulp mill delivered wood cost along with inventory costs to determine if these hardwood plantations are feasible. Thus, the objective of this paper is to develop a decision model for managers that includes the major cost components for establishing short-rotation, intensively-managed (fertigated) hardwood plantations in the southeastern Atlantic coastal plain, either as a direct source into the pulp mill or as part of a "green" inventory system.

MATERIALS AND METHODS

Developing the Decision Model

A decision model was developed to include all these operational costs and determine how short-rotation, intensively-managed, hardwood plantations would fit into a pulp mill wood supply. The decision model gives the user the flexibility to include only those costs which are necessary for their specific location, and then incorporate the hardwood plantation in a beneficial way to their wood supply system.

Inputs for the Decision Model

There are many inputs into the model: some are needed for the financial aspects; others tend more to the operational and silvicultural aspects of hardwood plantations and therefore included on a per-acre basis; and lastly there are the wood cost and inventory inputs that are needed to determine the feasibility of short-rotation, intensively-managed plantations for a southeastern pulp mill.

Financial inputs – There are two financial inputs into the model. The first is cost of capital. Cost of capital is used to determine the land and irrigation system cost in the model. Cost of capital is considered to be what a company has to pay to borrow money. The rate that is used for cost of capital can be determined by visiting a financial site on the internet and looking at the rates for corporate bonds. The rate for corporate bonds is used because a company will take money out of their marginal investments (bonds), not their best investments (likely whatever business they are in, such as pulp machines). This is what the company will pay to the market to borrow money.

The accumulated interest rate is the interest rate used by the model on all other costs as they are carried through the years. This interest rate is used if the user wants to estimate what the delivered cost of hardwood plantations might be to the pulp mill. The interest rate is applied to all the costs at the end of each year. The interest rate is usually the same as the cost of capital. It is only listed on a separate line because some users may choose to ignore this cost while cost of capital is required for the land and irrigation.

Operational and silvicultural costs – There are several inputs that are used for the operational aspects of the hardwood plantation. The number of acres in the fiber farm and the expected rotation length are used to evenly allocate the acres to each age class.

For example, a 400-acre fiber farm on an eight-year rotation would have 50 acres of plantation in each age class. During an analysis, age may extend beyond the expected rotation due to some carry-over of inventory, but the initial allocation will be based on these inputs.

Land cost and irrigation costs are handled in a similar manner. Because each of these costs extend beyond one rotation, their costs are included as an annual rental payment. An annual rental payment is used because it represents the annualized equivalent of the net present value of the land as a perpetual payment. Land and irrigation costs must be spread over more than one rotation, so by including them as a rent we have the same value as the net present value of the perpetual activities on the land. In the decision model, the initial land purchase cost and the cost to install an irrigation system across the site are entered in a per acre value. These costs are then included in the model by taking the cost of capital times each individual estimate, which yields the annual "rent". Land costs can vary depending on site characteristics. Forestland is cheaper to purchase than farmland, but will require much more site preparation to establish the hardwood plantation on the fiber farm. While the irrigation system is input onto the model at one time and cost, actual establishment in the ground may occur over years as the fiber farm expands.

Site preparation and planting costs to establish the hardwood plantations are two more inputs into the model. Site preparation costs are all costs needed to clear the site and leave a loose soil for the cuttings to be placed in the ground. Most short-rotation hardwood plantations are established using an eight to twelve inch cutting. These cuttings will need to be hand planted directly under the drip point of the irrigation tube.

Labor costs are a separate input into the model and covers all the costs needed to maintain the fiber farm. The decision to have a full-time manager and seasonal help or extend oversight of the farm to various personnel will affect these costs. Fiber farms are labor intensive, as irrigation systems distributing water, fertilizer and insecticides need to operate uninterrupted on a daily basis for the six months or so of the growing season. These same personnel will likely supervise many of the silvicultural operations during establishment. While all the previous inputs have been on a per acre basis, labor costs are estimated for the entire year and the model will distribute them across the fiber farm.

The previous inputs into the decision model were all costs that are either used one time (site preparation) or are the same each year (land rent). The following costs are for operations that may vary from year-to-year. Annual irrigation costs are for the power supply to get water to the plantations. It is commonly included as the electricity to run the pumps. In some occasions, diesel motors may run the pumps and the annual costs for fuel should be included. Electricity costs will vary greatly from region to region, and electric requirements will also vary with pump size for the wells. Getting a good estimate for electricity requirements from the irrigation system contractors will help in estimating this amount.

To get good survival and growth of the hardwood plantations, it will be very important to minimize the impact of weeds. Weeding costs will generally start high and rapidly decrease through the first three years. After crown closure, shading and leaf litter prevent most weed impacts. Tillage and spraying are generally used during the first two years and spraying only is in the third year.

Fertilization costs are another input that will vary from year-to-year. Young (years one and two), recently established plantations require less nutrients than older plantations, so fertilizer costs start small and increase over the first few years. By year three and beyond, tree nutrient requirements tend to be equal each year. Fertilizer is applied through the irrigation system on a daily basis during the growing season.

The input for insecticide costs will depend on species selection. Certain species are more susceptible to insect infestations and will require more costs than some heartier insect resistant species. Insecticide costs usually do not vary much from year to year. Insecticides may also be applied through the irrigation system.

The final operational and silvicultural input required in the decision model is expected yield from the hardwood plantation. Yield will vary with species selection and the impact of other operations during plantation management. The quality of site preparation, species genetics, weed control, amount of nutrients and impacts of insects will all effect yield from the plantation.

<u>Wood costs and inventory inputs</u> – To determine whether short-rotation, intensively-managed hardwood plantations are feasible as "green" inventory for a pulp mill operation, wood costs and inventory levels are needed to complete the decision model. Inventory level for the pulp mill is included in the model so a user can decide whether to harvest the hardwood plantations. Delivered costs for these hardwood plantations are quite high, so harvesting should only occur when most other wood supply alternatives are exhausted. Having inventory numbers will help a manager decide when harvesting is necessary.

The exact level of inventory when a manager will decide to harvest the plantations will vary from operation to operation and time of the year. Some pulp mill procurement organizations have the ability to respond better than others to low inventories because of company harvesting operations, more capable dealer organizations, or having company land and stumpage available. So while one manager may harvest plantations when inventory drops to 50% of goal, another may wait until it hits 30%. Also, time of year will impact a manager's decision. A level of 50% in December may seem critical, but that same 50% level in April may not be considered a problem. So there is no specific level at which plantations are utilized. That decision will be made by the user when the analysis is run.

Delivered wood costs are required to run the analysis and determine the benefit of hardwood plantations. Deliveries from hardwood plantations will offset other sources of wood and the cost difference between the two sources must be included to evaluate the feasibility of short-rotation, intensively-managed fiber farms. Also, in some instances, the plantation will be harvested as roundwood; while other times chips may be a more preferred delivery form.

RESULTS AND DISCUSSION

The above inputs for the decision model were organized into an Excel spreadsheet that can be found in Appendix A. A spreadsheet format was chosen because they are relatively simple to use and they allow the user to easily determine the impact of changes on the results of an analysis (LeBel and Carruth, 1997). This gives the user the opportunity to do a sensitivity analysis with the inputs. Also, spreadsheets allow the user to customize the analysis to local situations.

The decision model consists of four worksheets: a general information sheet that includes all the financial inputs and many of the operational inputs; the second worksheet summarizes all the costs on a per acre basis for each year. Yield is an input on this worksheet. The third worksheet includes all the hardwood inventory numbers and is the worksheet where the user will make many of the decisions during an analysis. The last worksheet summarizes the costs and benefits and calculates the net present value for the analysis.

Based on the specifics of the site, the user must decide what costs will be included in the analysis. For example, Bowersox and Ward (1976) tested the feasibility of hybrid poplar on abandoned farmland, where site preparation costs were low and irrigation was not used. In a later study, Lothner et al. (1981) did include irrigation on a site, but the emphasis in the study was to produce biomass for energy, so rotation length was short (two to four years).

To make these plantations operational at any time during the year, drier sites with good access will need to be used. Because of the low productivity of many of these sites, many of the model inputs will be required to attain the yield necessary to justify hardwood plantations. Bar (1998) came the closest to including all the costs from the needed silvicultural operations, but his estimated yield was very high (this will be further evaluated in the next chapter).

The user has the option to decide which costs are necessary. Those costs and species selection will have a direct effect on how much yield will be harvested. Yield for the decision model is input as tons/acre that can be harvested. It would be much more beneficial to determine yield of pulp fiber per acre from the hardwood plantation, but that is beyond the scope of this study. Steinbeck and Brown (1976) looked at pulp yield and quality from American sycamore (*Platanus occidentalis*) and found no unusual problems with the use of this material in the pulping process. Goyal et al. (1999) found hybrid poplar clones to have large variations in specific gravity and pulp yield, both of which could affect pulp production. This yield variation should be considered by the user during an analysis.

The benefit of “green” inventory can be determined using the decision model. By evaluating the pulp mill inventory levels from month to month, a user can decide whether to harvest plantations or not. Determining how much hardwood plantation to harvest in a given year is required. Some years, no plantations will be cut. Therefore, there will be times when the plantations are older than the planned rotation. While this works in the analysis, an upper age needs to be set for harvesting the plantations. Since most plantations are grown on a seven-year rotation, an assumption in the decision model is that a plantation will be harvested no later than year 10. If plantations are harvested, the wood cost savings from the offset wood must be included in the NPV analysis, along with the plantation costs and inventory savings that are included by the model.

The output from the decision model is the net present value (NPV) of operating a fiber farm as “green” inventory. Lothner (1981) used NPV to evaluate hybrid poplar in the Lake states. While he was not able to attain a positive return for the four alternative rotations, the study showed the benefits of an NPV analysis. These benefits include allowing the user to set the risk adjusted discount rate to determine if the project is profitable; the time value of money is accounted for; and the results are easily understood in that a positive NPV indicates the project out-performed the discount rate. Alternative decision criteria such as payback period and internal rate of return do not include these benefits.

Stanturf and Portwood (1999) used NPV to determine the economics of an eastern cottonwood plantation on the Mississippi alluvial valley. Again, different sites required the inclusion and exclusion of various costs and NPV allowed for the flexibility to complete the analysis. By maximizing NPV in the decision model, the feasibility and optimum scenario can be determined.

All the costs associated with a short rotation operation were included and a sensitivity analysis could be included for dealing with the uncertainty of estimating costs and yields. For instance, a user may want to evaluate how many acres are necessary for their operation. By using the decision model and varying the acres, the point at which NPV is maximized will indicate the optimal acres. A sensitivity analysis can also be used to determine the value of various operations, but yield will have to be adjusted appropriately.

CONCLUSIONS

Short-rotation, intensively-managed hardwood plantations are a potential source of wood for a southeastern pulp mill. Determining all the costs and potential yield will result in a delivered price that can be compared against other wood sources. Having a decision model that allows a user to incorporate all the costs and evaluate the potential of a fiber farm will help show if these fiber farms are feasible.

Using a spreadsheet is a user-friendly form for an analysis. It allows the user to easily change inputs and evaluate their impact on the results. A spreadsheet can also be customized to the user's specific situation.

Net present value was used as a decision criteria to determine the feasibility of intensively-managed, short-rotation hardwood as "green" inventory. NPV was chosen because it is widely understood by industry and gives a clear indication as to whether a project is profitable or not at the risk adjusted discount rate set by the user.

CHAPTER IV. COSTS FOR SHORT-ROTATION, INTENSIVELY-MANAGED HARDWOOD PLANTATIONS ON THE SOUTHEASTERN COASTAL PLAIN

ABSTRACT

There is renewed interest in intensively-managed, short-rotation plantations as a source of wood for pulp mills. While they are common in the Northwest, few have been established in the Southeast. Understanding all the costs associated with these plantations will help determine their feasibility. Using a decision model developed to summarize all the costs, the delivered cost for plantations of eastern cottonwood (*Populus deltoides*) from a hypothetical fiber farm was analyzed and compared to actual delivered wood cost for three southeastern pulp mills. Using current yield from an experimental fiber farm, short-rotation hardwood was not cost effective, as delivered cost to a pulp mill averaged $71/ton. If yield can be increased by 33% through improvements in genetics and silvicultural practices as has been accomplished in the Northwest, delivered cost is reduced to $56/ton. One of the three pulp mills purchased wood above the $56/ton price, and the other two pulp mills had delivered cost near that price. Thus, finding additional yield through improved genetics or better operational practices are key to the cost feasibility of intensively-managed, short-rotation hardwood plantations

INTRODUCTION

A decision model was developed to estimate the cost feasibility of short-rotation, intensively-managed hardwood plantations. The costs to include in such an analysis are very site specific. A wet site will usually need very little irrigation and fertilizer to maximize tree growth, but cannot be harvested during wet weather due to operational restrictions. A dry site needs irrigation and fertilizer, but has the advantage of being available as a wood source year-round. Thus, the selection of a site will impact the costs for intensively-managed, hardwood plantations and also determine their operability.

A decision model allows the user to include only those costs that are applicable to a specific operation. It also gives the user the ability to run a sensitivity analysis to determine the impact of various cost changes. The model developed in the previous chapter may be used as a tool to estimate the value that hardwood plantations may have to a southeastern pulp mill by calculating a net present value for an operational fiber farm investment.

Validating this decision model by inputting cost components and yield and analyzing the results is necessary to establish the accuracy of the output. Some cost estimates for the various operations of a fiber farm are available from published articles. Some will need to be calculated by the user based on specific company decisions. Other costs will be developed from contractors who might install the equipment. Getting the best estimates of these costs will strengthen the analysis.

Growth and yields for poplar species have been studied for many years. Ek and Dawson (1976) looked at *Populus tristis* grown under intensive culture in Wisconsin. Their findings indicated annual height growth of 6 – 8 feet and diameter growth of 1 inch per year. A study conducted in the Southeast (Cox and Leach, 2000) yielded height growth of 10 feet and diameter growth of 1.1 inches each year for four-year-old plots of cottonwood, equating to nearly 1200 cubic feet per acre of volume. Sycamore and sweetgum trials at the same site were less productive. A recent personal visit to a forest industry site in South Carolina growing eastern cottonwood also supported these findings. Cottonwoods in various age classes were averaging similar growth rates of 10 feet of height and 1 inch of diameter per year.

The U. S. Department of Energy has also been investigating hybrid poplar for biomass production for many years. In a recent report (De La Torre Ugarte et al., 2000) on bio-energy crop production, hybrid poplar yield in the Southeast averaged 4.5 dry tons/acre/year. How much yield to include in the analysis will depend primarily on the site and the species selected.

While several species have been studied, eastern cottonwood with its superior growth rates appears to have the most potential. Therefore, this paper has the following research objective:

1 - Use the best available component costs from literature and yield information from an industry trial to validate the decision model developed in the previous chapter and estimate wood costs for a typical eastern cottonwood plantation.

2 – Complete a sensitivity analysis on plantation costs if individual operational costs increase by 50% from current levels.

MATERIAL AND METHODS

Developing Hardwood Plantation Growth and Yield Estimates for the Analysis

While several studies on West Coast short-rotation fiber farms provide yield information for their plantations, diameters and heights for this study came from measurements of an existing industry cottonwood plantation in South Carolina. The company provided data on the height and diameter for 485 trees planted across several eastern cottonwood trial plantations. These trees were measured during ages 2 through 6. These are the oldest plantations in operation, so diameters and heights for years 7, 8, 9 and 10 were extrapolated out using Schumacher's (1939) equation:

$$\text{Ln (DBH or Height)} = b_0 + b_1/\text{Age} + \varepsilon$$

where

b_0 = the y intercept

b_1 = the slope of the line

ε = random error for the equation

The height and diameter estimates by age was then used in the Krinard (1988) formulas for yield from eastern cottonwood plantations. The two formulas are:

$$TVOB = 0.06 + 0.002221\, D^2H$$

and

$$MVIB = -0.86 + 0.001904\, D^2H$$

where

TVOB = total tree volume outside bark in cubic feet from a 1 ft. stump to the tree tip

MVIB = merchantable tree volume inside bark in cubic feet from a 1 ft. stump to a 3 in. top

D = diameter at breast height (dbh) in inches

H = total height in feet

For an operational analysis, neither equation correctly produces an accurate estimate of volume because of the way the timber is actually harvested. The total volume outside bark (TVOB) equation will calculate a slightly greater volume than is likely to be harvested because it measures volume to the tip of the tree. If the plantation is harvested by a conventional roundwood operation, the stems will be severed at 3 inches. If the stand is chipped on site, wood will be used to the tip of the tree, but stems will be debarked on site. Thus, the total volume outside bark equation is likely to slightly overestimate the actual fiber yield.

However, using the merchantable volume inside bark (MVIB) equation will likely underestimate total recoverable volume. If the stand is harvested by a roundwood operation, the three-inch top is viable but bark will remain on the tree delivered to the mill; therefore, bark volume should be included. If the stand is harvested by a chipping operation, the bark will not be included, but the tree will be utilized to the tip.

Thus, for this analysis, diameter and height by age from the regression was entered into both equations to determine cubic foot volume. These two estimated volumes for each diameter class (TVOB and MVIB) were then averaged to get the volume per tree in cubic feet for the stem that will be harvested. Weight in tons is the common unit used to measure pulpwood, so the cubic foot volume was converted to tons using 46 pounds per cubic foot of wood (Wenger, 1984). Lastly, it was assumed there are 490 trees per acre at year 5 (a 10% mortality rate from planting through year 5) and a loss of 5 trees each year over the remaining life of the stand.

Determining Hardwood Plantation Silvicultural Costs

To validate the decision model and evaluate all the costs for a short-rotation, intensively-managed hardwood plantation in the southeastern coastal plain region, costs were estimated for the land use, contract site preparation and planting, and annual management practices such as fertigation and weed control. The costs were input into the model on a per acre basis. A sensitivity analysis was performed to determine how a 50 percent cost increase to individual operations would effect the delivered cost of fiber farm material.

Land costs – The value of bare land for plantation establishment can vary greatly across a region. For this study, land costs were determined by a telephone survey of fifteen consulting foresters who had experience in selling land located in the southeastern coastal plain region in the vicinity of pulp mills. Each consultant was asked to supply an average, high and low price for both forestland and farmland for their respective location. Land values were determined for dry, sandy sites with good road access. When the average land value was determined, it was entered into the model as a land rent so land costs could be spread over several rotations. The average price per acre was used with an assumed cost of capital to give an annual cost in perpetuity.

Initial irrigation costs – several companies in the southeast region design and install irrigation systems for farm use. Two were asked to estimate the cost for a complete drip irrigation system and their expectations of annual costs. The costs from the two suppliers were averaged, then treated like land cost and included in the analysis as a perpetual annual cost. By treating the irrigation cost as an annual rent, it allows the cost to be spread over more than one rotation.

Site preparation costs – *Forest Landowner* magazine publishes a survey every other year summarizing various site preparation costs for the southern region. There have been 16 issues of the report, and the most recent survey was published in March 2001 (Dubois et al., 2001). This survey originated in 1952 and was updated every several years. Beginning in 1982, it became a biennial survey. The survey covers 12 southern states and summarizes the responses from 37 forest products companies, contractors and public agencies to determine the costs of various site preparation and reforestation operations. The amount of site preparation will vary with each site, but the same average cost per acre was used for each pulp mill analysis.

Planting costs – Private and state nurseries in the southern region that offer cottonwood cuttings for plantation establishment were surveyed to determine the cost of cuttings for eastern cottonwood. Hand planting is the preferred method for establishment because the cuttings must be placed precisely at the drip tube openings. Cost of hand planting was obtained from Dubois (2001), even though placing hardwood cuttings in the ground at predetermined locations (the drip tube openings) may result in a lower cost than conventional tree planting.

Annual maintenance costs – the cost of weed control and operating the irrigation system to supply water, fertilizer and insecticides were estimated for each year. Weed control costs should decrease each year as the tree crowns develop and begin to shade out the forest floor, thus preventing most weed germination. Costs for tractor tillage and a side spray herbicide application completed by contractors were estimated for years one and two, with herbicide only in year 3. Fertilizer needs will increase each year as the trees require additional nutrients for maximum growth. Eastern cottonwood is highly susceptible to insect infestations, so insecticides were applied each year. Both fertilizer and insecticide were applied through the irrigation system. Costs for the herbicide, fertilizer and insecticide were obtained from a local supplier.

Supervision – While most costs were calculated on a contract basis, it will likely take one or two employees to maintain the plantations, and this labor cost was included in the analysis. Interviews with companies conducting these operations verified that two people are typically required during the growing season because of the necessary constant monitoring of the irrigation system, as well as the periodic sampling for insect presence.

Sensitivity Analysis

A sensitivity analysis was performed to determine the impact of varying individual operational costs to the total cost of the fiber farm. Each operational cost was increased by 50% to determine which component of fiber farming would have the most impact on overall costs.

RESULTS AND DISCUSSION

Short-Rotation Plantation Costs

The costs associated with a hypothetical short-rotation, intensively-managed hardwood plantation were summarized in an Excel spreadsheet (Table IV.1). The costs were reflected by the following categories:

Capital (Initial) Costs	Annual Costs
Land	Weed Control
Irrigation System	Fertilizer
Site Preparation	Insecticides
Planting	Irrigation
	Supervision

The following section explains how the costs were developed. These cost will vary greatly depending on the site, so each user of the decision model will need to consider their own special circumstances.

Initial Costs

Land Costs

Of the 15 forestry consulting firms contacted, 11 responded (Table III.2). Values reported for forestland (bare land cost only, excluding timber value) varied from a minimum of $300/acre to a high of $1000/acre, with an average of $592/acre. For farmland in the same area, only 8 of the same consultants responded and estimated an average land cost of $1000/acre, with a low of $600/acre and a high of $1800/acre.

Table IV.1. Example of spreadsheet used to summarize costs for a short-rotation, intensively-managed plantation.

	year	1	2	3	4	5	6	7	8	9	10
Initial ($/Acre)	Land	X	X	X	X	X	X	X	X	X	X
	Irrigation System	X	X	X	X	X	X	X	X	X	X
	Site Prep & Tillage	X									
	Planting	X									
Annual ($/Acre)	Irrigation electric	X	X	X	X	X	X	X	X	X	X
	Weed Control	X	X	X							
	Fertilizer	X	X	X	X	X	X	X	X	X	X
	Insecticide	X	X	X	X	X	X	X	X	X	X
	Supervision	X	X	X	X	X	X	X	X	X	X
	Annual Total										
	Interest Cost	X	X	X	X	X	X	X	X	X	X
	Rotation Total										
	Yield (tons/acre)					Y	Y	Y	Y	Y	Y
	Cost per Ton										

X - indicates a year in which costs for that operation will occur.
Y - indicates a year in which plantations are available for cutting.

Table IV.2. Estimated land values for southeastern forestland and farmland.

	Consultant	Average	Low	High
		Dollars per Acre		
Forestland	1	600	325	1000
	2	800	600	900
	3	440	400	500
	4	500	350	800
	5	600	400	800
	6	550	300	600
	7	575	350	750
	8	500	400	600
	9	700	450	1000
	10	600	500	800
	11	650	500	750
Averages/Acre		592	416	773
Farmland	1	1200	700	1800
	2	1000	800	1200
	3	1000	800	1200
	4	800	600	900
	5	1000	800	1500
	6	1000	700	1400
	7	1200	1000	1500
	8	800	750	1000
Averages/Acre		1000	769	1313

For this analysis, the more expensive farmland was used along with the lower site preparation costs because it resulted in a higher NPV. An added benefit to agricultural land is also allows for a quicker establishment of a short-rotation, intensively-managed hardwood plantation. Using farmland instead of the less expensive forestland with higher site preparation costs should be analyzed for each specific location to determine if has a higher NPV. An advantage to choosing forestland is the entire current tree cover may not have to be removed initially unless installing the irrigation system requires immediate clearing. The average $1000 purchase cost per acre for forestland is carried forward by the 5-year average corporate bond rate of 5% (www.usatoday.com, 2002) to produce an annual land rent of $50 per acre.

Irrigation System Installation

While the site layout and the sophistication of irrigation systems will cause the costs to vary, the two companies contacted supplied estimates that ranged from $900 - $1400/acre for a system installed on a 600-acre tract of land. The pipe is the most expensive component. The system design may include either a large pump with smaller diameter pipes (lower initial cost), or large diameter pipes with a smaller pump (higher initial cost). If the smaller pipe is chosen for lower initial cost, the monthly electric costs will be higher to run the larger pump. For an average of $1150/acre, the example system will have two pump houses that can be run individually or simultaneously to supply 1 to 1 ¼ inches of water per week to the entire plantation during the growing season (Bar, 1996). The irrigation system must also have storage tanks included so fertilizer and insecticides can be applied to the site as necessary.

According to the irrigation companies, the system must be installed near the beginning of the process so that all the pipelines can be put underground at a depth of three feet. Only the drip hoses and the taps they connect to are left on the surface. The system has three potential water sources and each has its advantages and disadvantages. The most common source at the various study sites in the east is a deep well (Bar, 1996). The advantages to a deep well are: 1) no constraints on the location of the plantation during land rent or purchase, and 2) the water tends to be devoid of sediment and therefore requires a low-end filtering component. The disadvantage of a deep well is that the water tends to have a high mineral content, primarily iron, and may clog the drip lines, which may require additional staff to flush the lines.

In the West, water is often pumped from nearby rivers, which eliminates the mineral problem, but requires a very sophisticated and costly filtering system to remove sediments from the water to prevent blocking the drip lines (Wierman, 1994). It also requires locating the fiber farm near a river (though at some Northwest United States locations they do pump water as far as 5 miles).

The third source is to pump water from a constructed pond with a reliable source of water. The water source feeding the pond may contain mineral sediments, but the holding pond should allow some settling of the minerals before entering the irrigation system. Two drawbacks to this system are the difficulty of locating a pond on the high, dry site desirable for short-rotation plantations, and the chance of aquatic life entering the pond and causing problems with the pump and filtering system.

Given a location in the Southeast for the analysis and to allow the most flexibility for the plantation, this study will assume a deep well for the water supply. The additional labor necessary to regularly flush the lines will be included in the annual costs for irrigation.

A computer system will monitor the entire system and regulate the flow of water to different areas of the fiber farm. The same computer may also turn on pumps that will inject the fertilizer into the water flow to meet the requirements of the plantation. The computer system is necessary to minimize the supervision of the irrigation process.

At the beginning of the third year, the drip lines will be moved to the center of the rows. As the trees grow and their root systems spread, watering in the middle of the rows places the water and fertilizer at the most beneficial location for the trees to absorb.

Total cost for this system was estimated at $1150 per acre. This value is in line with Bar's (1998) study for the Southeast. To spread the costs for irrigation over multiple rotations, the system costs are included in the analysis as an annual "rental" payment (similar to land). The $1150 per acre at the 5-year average corporate bond rate of 5% (www.usatoday.com, 2002) produces an annual cost of $57.50 per acre.

Site Preparation

The selection of farmland for the plantation location in this analysis means minimal site preparation costs. If forestland were selected, the amount of site preparation would vary with each site. As a minimum, to transfer forestland to a short-rotation, intensively-managed site would require a good, clean clearcut of the previous stand; a shear, rake and pile operation to clear the site and gather the logging debris for burning; possibly a chopping operation to enhance burning by consolidating fuel and loosening the surface soil; and then a good site preparation burn to remove the woody debris, reduce competition and return nutrients to the soil. These three steps together should clear the site and allow for disking, but at a cost of $300 – 400 per acre (Dubois et al., 2001).

Either site will require at least two passes of disking (Kaiser, 2000). Disking to establish a hardwood plantation will require a heavier plow than is used for most agriculture applications. The top 18 inches or so must be thoroughly mixed to allow good root growth. Earlier field studies in 1995 estimated disking costs at $15.00/acre. In the Dubois report (2001), costs for forestry practices in the South are listed from cost surveys completed during the previous 50 years. By tracking these costs, an annual inflation factor can be estimated for various types of forestry operations. Using the cost increases indicated for the mechanical site preparation category from 1995 through 2000, costs increased roughly 5.4% annually. Using this annual inflation factor, the current cost for disking and the amount used in this study is $22.00/acre for each pass. Since farmland is being used, total site preparation cost is $44/acre.

Determining the NPV of the cheaper forestland with the higher site preparation costs against the higher priced farmland and lower site preparation cost should be an early consideration for the decision model user.

Planting

For this analysis, rows were planted every 10 feet with 8 feet between trees, resulting in 544 trees/acre. That spacing is typical for a pulpwood rotation and is representative of the plantations where diameters and heights were collected for the growth and yield portion of the study. Planting cost for a site prepared tract is $40.00/acre (Dubois et al., 2001). Placing hardwood cuttings in the tilled ground at pre-determined locations (the drip tube water mark) might result in a lower planting cost, but that will vary with each site. For this analysis, $40/acre was used.

Seedling cost for genetically improved eastern cottonwood is $240/thousand (Forest Landowner, 2002), or $131/acre. Seedling cost has not changed significantly over the past few years as clones are continually being evaluated and improved. As a new rotation begins, the newer clones will generally outperform the older stock and therefore justify their purchase. If possible, the newer clones should be evaluated for highest pulp yield rather than the best diameter and height. It will be important to communicate with the nursery to ensure that the most productive clone of eastern cottonwood is planted.

Annual Costs

Weed Control

Controlling competing vegetation is critical to establishing a short-rotation plantation and for ensuring that water and nutrients are available for the desired trees. Mechanical and chemical weed control is usually necessary for only the first two years; after that, shading from crown closure and leaf litter prevents most weed encroachment.

The mechanical weed control process involves passing through the plantation between the rows of trees with a narrow disking plow. This can be done only during the first and second years of establishment while the drip tube is directly along the stems of the trees. It will usually take about three passes during the first growing season spaced six weeks or so apart to control weeds between the rows. During the second season, two passes will usually keep weeds in check as shading from the trees will begin to reduce weed establishment. By the third season and beyond, cultivation is no longer necessary or plausible because shade cover and leaf litter will minimize weeds and the drip tubes are now located near the center of the rows.

The cost for cultivation between the rows on a 1995 plantation establishment was $10/acre (Downing et al., 1997). Another report had cultivating between rows at $9/acre

PNW 356, 1995). Applying the same 5.4% annual inflation factor from the Dubois paper, the current cost would be $13/acre for each cultivation.

Chemical control is used on the weeds that grow within the rows between the trees where the plow cannot travel, and also during the third year. The number of applications is similar to the mechanical process and therefore includes three passes during the first year, two passes in the second year, followed by one in the third year. Again, after three years, weeds are generally not a problem due to the shading from the trees. Occasionally, some specific areas of a plantation may have weed establishment and require a spot chemical treatment, but costs are minimal.

Many choices of chemicals that will eliminate unwanted, competing vegetation are available. After discussion with several managers of established fiber farms, the chemical Gramoxone PDQ (Syngenta Crop Protection Canada, Inc.) was chosen for this analysis because the managers interviewed indicated it achieves superior weed control results. A study by Ezell (1994) also supports the fiber farm managers' recommendations. Gramoxone PDQ can be sprayed at the base of the tree from a tractor-mounted sprayer: as the tractor makes a pass within a row, the trees on both sides of the tractor are sprayed on one side of the trees; the other side is sprayed as the tractor makes a pass down the next row. Application cost is similar to the cost of making a cultivation pass ($13/acre). Gramoxone PDQ is normally applied at 24 ounces/acre. The cost for Gramoxone PDQ is $25/gallon, or $5/acre; thus, the total cost per chemical application is $18/acre.

Adding the scheduled mechanical and chemical treatments produces a first year weed control cost of $93/acre. Second year cost declines to $62/acre, and third year cost to $18/acre. No additional weed control costs were included in this analysis.

Fertilization

Fertilizer is applied regularly during the growing season, usually 3 times/day, through the drip irrigation system. The computer system that controls the irrigation process can pump it directly into the lines on a scheduled basis. The benefit of daily fertilizer applications is that the tree will absorb the nutrients in a more uniform fashion, and, in the event of heavy rainfall on any given day, only a small portion of the annual application may be washed away. The main disadvantage to daily fertilization is the additional pump maintenance required. Fertilizer is somewhat corrosive to the system and additional work on the pumps may be necessary.

Liquid fertilizer can be purchased directly from most farm supply companies and will be stored in separate tanks integrated into the irrigation system. The type and amount of fertilizer will vary slightly with each site, but for this analysis liquid fertilizer 10-1-6 (manufactured by Liberty Acres Co., Darlington, SC) was used at a rate of 60 pounds/acre the first year, 80 pounds/ acre the second year, and 100 pounds/acre each subsequent year, as recommended by several fiber farm managers. This fertilizer, characterized as a potassium nitrate, has as its major elements potassium and nitrogen, although it also contains some phosphate, magnesium, calcium, copper, zinc, manganese, boron and molybdenum. Soil sampling or foliar analysis should indicate what elements are necessary. Bar recommended a similar formula in his 1996 report.

Current cost for potassium nitrate fertilizer is $180 per ton. Assuming 100 pounds/acre of nitrogen is needed, a 10% formulation would require 0.5 tons/acre for a cost of $90/acre for years three and beyond. The 60-pound application in the first year would cost $54/acre and the second year 80-pound application cost is $72/acre.

Insecticides

Various defoliators, borers and miners of intensively cultivated poplars require treatments to prevent losses (Morris and Oliveria, 1976). Pheromone traps can be used to indicate which insects are present in the plantation, although the most common is likely to be the cottonwood leaf beetle (*Chrysomela scripta*). While the cottonwood pests have several natural predators, chemical treatments are the most economical and effective means of eliminating outbreaks (Oliveria and Abrahamson, 1976).

Insecticides may be applied as fumigants, sprayables or systemics. Fumigants are expensive and time-consuming as a treatment for active plantations. Sprayables are less costly, but aerial applications tend to draw unwanted attention from the public. For plantations with drip irrigation, systemics have become the treatment of choice.

Dimethoate (Gowan Company, Yuma, AZ) is a systemic insecticide that has worked effectively in controlling most cottonwood pests (personal communication with fiber farm managers). Three treatments per summer on a 35-day rotation will eliminate most pests (Morris et al., 1975). Each treatment consists of applying 5 pounds/acre of chemical through the drip irrigation system. Chemical cost for a 5-pound treatment is approximately $9/acre. Three treatments per season would cost $27/acre.

Daily Irrigation

The daily irrigation cost is primarily due to the electricity cost. Minor repairs for hoses, fittings, etc. are included in the labor cost (see supervision). However, the irrigation system will require a substantial amount of electricity to run the two pump houses. Each system will be scheduled to run for 12 hours daily, as this schedule allows for flexibility in the event of maintenance for one of the pump houses. If pump maintenance or repair work needs to be done, the other pump house may be run for 24-hours to keep water to the trees.

Electricity costs will vary with the size of the pumps running the system and the electricity supplier for the region. For a southeastern region fiber farm, it costs approximately $2000 per month per pumping station to keep the pumps running on a 12-hour schedule and supply adequate water and nutrients to the trees (personal communication with a fiber farm manager). Therefore, electricity costs for this analysis was $2000 per station (there are two) operating for six months, or $24,000. For a hypothetical 600-acre fiber farm, that amounts to $40 per acre per year.

Supervision

Two employees are needed during the growing season to do maintenance on the irrigation system, cultivate to minimize weeds, flush the irrigation lines to prevent blockages, make daily visual inspections for insect attacks, and keep the irrigation system in good working order. For this analysis, two part-time workers during the summer months were estimated to cost $48,000/year. This estimate includes a pay rate of $12.50/hour, 20% fringe benefits, occasional overtime and a pick-up truck for hauling supplies. An additional $20,000 was included to cover overhead for supervisory costs, resulting in a total supervision cost of $68,000. The annual pay for these workers was increased at a rate of 3% each year to allow for raises. Annual supervision costs were allocated over the entire fiber farm, thus varying the per acre cost depending on the size of the farm.

Total Costs

Total costs for each year are illustrated in Table IV.3 on a per acre basis for a hypothetical 600-acre fiber farm. Costs are listed for individual operations each year and totaled in the Annual Total row. The overall cost to-date over the rotation is totaled on the Accumulated Total Cost. Fiber farming is an expensive operation - annual costs without interest during a non-planting year average $300 or more per acre, but during a planting year, they are over $600 per acre. Table IV.4 shows that interest cost (26%) is the single largest annual cost component. While all the costs vary from year to year, the percentage component of each cost category averaged over the life of the plantation is summarized in Table IV.4.

Table IV.3. Summary of all costs ($) per acre of a 600-acre fiber farm in the southeastern coastal plain growing eastern cottonwood.

	year	1	2	3	4	5	6	7	8	9	10
Initial ($/Acre)	Land Rent	50	50	50	50	50	50	50	50	50	50
	Irrigation Rent	58	58	58	58	58	58	58	58	58	58
	Site Prep & Tillage	44									
	Planting	171									
Annual ($/Acre)	Irrigation electric	40	40	40	40	40	40	40	40	40	40
	Weed Control	93	62	18	0	0	0	0	0	0	0
	Fertilizer	54	72	90	90	90	90	90	90	90	90
	Insecticide	27	27	27	27	27	27	27	27	27	27
	Supervision	68	70	72	74	77	79	81	84	86	89
	Annual Total	605	379	355	339	341	343	346	348	351	353
	Interest Cost	30	51	71	91	113	136	160	185	212	240
	Accumulated Total Cost	635	1064	1489	1920	2374	2853	3359	3892	4455	5048

Table IV.4. Sum of annual costs over a 10-year rotation and percentages per acre for each operation for a 600-acre short-rotation hardwood plantation fiber farm.

	Total Cost ($)	Percent of Total Cost
Land Rent	500	10
Irrigation Rent	575	11
Site Prep & Planting	215	4
Electric	400	8
Weed Control	173	3
Fertilizer	846	17
Insecticide	270	5
Supervision	780	16
Interest Cost	1290	26
Total	5048	100

Growth and Yield Volumes

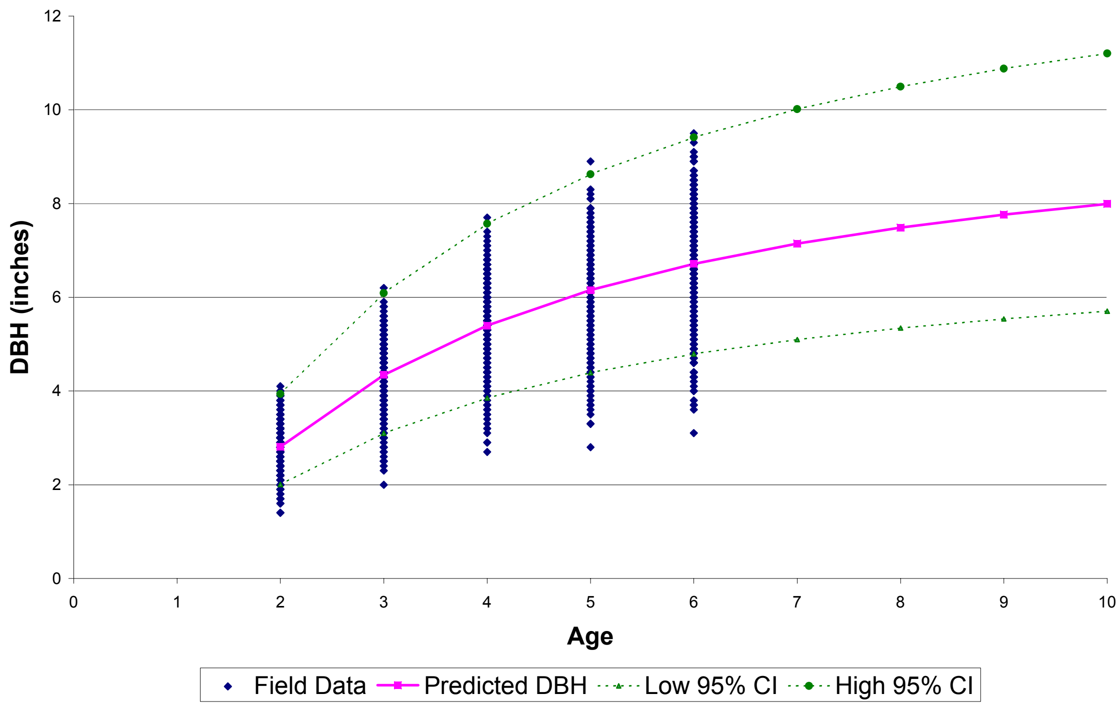
The statistical results from a regression analysis on the diameter and height data for eastern cottonwood are found in Table IV.5. Graphical representation of each curve with the data range shown is found in Figure IV.1. The average diameter and height for each age class was used to determine the average volume per tree. It was assumed there are 490 trees per acre at year 5 (a 10% mortality from planting through year 5) and a loss of 5 trees each year over the remaining life of the stand. Using the volume per tree and total trees per acre resulted in the average yield per acre for a given year. Total yield per acre is presented in Table IV.6.

Table IV.5. Equation and summary statistics for regression analysis on DBH and height data.

DBH Equation -		$DBH = e^{2.340 - 2.614/Age} + \varepsilon$		$R^2 = .77$	
Source	df	Sum of Squares	Mean Square	F value	Pr>F
Model	1	235.193	235.193	8260.57	<.0001
Error	2425	69.044	0.0285		
Total	2426	304.237			

Height Equation -		$HT = e^{4.368 - 2.538/Age} + \varepsilon$		$R^2 = .84$	
Source	df	Sum of Squares	Mean Square	F value	Pr>F
Model	1	221.713	221.713	12663.23	<.0001
Error	2425	42.458	0.0175		
Total	2426	264.171			

Analysis indicates that the plantations are growing 8 to 9 tons/acre/year of green fiber. This yield per acre is less than one-half what Bar (1998) used in his analysis (59 tons/acre versus 140 tons/acre) and only about one-half of typical Northwestern operations (120 tons/acre) (Stanton et al., 2002). Initial eastern cottonwood plantations have not yet produced the yield that some proponents have speculated, but based on the wide variance of the data from the trial plantation, additional genetic or cultural work may improve that yield dramatically.



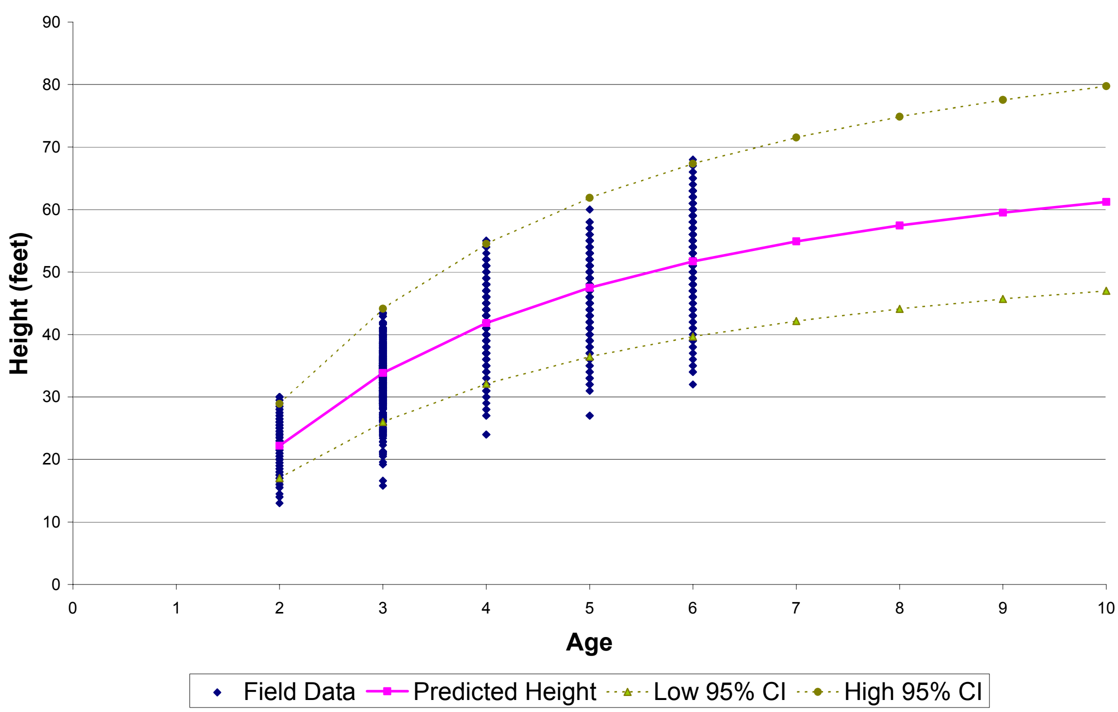


Figure IV.1. Projected DBH and height by year for eastern cottonwood plantations in the southeast. At each age measurement, n = 485.

Table IV.6. Estimated per acre yield by year for eastern cottonwood plantations growing in the southeast.

Age	Yield/Tree (tons)	Trees/Acre	Total Tons/Acre
5	0.076	490	37.25
6	0.101	485	49.09
7	0.124	480	59.31
8	0.144	475	68.32
9	0.161	470	75.56
10	0.176	465	81.90

Delivered Cost Estimates

Cost estimates for the fiber farm material delivered to a pulp mill as roundwood or chips were estimated. Harvesting and transportation costs will be impacted by the distance from the fiber farm to the pulp mill. The costs used in this analysis were based on a typical haul distance of 30 miles. For the roundwood, a $12/ton harvest and transport rate was assumed. For clean chips, the harvest and transport rate was $18.00/ton, due to the cost of chipping on site.

Table IV.7 summarizes all the costs and yields for the hypothetical 600-acre fiber farm, as well as a delivered cost estimate for both roundwood and chips. Material from the fiber farm delivered to the mill as roundwood averaged $71 per ton, with the seventh year of the first rotation being lowest cost at $68.63 per ton. Chip deliveries from the fiber farm fell in the $77 range.

Table IV.7. Costs per acre and delivered cost per ton for alternative rotation lengths of intensively-managed eastern cottonwood plantations in the southeast. Delivered costs represent the cost for the fiber farm material for that given year.

	year	1	2	3	4	5	6	7	8	9	10
Initial ($/Acre)	Land Rent	50	50	50	50	50	50	50	50	50	50
	Irrigation Rent	58	58	58	58	58	58	58	58	58	58
	Site Prep & Tillage	44									
	Planting	171									
Annual ($/Acre)	Irrigation electric	40	40	40	40	40	40	40	40	40	40
	Weed Control	93	62	18	0	0	0	0	0	0	0
	Fertilizer	54	72	90	90	90	90	90	90	90	90
	Insecticide	27	27	27	27	27	27	27	27	27	27
	Supervision	68	70	72	74	77	79	81	84	86	89
	Annual Total	605	379	355	339	341	343	346	348	351	353
	Interest Cost	30	51	71	91	113	136	160	185	212	240
	Accumulated Total Cost	635	1064	1489	1920	2374	2853	3359	3892	4455	5048
	Yield (tons/acre)	0	0	0	0	37.3	49.1	59.3	68.3	75.6	81.9
	Stumpage Cost per Ton					63.73	58.12	56.63	56.97	58.96	61.64
	Delivered Cost as Roundwood					75.73	70.12	68.63	68.97	70.96	73.64
	Delivered Costs as Chips					81.73	76.12	74.63	74.97	76.96	79.64

A sensitivity analysis similar to the Lothner study (1981) was completed to determine the impact of cost increases for each operation. Costs may vary depending on region, time of year, competition for services and availability of materials. Due to this uncertainty, the cost for each operation was individually increased by 50% to determine the impact on the short-rotation stumpage costs. As shown in Table IV.8, no individual operation had a huge affect on final costs. A 50% increase for either fertilization or supervision resulted in a 10 percent increase in stumpage cost.

Table IV.8. Increase in hardwood plantation stumpage cost if individual operational costs are increased by 50% while all other costs are held constant.

Operation	Percent Increase
Land rent	6.6
Irrigation rent	7.5
Site prep & planting	3.5
Electric	5.2
Weed control	2.7
Fertilizer	10.9
Insecticide	3.5
Supervision	10.1

Comparison to Actual Mill Wood Cost

Actual hardwood pulp mill wood prices and volumes were obtained from three cooperating coastal plain mills for roundwood and chips delivered over a three-year period (July 1998 – June 2001). These delivered wood prices were then compared with the estimated delivered cost for fiber farm material as determined using the decision model.

Using an average delivered cost for the six possible years of wood deliveries from the fiber farm ($71.00 per ton for roundwood), none of the three cooperating pulp mills purchased any material at a price this high (see Figures IV.2, IV.3, IV.4). Pulp mill 3 did buy some roundwood during the second year of the analysis for $69/ton, which was well above any other furnish they bought during the three-year window. Pulp mills 1 and 2 never bought roundwood at a price higher than $50/ton.

Using delivered chip cost did not improve the direct comparison. The closest any of the mills came to the $77/ton fiber farm cost were pulp mills 2 and 3, which both received chips approaching $60/ton (Figures IV.5 and IV.6). Thus, the fiber farm chips were approximately 28% higher than the highest cost chips actually purchased during the study period.

Something must change to bring the cost of wood from fiber farming more in line with current market prices if it is to become economically feasible. Two potential ways to lower the delivered price are: (1) reduce operational costs, and/or (2) increase yield. There are not many areas to reduce operational costs. For the fiber farm to be accessible year-round, a high, dry site is required. To make such a site productive, irrigation and fertilization are necessary. And to keep the trees growing, weed control and insecticides are required. And it takes labor to make all this happen. Thus, very little change is foreseeable on the cost side.

Yield, on the other hand, could improve. Table IV.6 shows that the average fiber farms currently yield approximately 59 tons/acre in year 7. Discussions about yield with supervisors from West Coast operations indicate that through improved genetics and a better cultural practices, they have successfully increased yield nearly 60% over the past 10 years. Similar increases have been found in many intensively-managed plantations (Stanturf, 2003). The estimated yield for this analysis was developed for a first generation plantation established in the South. However, if succeeding hardwood plantations in the South take advantage of genetic and cultural improvements and gain one-half that increase, yield may conceivably approach 79 tons/acre by year 7, thus providing the potential to reduce delivered costs by as much as $14/ton.

Attaining this level of yield improvement could result in fiber farm delivered costs of approximately $56.50/ton for roundwood and $62.50/ton for chips (Table IV.9). While these prices are within the range of what pulp mills 2 and 3 have historically paid for some of their furnish (see Figures IV.3, IV.4, IV.5 and IV.6), fiber farm deliveries would still be on the high end of the cost spectrum into either pulp mill.

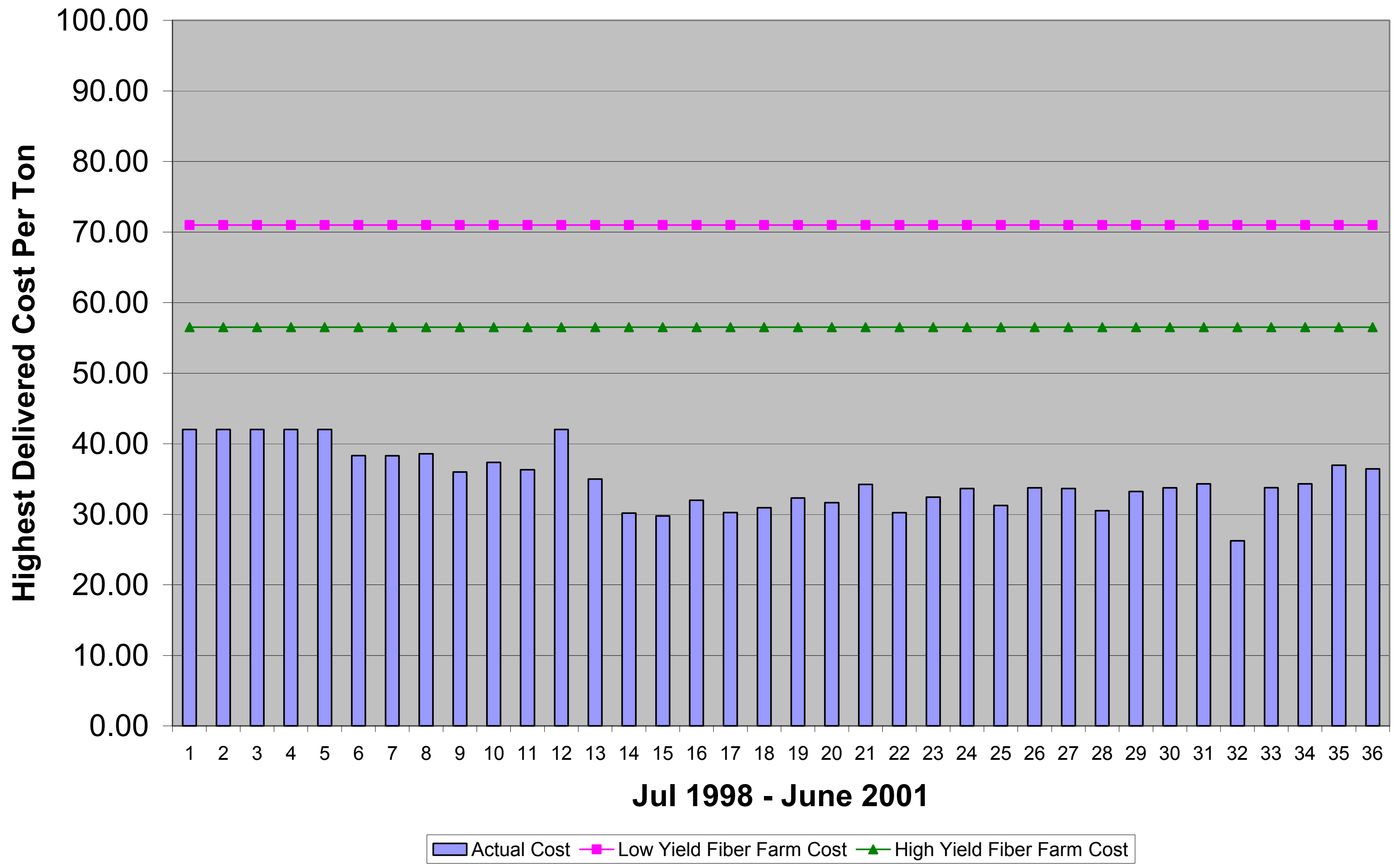


Figure IV.2. Pulp mill 1 hardwood roundwood cost. The top line shows the low yield fiber farm and is representative of the yield that is currently harvested. The high yield fiber farm delivered price is attained through improved genetics of eastern cottonwood.

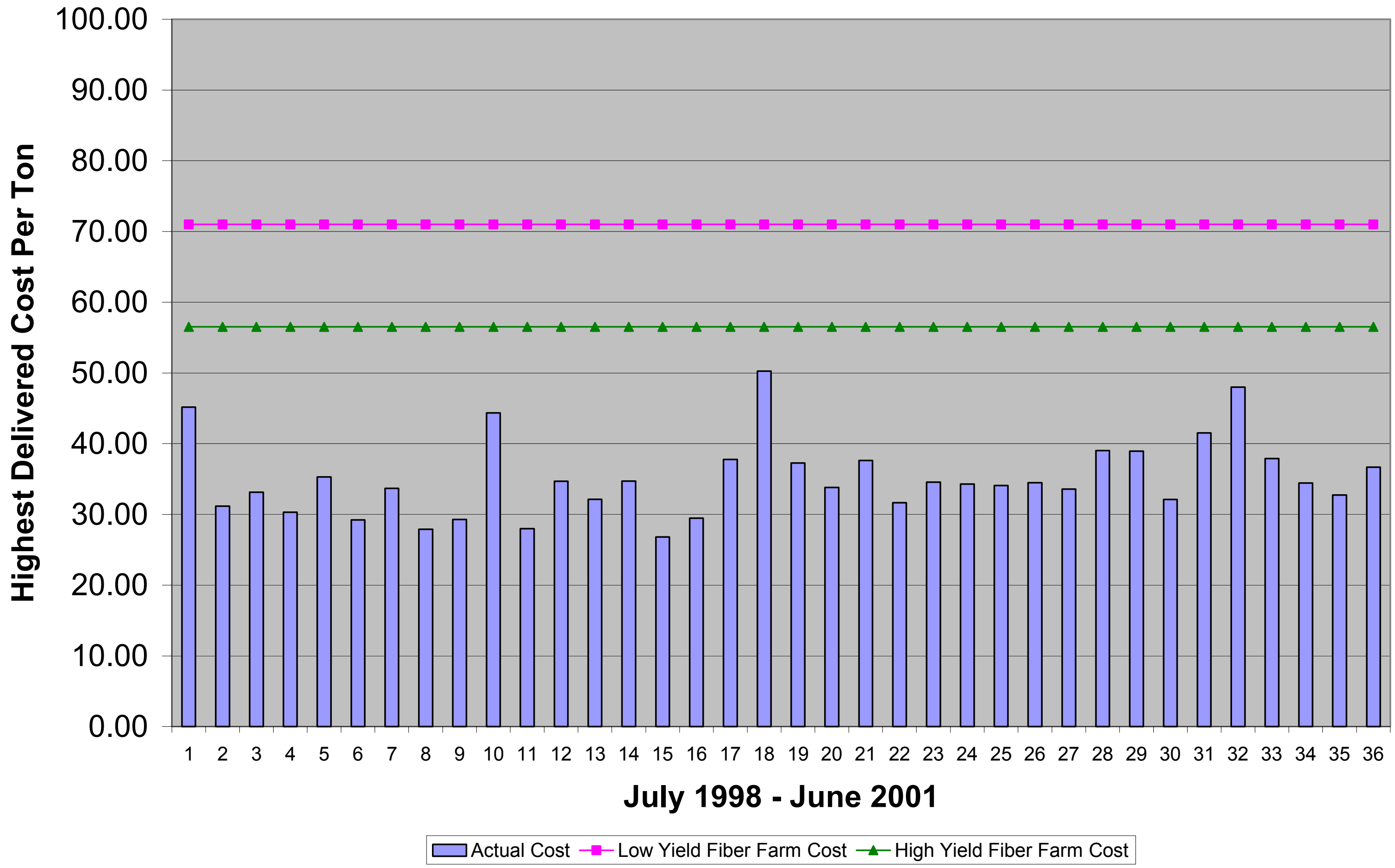


Figure IV.3. Pulp mill 2 hardwood roundwood cost. The top line shows the low yield fiber farm and is representative of the yield that is currently harvested. The high yield fiber farm delivered price is attained through improved genetics of eastern cottonwood.

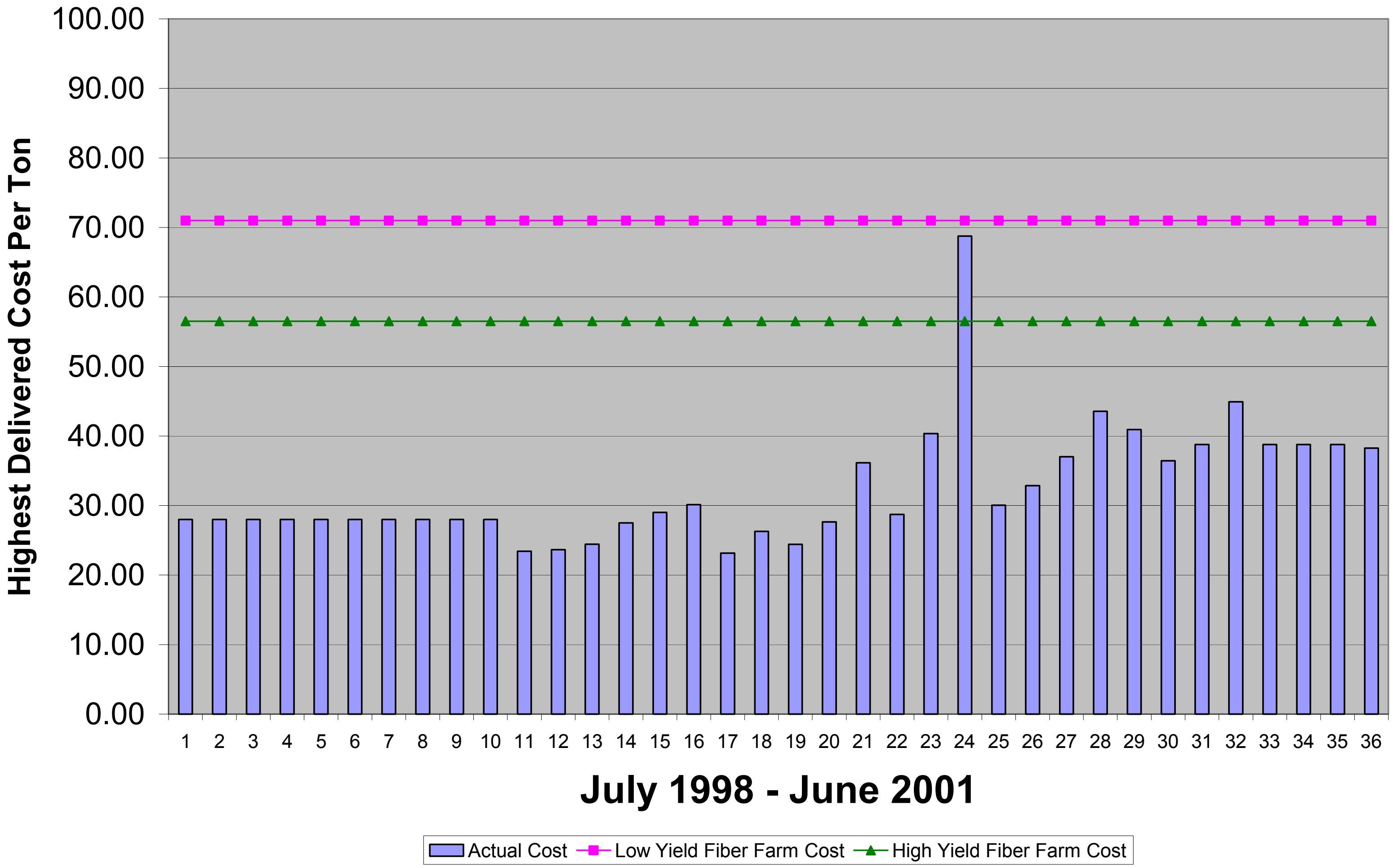


Figure IV.4. Pulp mill 3 hardwood roundwood cost. The top line shows the low yield fiber farm and is representative of the yield that is currently harvested. The high yield fiber farm delivered price is attained through improved genetics of eastern cottonwood.

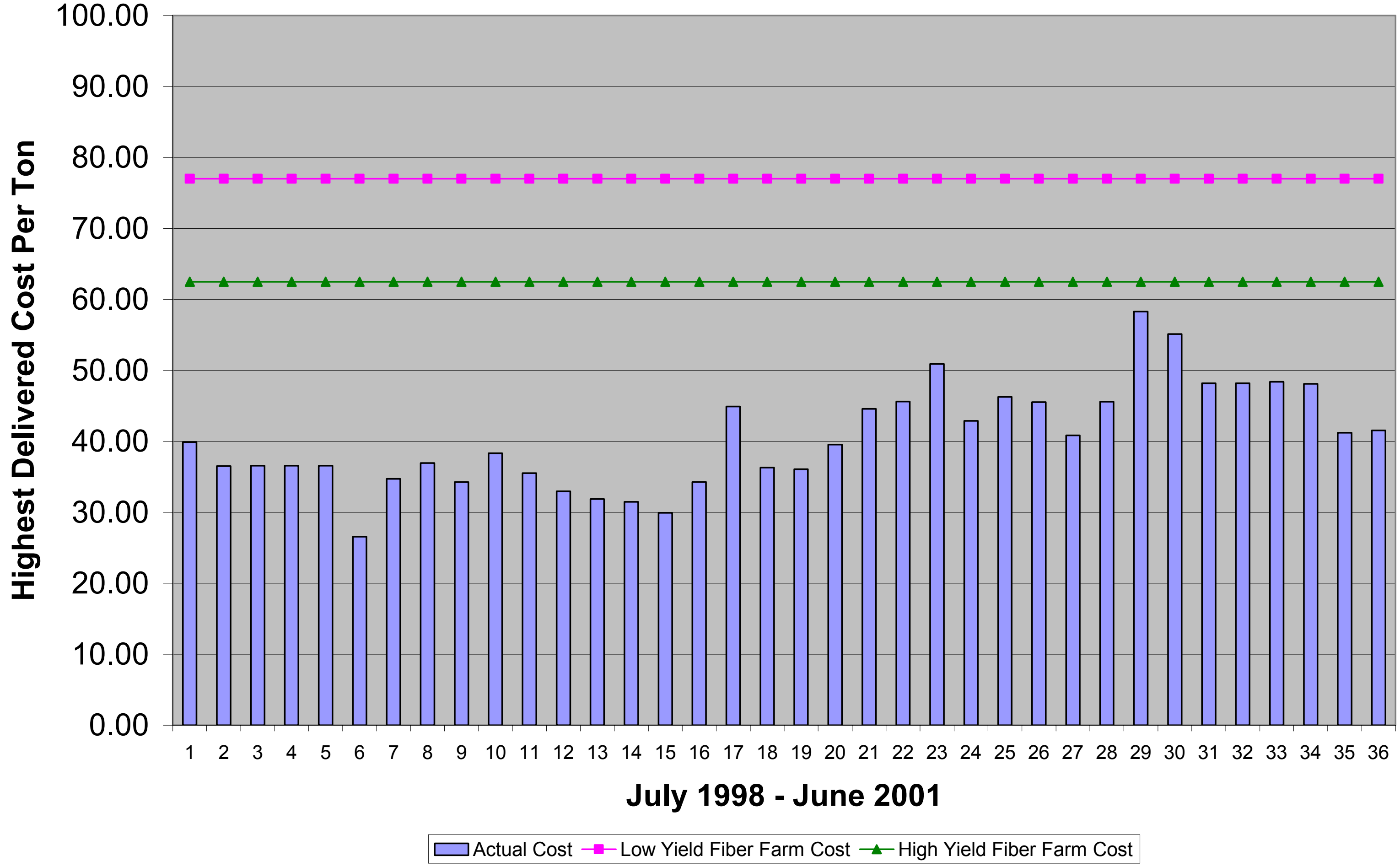


Figure IV.5. Pulp mill 2 hardwood chip cost. The top line shows the low yield fiber farm and is representative of the yield that is currently harvested. The high yield fiber farm delivered price is attained through improved genetics of eastern cottonwood.

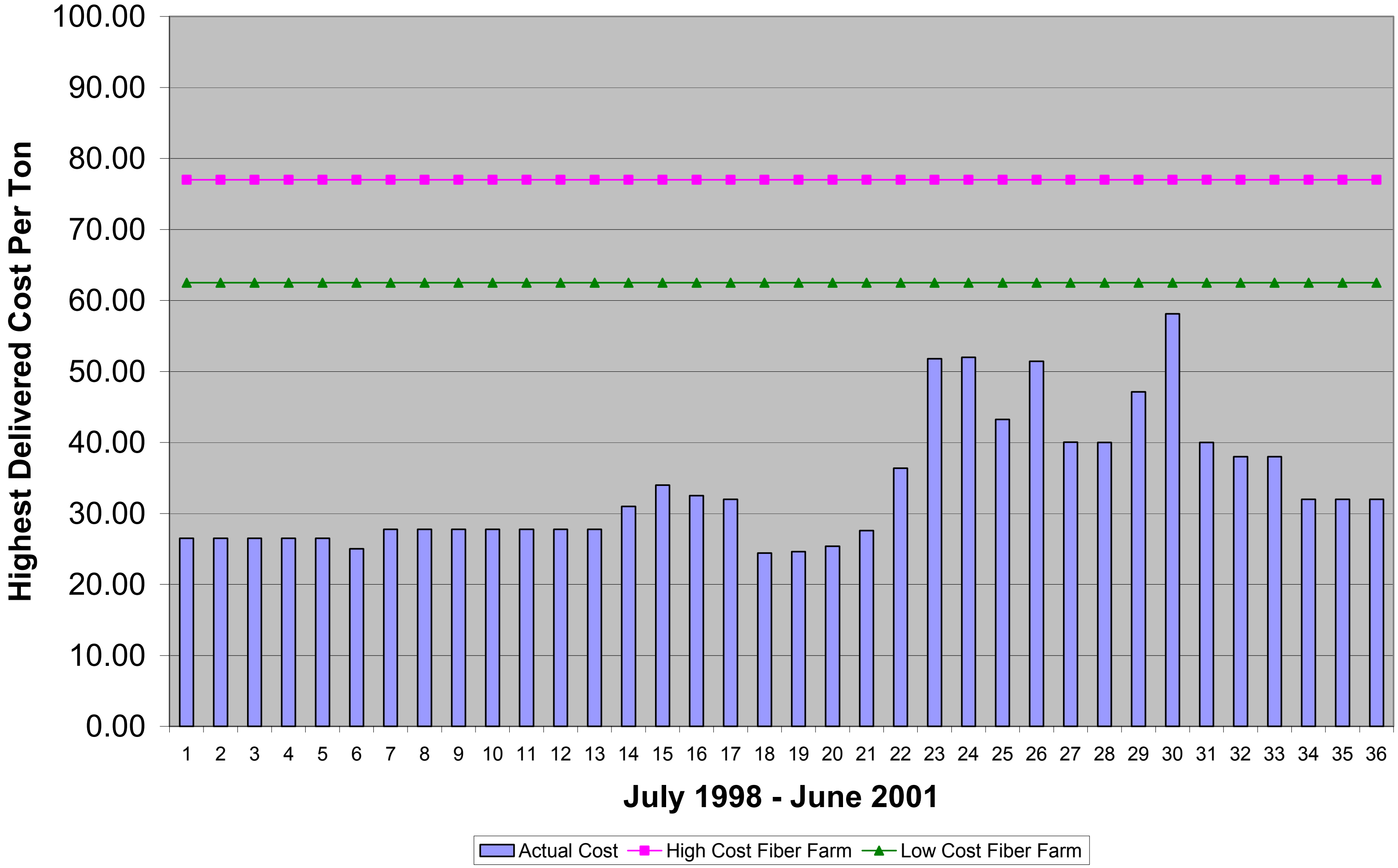


Figure IV.6. Pulp mill 3 hardwood chip cost. The top line shows the low yield fiber farm and is representative of the yield that is currently harvested. The high yield fiber farm delivered price is attained through improved genetics of eastern cottonwood.

Table IV.9. Costs per acre and delivered cost per ton for alternative rotation lengths of intensively-managed eastern cottonwood plantations in the southeast with higher yield per acre. Delivered costs represent the cost for the fiber farm material for that given year.

	year	1	2	3	4	5	6	7	8	9	10
Initial ($/Acre)	Land Rent	50	50	50	50	50	50	50	50	50	50
	Irrigation Rent	58	58	58	58	58	58	58	58	58	58
	Site Prep & Tillage	44									
	Planting	171									
Annual ($/Acre)	Irrigation electric	40	40	40	40	40	40	40	40	40	40
	Weed Control	93	62	18	0	0	0	0	0	0	0
	Fertilizer	54	72	90	90	90	90	90	90	90	90
	Insecticide	27	27	27	27	27	27	27	27	27	27
	Supervision	68	70	72	74	77	79	81	84	86	89
	Annual Total	605	379	355	339	341	343	346	348	351	353
	Interest Cost	30	51	71	91	113	136	160	185	212	240
	Accumulated Total Cost	635	1064	1489	1920	2374	2853	3359	3892	4455	5048
	Yield (tons/acre)	0	0	0	0	49.7	65.5	79.1	91.1	100.8	109.2
	Stumpage Cost per Ton					47.76	43.56	42.46	42.72	44.19	46.23
	Delivered Cost as Roundwood					59.76	55.56	54.46	54.72	56.19	58.23
	Delivered Costs as Chips					65.76	61.56	60.46	60.72	62.19	64.23

CONCLUSIONS

The objective of this paper was to validate the decision model for short-rotation, intensively-managed hardwood plantations and test if fiber farms are a viable wood source alternative for a southern pulp mill. Using costs from literature and yield from an ongoing industry fiber farm in South Carolina, a hypothetical eastern cottonwood plantation was analyzed in the model. A sensitivity analysis was used to determine the effect of cost increases to the delivered cost of hardwood plantations. If the plantation is established on a dry, sandy site, the hardwood should be available year-round as pulp mill furnish. Due to the growth limitations of eastern cottonwood on a dry, sandy site, various inputs (such as water, fertilizer and weed control) are necessary to maximize productivity.

The decision model results from establishment of these hypothetical plantations and comparing their delivered costs to delivered costs from three cooperating southern pulp mills indicates the following:

a. The decision model allows the user to include all costs he/she may deem applicable to their analysis.
b. Costs can be changed easily in the decision model to allow the user to complete a sensitivity analysis.
c. When current costs for all operations along with current yields from industry trials are attributed to determine a stumpage price, intensively-managed, short-rotation hardwood plantations seem to be cost prohibitive for southeastern pulp mills, based on input assumptions.

d. However, if plantations can be established under a “high yield” scenario where yields from the fiber farm increase over time above volumes previously reported by the limited operational trials in the south, then fiber farm delivered costs are closer to current actual wood costs for southern pulp mills. Yield increases in southeastern fiber farms are reasonable to expect, given the documented increase in yields realized from existing, large-scale operations in the Pacific Northwest through genetic manipulation.

In summary, wood from short-rotation, intensively-managed hardwood plantations is generally too expensive to become a regular source of furnish for southern pulp mills any time soon, but may, under certain circumstances, become cost effective as a smaller part of company operations.

CHAPTER V. USING SHORT-ROTATION, INTENSIVELY-MANAGED HARDWOOD PLANTATIONS AS "GREEN" INVENTORY FOR SOUTHEASTERN PULP MILLS.

ABSTRACT

As a routine wood source for a pulp mill, recent studies have shown that intensively-managed, short-rotation hardwood plantations are not cost effective. The objective of this study was to determine if these plantations may be cost effective as "green" inventory, replacing some portion of high cost remote woodyard inventory. Three southeastern pulp mills were used as case studies in a net present value analysis. Short-rotation hardwood plantations of eastern cottonwood (*Populus deltoides*) were simulated to replace a portion of remote woodyard inventory, with wood delivered to a pulp mill from this "green" inventory only when pulp mill inventory levels become critical. If this "green" inventory is not used, these plantations continue to grow until needed. With current yield from an experimental fiber farm, short-rotation plantations were not cost effective as "green" inventory. However, if yield could be increased approximately 33% through either genetic or cultural improvements, all three pulp mills could have reduced overall wood cost by establishing a fiber farm. A sensitivity analysis completed on a participating pulp mill indicated an 800-acre farm resulted in the highest net present value.

INTRODUCTION

Procuring wood, especially hardwood, during the winter months for a pulp mill in the Southeast has some difficulties. Soft ground reduces the operational feasibility of many sites, forcing companies to store hardwood in woodyards for retrieval during wet weather. Short-rotation, intensively-managed hardwood plantations grown on dry sites could replace some volume companies are storing in remote woodyards.

The previous chapter determined hardwood fiber farms are expensive to establish and the wood from these hardwood plantations delivered to a pulp mill is well above that of normal delivered furnish when only evaluated on a cost per ton basis. It was also a much higher cost than what Bar (1998) determined, probably due to yield differences. Both reports indicate that it could be several years before hardwood stumpage prices in the South increase to the level necessary to justify intensive culture plantations as a daily source of fiber. However, short-rotation hardwood plantations could be used as a "green" inventory alternative to supply a pulp mill during severe weather, thereby possibly saving the costs associated with storing excess winter inventory on remote woodyards. "Green" inventory refers to a strategically located, intensively managed, short-rotation hardwood plantation (fiber farm) that could be harvested at any time to provide an emergency supply of wood into the pulp mill.

The major advantage of fiber farms in the Southeast are likely to be achieved when they are used to supplement short-term hardwood inventory systems. Inventorying a significantly increased amount of wood into dry storage at remote woodyards is a practice that occurs every fall to help the pulp mill make it through the upcoming winter when logging production is typically reduced. In the event of a "dry" winter, this winter inventory wood must be consumed in a timely manner because it will deteriorate and become unusable. If a portion of the expensive "winter building" wood inventory could be replaced by "green" inventory, there could be annual savings due to the reduced quantity of expensive remote woodyard inventory that must be purchased (and subsequently used) to provide sufficient furnish through the winter months

Wood cost savings should accrue since the company will buy less wood to be stored on remote woodyards (a more expensive option) and will replace it with wood purchased directly from the woods to the pulp mill. If less wood is purchased during the inventory building phase in a given year, savings should occur in total wood cost. The additional volume in "green" inventory hardwood plantations would be harvested only when the procurement manager for each pulp mill determines inventory levels at the pulp mill have reached a critical stage. If a dry winter occurs, and the pulp mill wood inventories do not drop below acceptable levels, the hardwood plantation will be left standing to grow another year. Then, the following winter, a reduced volume will need to be purchased for storage on remote company woodyards. Assuming this occurs over a period of several years, a substantial reduction in total, overall wood cost may be achieved.

As referenced earlier (pg. 41), wood stored in remote woodyards typically carries a $10/ton premium over deliveries directly to the mill from the woods (Martin, 2001). Wood stored at a remote woodyard must be unloaded, stored, and then reloaded onto trucks or railcars. These additional operations, along with some deterioration as the wood ages in the woodyard, add cost to the material. Additionally, remote woodyard material must then be transported to the pulp mill, further increasing costs. The amount of additional costs will vary with age of the wood (amount of deterioration), distance to the mill, and size of the woodyard, but $10/ton is typical. Thus, if 10,000 tons of material were available in "green" inventory and could replace an equal amount of remote woodyard inventory, a potential $100,000 savings in wood cost during the year ($10/ton savings x 10,000 tons) could be realized. Although our earlier analysis showed that wood deliveries from a fiber farm cannot compete on a cost (per ton) basis with gatewood, this additional savings over remote woodyard storage may offset the relatively high cost of the fiber farm material used when pulp mill wood supplies are low.

LeBel and Carruth (1997) used a stochastic model to help determine the amount of inventory for a pulp mill. They had three categories of loggers bringing wood to a pulp mill and had a random number generate the impact of weather on deliveries. By customizing the logging force in the woods, they were able to maintain inventory and minimize putting production quotas on in-woods operations. If a fourth type of "logger" were "green" inventory that minimized risk to the company by ensuring deliveries during any adverse weather period, total inventory might be further optimized.

The pulp and paper industry is continually searching for ways to reduce their wood cost while ensuring a reliable raw material supply, and woodyard inventories have long been a valuable resource in this goal. Short-rotation, intensively-managed hardwood plantations may also present an opportunity to optimize the inventory strategy for a pulp mill. Evaluating whether "green" inventory is cost-effective and operationally feasible for certain Southeastern pulp mills should be determined by this analysis.

Research Objectives

The objective of this research project is to develop an approach for determining if strategically-located, short-rotation, intensively-managed hardwood plantations are economically and operationally feasible in the Southeast as a cost-effective alternative to the annual storage of large volumes of hardwood pulpwood inventory. For example, if the procurement organization for a pulp mill has determined that it requires 150,000 tons of hardwood fiber available to carry the mill through the winter, savings could occur if alternatively, 130,000 tons were inventoried in conventional storage methods, and 20,000 tons were inventoried on hardwood plantations. During a mild winter, the plantation wood may not be used, allowing the trees to grow for another year. That annual growth along with possible in-growth from a new age class might total 30,000 tons. Thus, only 120,000 tons would need to be inventoried the next year before winter arrives. Analyses will allow us to determine the possible cost benefits involved in short-term wood storage versus long-term plantation establishment.

Thus, this research project has the following specific objectives:

1. Using a modified version of the decision model developed in a previous chapter, determine the cost feasibility of using short-rotation, intensively managed plantations as "green" inventory in actual pulp mill inventory situations. While Lebel and Carruth (1997) studied inventory in a theoretical sense, actual hardwood inventory and costs for three southeastern pulp mills will be used as case studies to investigate the feasibility of "green" inventory.

2. Using the decision model, determine the optimal size of a fiber farm as "green" inventory for a southeastern pulp mill.

MATERIAL AND METHODS

The cost feasibility of short-rotation hardwood plantations as "green" inventory for Southeastern pulp mills was analyzed by determining the total wood cost savings of keeping "green" inventory instead of roundwood inventory on remote woodyards. Three cooperating southeastern pulp mills who supplied hardwood wood cost and inventory levels over a three-year period were used as case studies to determine if using short-rotation hardwood plantations as "green" inventory would have reduced wood cost.

Data for all three pulp mills is available on a monthly basis from July 1998 and continuing until June 2001. As a first step, a statistical analysis was conducted to compare the hardwood inventory building process for the three different size pulp mills. Obviously, the larger the pulp mill, the more wood they will likely store. But, do both a small and large pulp mill build inventory during the fall, peak in December and January, and then reduce inventory during the spring to a minimal summer level? The Kolmogrov-Smirnov non-parametric test (ks test) was used to determine if each pulp mill built hardwood inventory similarly (Hollander and Wolfe, 1999). This test was selected because it was important to remove the effect of magnitude from the comparison, i.e. that a small mill that built 80,000 tons of inventory used a similar process to a mill that built 150,000 tons of inventory.

A second statistical test will determined how closely each pulp mill followed their inventory plan by looking at the amount of variation between actual inventory and the pulp mill's inventory goal. For each month, actual hardwood inventory was measured as a percent of inventory goal. By looking at variation this way, magnitude was again removed from the analysis since all three pulp mills had different production capacities and stored different amounts of wood. The variation was calculated monthly for the three-year period and then averaged to determine one variation for each pulp mill. The pulp mill with the lowest variation did the best job of following their inventory plan.

In a second step, hardwood inventory levels were analyzed for each of the three years to determine if pulp mill inventory ever reached a critical level and to determine the cost savings (if any) that could be attained through implementation of a "green" inventory system. The critical level was defined by procurement personnel from each mill and was determined to be when actual inventory levels dropped below 50% of inventory goal; however, it will vary slightly with season (see page 44). Inventory goals are set by management and are determined to be the amount of wood the pulp mill needs to store each month to effectively buffer day-to-day and week-to-week inventory fluctuations, and these goals provide a set probability that the mill will not run out of wood, causing a curtailment in paper production. Actual inventories, of course, vary due to consumption and deliveries. Only when inventory reached a critical level would "green" inventory be harvested and delivered to the pulp mill.

Savings could occur each year for the available volume of "green" inventory as an equivalent volume of roundwood would not be purchased and stored at remote woodyards. The savings for this volume was the $10/ton additional cost associated with remote woodyard roundwood.

Each pulp mill was analyzed as a separate operation, first using low yield and then high yield plantations. For each analysis, it was assumed that a fully operational fiber farm was already established with equal acres in each age class for the selected rotation length in the decision model, as though the "green" inventory system were already up and running after initial establishment in order to understand how a working fiber farm could influence annual operations and costs. For each year at each pulp mill, there are three potential cash flows: 1) costs to operate the fiber farm, 2) annual savings from the volume of wood in hardwood plantations, and 3) replacement of high cost deliveries.

Costs each year to operate the fiber farm were summarized and considered as expenses. These costs were calculated on the acres in each age class of plantation on the fiber farm. Savings were totaled by multiplying the amount of volume available from the hardwood plantations by the woodyard premium ($10/ton). Volume was only included from plantations that were age 5 and higher.

The last annual cash flow in the decision model came from offsetting wood purchases with plantation wood. This occurred only during a year when "green" inventory was harvested. All the costs associated with the hardwood plantations were already accounted for on an annual basis in the decision model as an expense. When the "green" inventory wood was harvested, it was then delivered to the pulp mill at the average harvesting cost for the area (all stumpage cost was included above as expenses). This plantation wood offset the highest priced hardwood delivered during a similar time period (within 2-3 months). Therefore, the price differential between plantation wood and these suppliers was accounted as savings.

All the costs and all the savings over the three-year period were used as cash flows in a net present value analysis, similar to the way Lothner (1981) analyzed plantations in his study. Two scenarios were analyzed with the decision model for each pulp mill. The first analysis was done using the lower yield plantations that are representative of the operational, industry fiber farm located in the Southeast. A second scenario was completed for each pulp mill using the higher yield plantations, assuming that genetic improvements and operational efficiencies result in the higher yielding fiber farms.

While the decision model was being used, if a dry winter occurred and critical levels were not reached, the volume was carried over to the next year and additional volume was added due to growth. Also, in the event of several dry years in a row, an assumption was made to harvest any plantations reaching age 10.

RESULTS AND DISCUSSION

Statistical Tests

The cumulative distribution of the hardwood inventory goal at the three pulp mills is depicted in Figure V.1 on an "inventory" year basis (July – June). The results of the ks test, which compares the cumulative distributions, indicates there was not a significant difference ($\alpha > .99$) between all three pulp mills in how they built hardwood inventory (e.g., minimal pulp mill inventory during the summer; buildup during the fall and peaking

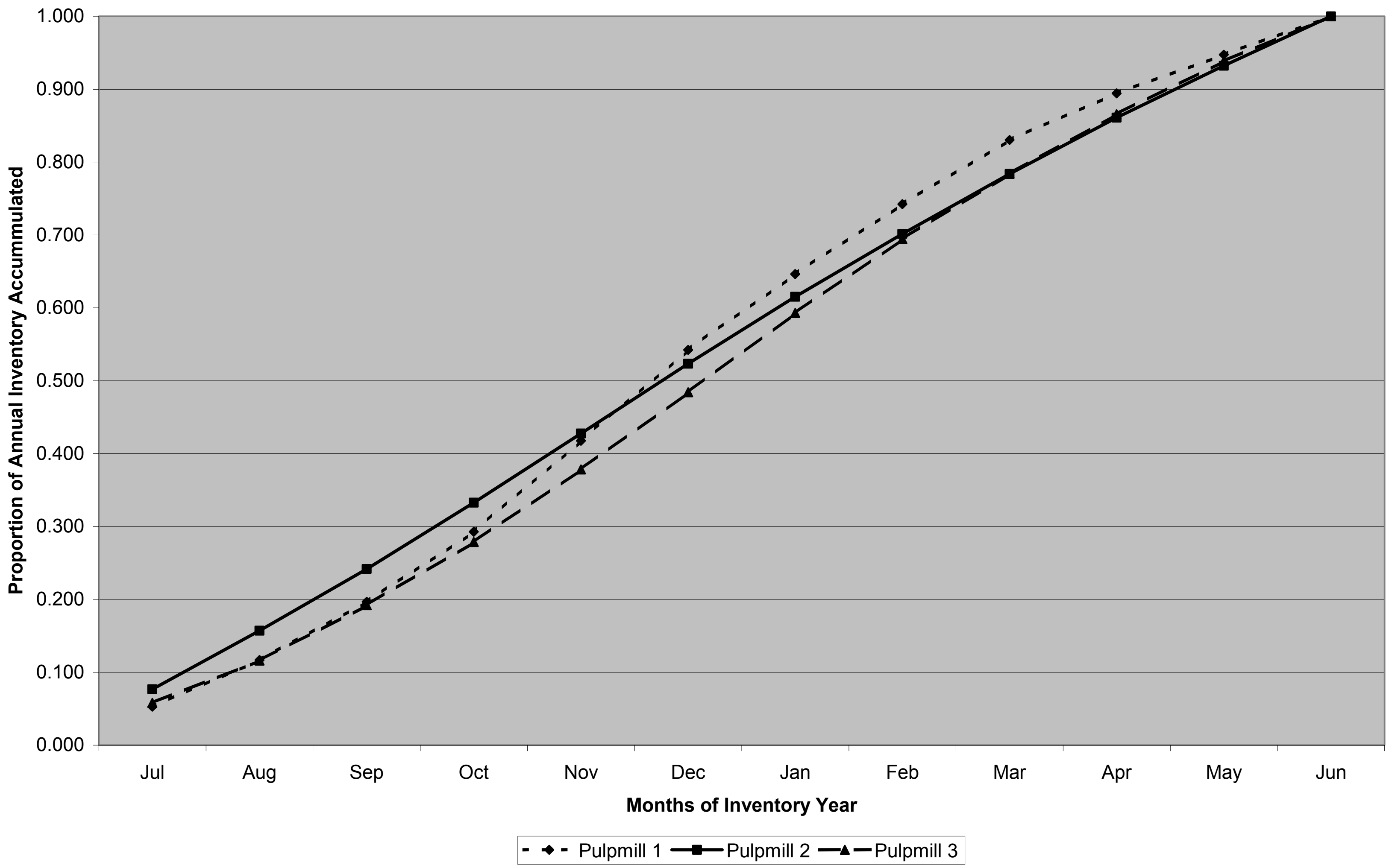


Figure V.1. Cumulative distribution of the annualized hardwood inventory indicates all 3 pulp mills used a similar plan to build inventory levels.

around the first of the year; then decreasing inventory during the spring). Size of these three pulp mills did not affect how they built inventory, therefore this analysis on the cost feasibility of short-rotation hardwood inventory should be applicable to most southeastern pulp mills who build winter inventory. Obviously, a larger pulp mill would need to consider establishing more “green” inventory than a smaller pulp mill.

A second statistical test looked at the amount by which the actual hardwood inventory varied from the inventory goal was compared for the three pulp mills. Pulp mill 3 had the least difference between actual inventory and the inventory goal, averaging around 19% per month. Pulp mill 2 averaged 21% per month difference between actual inventory and inventory goal, and pulp mill 1 averaged 26% difference (see Figure V.2). Note that all three pulp mills seemed to stay relatively close to plan during the first year. The second year, all three had pulp mill inventory levels below their goals. The final year, pulp mill inventory fluctuated both above and below plan.

Pulp Mill #1 Analysis

Pulp mill 1 (Figure V.3) had the lowest hardwood inventory goal of the three mills, peaking at 80,000 tons during the winter. For this first analysis with the low yield decision model, it was assumed a 400-acre plantation was already established. This assumption was made because there was only 3 years of cost and pulp mill inventory data available for this project. If more data covering more years were available, a user could consider starting the analysis from year 0 with fiber farm establishment.

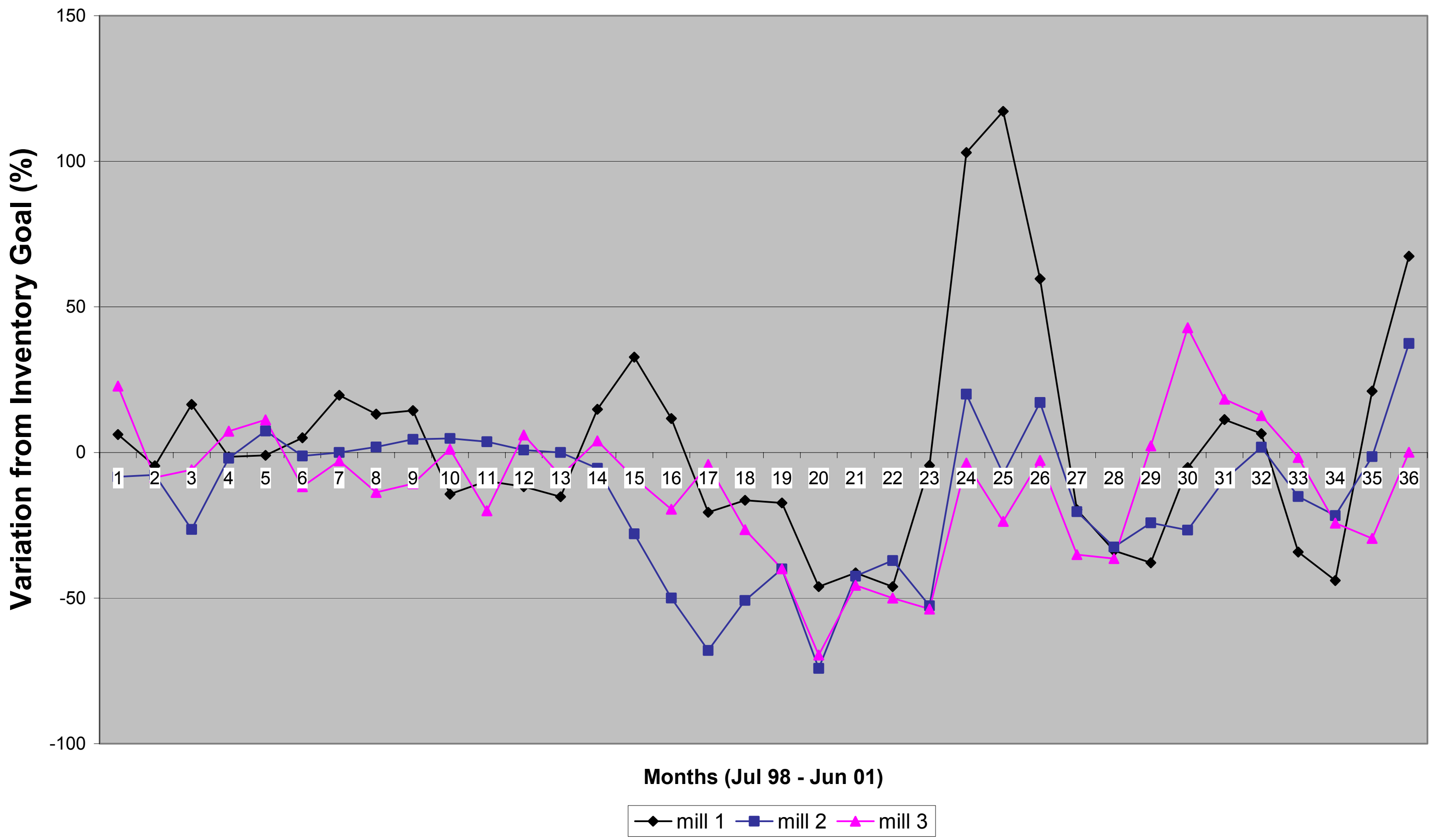


Figure V.2. Percentage difference between actual inventory and hardwood inventory goal for three cooperating southeastern pulp mills

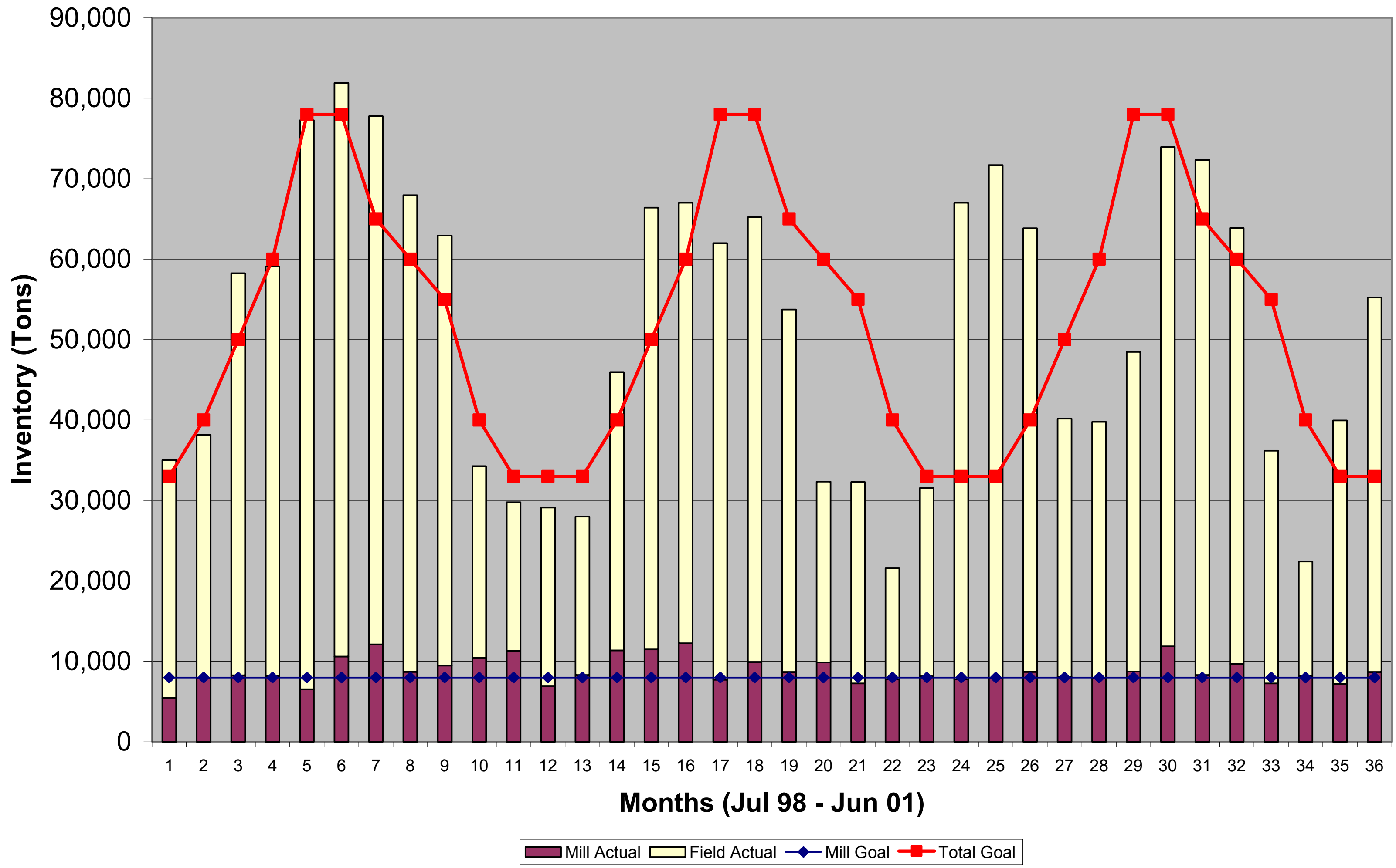


Figure V.3. Hardwood inventory levels for pulp mill 1. The actual mill and field (woodyards) inventory are stacked as a bar against the lines that indicate inventory goals.

Year 1

The costs and volume of fiber available in "green" inventory during the first year of this analysis are shown in Table V.1. All plantation costs for that year were $199,321. There were 8323 tons of "green" inventory available, therefore, that amount of less wood was purchased and stored in remote woodyards at a savings of $10/ton and totaling $83,229.

Although 8323 tons of "green" inventory were available during year 1, actual pulp mill inventory level never reached the critical level of less than 50% of goal. Hence, no short-rotation plantations were harvested. All the acres across each age class were carried into the next year, and no additional costs were incurred for replacing any harvested plantations.

Year 2

Year 2 plantation costs of $186,002 and savings of $122,335 (12,234 tons "green" inventory x $10/ton) are shown in Tables V.1 and V.2. During year 2, low pulp mill inventory levels in February resulted in 57 acres (1 age class) of hardwood plantation being harvested with a total of 3984 tons of fiber. Looking at hardwood deliveries to the pulp mill during that same period, some woodyard wood was delivered for $34.21/ton. Roundwood from the plantations offset that woodyard material and delivered for $12/ton (because all the other plantation costs were already accounted for), so an additional wood cost savings of $85,294 was realized.

Table V.1. Three years of plantation costs, yield available and harvested material from the low yield short-rotation hardwood fiber farm for pulp mill 1 (Scenario 1).

Year 1	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	57	707	40,371				
	2	57	484	27,634				
	3	57	463	26,449				
	4	57	450	25,729				
	5	57	456	26,048	37.3	2,129		
	6	57	462	26,376	49.1	2,805		
	7	57	467	26,714	59.3	3,389		
	Total	400		199,321		8,323		

Year 2	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	0	0	0				
	2	57	484	27,565				
	3	57	463	26,383				
	4	57	450	25,665				
	5	57	456	26,310	37.3	2,161		
	6	57	462	26,310	49.1	2,798		
	7	57	467	26,647	59.3	3,381		
	8	57	474	26,994	68.3	3,894	57	3,894
	Total	400		186,002		12,234		

Year 3	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	57	707	40,271				
	2	0	0	0				
	3	57	463	26,383				
	4	57	450	25,665				
	5	57	456	25,983	37.3	2,123		
	6	57	462	26,771	49.1	2,847		
	7	57	467	26,647	59.3	3.381		
	8	57	474	26,994	68.3	3,894	57	3,894
	Total	400		198,713		12,245		

Year 3

During year 3, plantation costs were $198,713 and savings from “green” inventory were $122,454 (12,245 tons x $10/ton). Low pulp mill inventory levels in October caused by reduced deliveries of wood resulted in 57 acres of hardwood plantation being harvested with a total of 3984 tons of fiber. These fiber farm deliveries offset some roundwood that arrived at the mill at a of cost $33.74/ton and generated a wood cost savings of $84,656.

A three-year summary of the costs and savings are shown in Table V.2. The net present value of this cash flow (5% discount rate) was a negative $83,694. Even though annual cash flows were positive for two of the three years, the fiber farm with a low yield was never able to make up for the first year loss.

Table V.2. Summary of all cash flows ($) for a net present value analysis of “green” inventory for pulp mill 1 with low yield plantations on a 400-acre fiber farm.

	Plantation costs	Inventory savings	Wood cost savings	Annual cash flow
Year 1	199,321	83,229	0	-116,092
Year 2	186,002	122,335	85,294	+21,627
Year 3	198,713	122,454	84,656	+8,397
	Net present value =	($83,694)	Average=	-28,689

Finding the net present value negative for the low yield plantations was expected given the high delivered cost for hardwood plantations developed in the previous chapter. A second scenario was run using the earlier assumption of higher yielding plantations and therefore lower costs per unit. These higher yields should come through genetic improvements and operation optimization (Stanturf, 2003). The same 400-acre farm is established (Table V.3), so plantation costs for the three years of the analysis are the same. Inventory savings are higher because there is additional volume available each year from the higher yielding plantations.

The need to harvest follows a similar pattern to the first scenario: no wood was cut in year 1, 57 acres were harvested in year 2 and 57 acres were harvested in year 3. Wood cost savings for the offset deliveries amounted to $111,702 in year 2 and $112,896 for year 3. The net present value (5% discount rate) for this scenario is a positive $63,485 (Table V.4). While year 1 was again a negative cash flow, years 2 and 3 had much higher positive cash flow from both inventory and wood cost savings, thereby resulting in a positive three-year average.

The benefit of getting additional volume from the high yield plantations for the same plantation costs, thereby allowing more woodyard inventory to be offset annually and more deliveries offset when plantations are harvested is shown by the positive NPV. While the volume is still nowhere near what Bar (1998) estimated, the additional volume from improved genetics and cultural operations is enough to justify a fiber farm as "green" inventory.

Table V.3. Three years of plantation costs, yield available and harvested material from the high yield short-rotation hardwood fiber farm for pulp mill 1 (Scenario 2).

Year 1	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	57	707	40,371				
	2	57	484	27,634				
	3	57	463	26,449				
	4	57	450	25,729				
	5	57	456	26,048	49.7	2,840		
	6	57	462	26,376	65.5	3,743		
	7	57	467	26,714	79.1	4,520		
	Total	400		199,321		11,103		

Year 2	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	0	0	0				
	2	57	484	27,565				
	3	57	463	26,383				
	4	57	450	25,665				
	5	57	456	26,310	49.7	2,883		
	6	57	462	26,310	65.5	3,734		
	7	57	467	26,647	79.1	4,509		
	8	57	474	26,994	91.1	5,193	57	5,193
	Total	400		186,002		16,318		

Year 3	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	57	707	40,271				
	2	0	0	0				
	3	57	463	26,383				
	4	57	450	25,665				
	5	57	456	25,983	49.7	2,833		
	6	57	462	26,771	65.5	3,799		
	7	57	467	26,647	79.1	4,509		
	8	57	474	26,994	91.1	5,193	57	5,193
	Total	400		198,713		16,333		

Table V.4. Summary of all cash flows ($) for a net present value analysis of "green" inventory for pulp mill 1 with high yield plantations on a 400-acre fiber farm.

	Plantation costs	Inventory savings	Wood cost savings	Annual cash flow
Year 1	199,321	111,029	0	-88,292
Year 2	186,002	163,175	111,702	+88,875
Year 3	198,713	163,333	112,896	+77,516
	Net present value =	$63,485	Average=	+26,033

Pulp Mill #2 and 3 Analyses

The hardwood inventory for pulp mills 2 and 3 are displayed in Figures V.4 and V.5 respectively. For both mills, they were able to keep actual inventory at or near inventory goal most of the time during years 1 and 3. But for both pulp mills, year 2 was impacted by a very wet winter that slowed deliveries and pulp mill inventory fell to critical levels. For these analyses, both mills required multiple age classes of "green" inventory to be harvested in year 2 to prevent curtailment of pulp mill operations.

The year-to-year costs and savings for each individual analysis from the decision model can be found in Appendix B. A summary of the costs and savings for both pulp mills with a low yield and high yield plantations are found in Tables V.5, V.6, V.7 and V.8. Pulp mills 2 and 3 were similar to pulp mill 1 in that they all had negative net present values (5% discount rate) with low yielding hardwood plantations. All 3 mills had a positive NPV once the higher yielding plantations were involved.

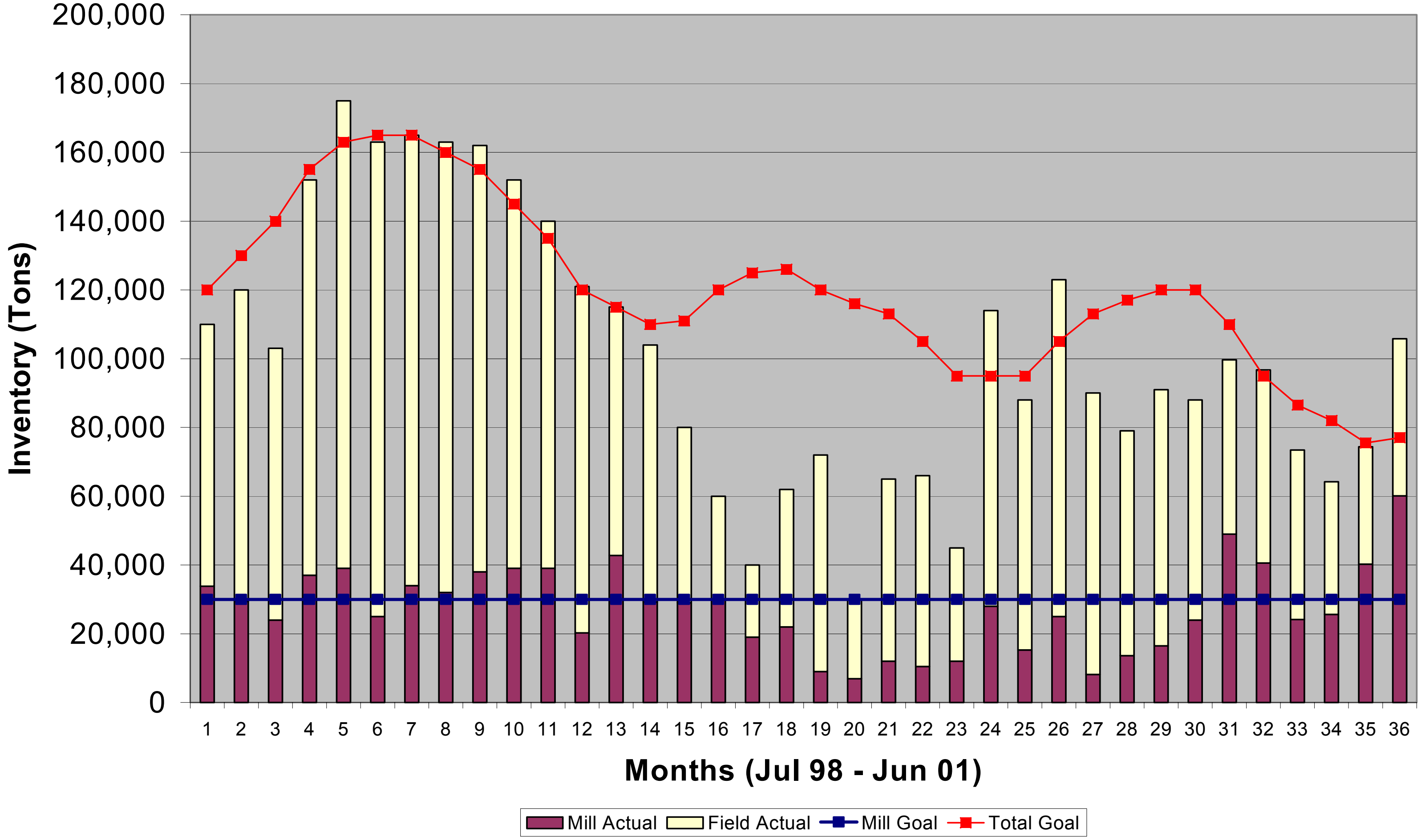


Figure V.4. Hardwood inventory levels for pulp mill 2. The actual mill and field (woodyards) inventory are stacked as a bar against the lines that indicate inventory goals.

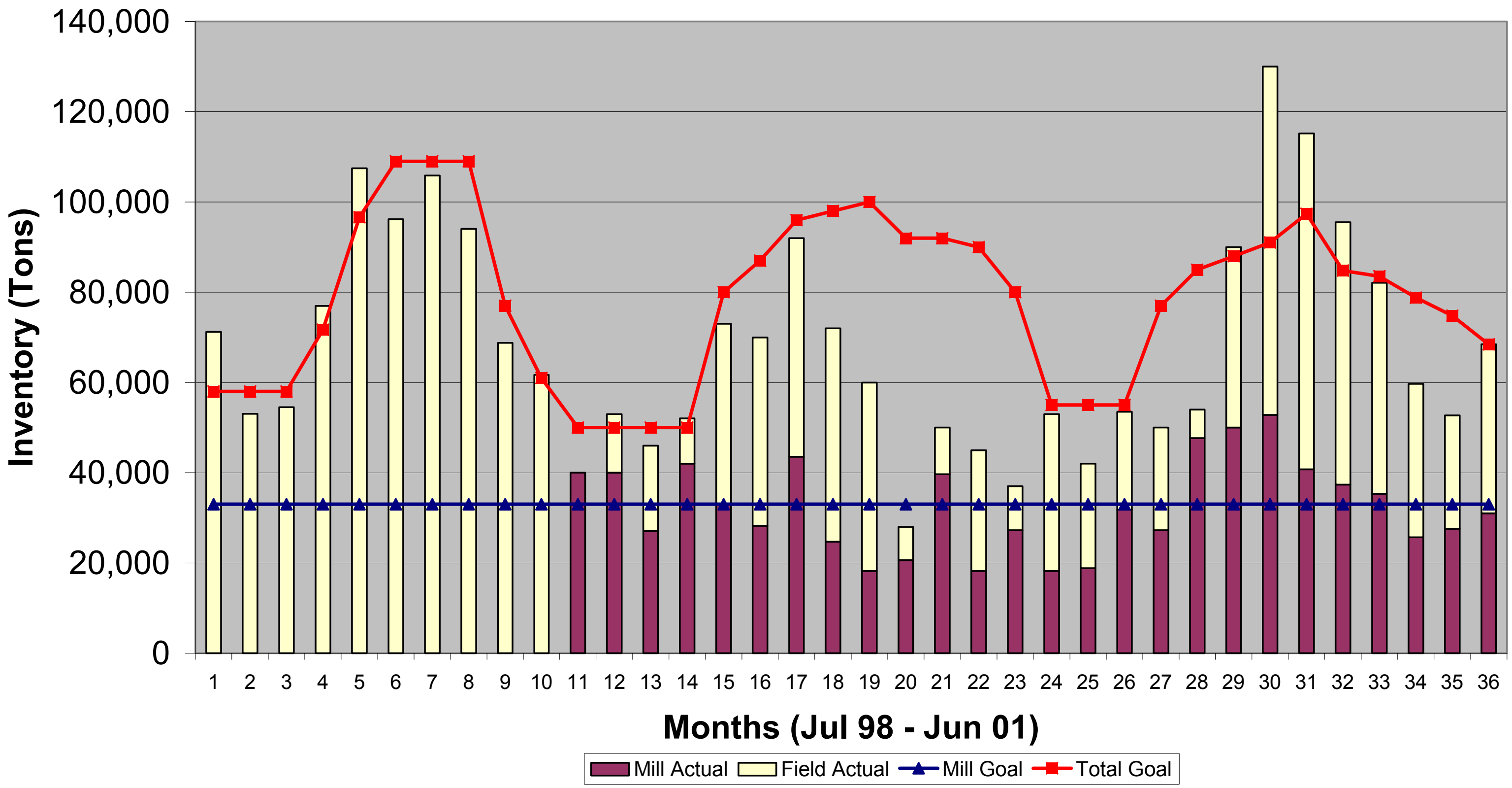


Figure V.5. Hardwood inventory levels for pulp mill 3. The actual mill and field (woodyards) inventory are stacked as a bar against the lines that indicate inventory goals.

Table V.5. Summary of all cash flows ($) for the net present value analysis of 600-acres of "green" inventory for pulp mill 2 with low yield plantations.

	Plantation costs	Inventory savings	Wood cost savings	Annual cash flow
Year 1	261,764	124,843	0	-136,921
Year 2	240,686	183,523	478590	+421,427
Year 3	324,254	32,035	0	-292,219
	Net present value =	($584)		-2,640

Table V.6. Summary of all cash flows ($) for the net present value analysis of 600-acres of "green" inventory for pulp mill 2 with high yield plantations.

	Plantation costs	Inventory savings	Wood cost savings	Annual cash flow
Year 1	261,764	166,543	0	-95,221
Year 2	240,686	244,789	625,080	+629,183
Year 3	324,254	42,742	0	-281,512
	Net present value =	$236,820		+84,150

Table V.7. Summary of all cash flows ($) for the net present value analysis of 600-acres of "green" inventory for pulp mill 3 with low yield plantations.

	Plantation costs	Inventory savings	Wood cost savings	Annual cash flow
Year 1	261,764	124,843	0	-136,921
Year 2	240,683	183,403	297,594	+240,314
Year 3	281,168	124,768	0	-156,400
	Net present value =	($47,533)		-17,669

Table V.8. Summary of all cash flows ($) for the net present value analysis of 600-acres of "green" inventory for pulp mill 3 with high yield plantations.

	Plantation costs	Inventory savings	Wood cost savings	Annual cash flow
Year 1	261,764	166,543	0	-95,221
Year 2	240,683	244,629	390,562	+394,508
Year 3	281,168	166,443	0	-114,725
	Net present value =	$168,040		+61,521

The underlying effect that drives the savings for fiber farms is not having to store large quantities of wood on woodyards to prevent pulp mill curtailment. It's the stochastic nature of wood deliveries that Galbraith and Meng (1981) first reported when doing inventory analysis that allows this assumption. And while supply, demand and production lead time change regularly due to environmental restraints, as shown by LeBel and Caruth (1997), some wood deliveries will still make it to the pulp mill. Only in the event of an extended drop in deliveries would fiber farms then support procurement efforts and prevent the mill from possible curtailments.

Determining Fiber Farm Size

This analysis framework is flexible and allows the examination of the optimal size of a "green" inventory system. To illustrate such an analysis, pulp mill 3 was further analyzed to determine how many acres of fiber farm would give the most benefit. The decision model was used with 200, 400, 600, 800 and 1000 acres of high yield plantations. Acres were harvested when pulp mill inventory was critical. Because of the impact on inventory levels, some years more than one harvest took place. The individual year-by-year changes to costs and savings for each scenario can be found in Appendix B. Table V.9 summarizes the scenarios and the decision model indicates an 800-acre fiber farm has the highest NPV (5% discount rate), given the pulp mill inventory conditions found over the 3 year study period. That indicates that somewhere between 700 and 900 acres is the optimal size. A fiber farm smaller than 800-acres misses some of the potential savings associated with "green" inventory. A fiber farm larger than 800 acres has a lower NPV because there is so much "green" inventory as a part of total inventory that harvesting becomes an annual event and the savings from less woodyard wood is offset by the high cost of the plantation wood. Additional runs of the decision model could more accurately determine the number of acres.

Table V.9. Summary of the net present values for alternate sizes of a fiber farm with high yield hardwood plantations as “green” inventory for a southeastern pulp mills (numbers in parenthesis are negative NPV).

Scenario	Yield	Acres	Net present value	Average annual cash flow
7	High	200	($47,525)	($17,942)
8	High	400	$57,031	$20,834
6	High	600	$168,040	$61,521
9	High	800	$512,705	$192,007
10	High	1000	$330,623	$118,703

The analyses for all three cooperating pulp mills indicate “green” inventory could potentially reduce wood cost. Note that the delivered cost from high-yield “green” inventory scenarios generated the positive net present values. Having data covering a longer period of time would have allowed for a more representative analysis.

CONCLUSIONS

The objective was to illustrate a model that can be used to examine the cost and operational feasibility of establishing a strategically located, intensively-managed, short-rotation hardwood plantation (“fiber farm”) to serve as “green” inventory for a southern pulp mill. Once established, the “green” inventory should allow the firm to reduce the traditional amount of purchased and stored woodyard “winter” inventory that *may* be needed to insure an adequate raw material supply. During the winter, if and when pulp mill inventory declines to a predetermined “critical” level, some portion of the “green” inventory would be harvested, otherwise it would remain growing for potential use in a future year.

The results of the “green” inventory analyses on three cooperating southern pulp mills show that the concept may be operationally feasible and cost-effective under the following conditions:

1. The pulp mill uses similar practices as the three case study pulp mills to build inventory for the winter, storing wood in remote woodyards for later retrieval when deliveries are slow.
2. Yields from the fiber farm will likely increase over time above volumes previously reported by the limited operational trials in the South. This is reasonable to expect, given the documented increase in yields realized from existing, large-scale operations in the Pacific Northwest through genetic manipulation and optimized cultural operations.
3. Wood from the fiber farm would not be needed or used *every* year, allowing substantial cost savings from reduced woodyard inventory to accrue and additional growth to occur during periods of the rotation. If (expensive) fiber farm wood deliveries had to be used too frequently, any woodyard inventory savings would likely be depleted.

In summary, wood from intensively managed, short-rotation hardwood plantations is currently too expensive to become a regular source of furnish for southern pulp mills any time soon, but may, under certain circumstances, be strategically used in a limited capacity as “green” inventory to reduce overall wood cost through inventory savings for some mills.

CHAPTER VI. SUMMARY

Very limited research has been done regarding hardwood "fiber farms" as a supplemental source of raw material for the forest industry in the South. The objective of this study was to develop a decision model that a manager could use to examine the cost and operational feasibility of establishing a strategically located, intensively-managed short-rotation hardwood plantation ("fiber farm") to serve as "green" inventory for a southeastern pulp mill. Once established, the "green" inventory should allow the firm to reduce the traditional amount of purchased and stored woodyard winter inventory that *may* be needed to insure an adequate raw material supply. During the winter, if and when woodyard inventory declines to a predetermined "critical" level, some portion of the "green" inventory would be harvested; otherwise it would remain growing for potential use in a future year.

The results of the "green" inventory analyses on three cooperating southeastern pulp mills show that the concept may be operationally feasible and cost-effective under the following conditions:

e. The intensively-managed, short-rotation hardwood plantations are established on dry sites that are operational year-round. Access will be key, as these plantations will usually be harvested during the wettest times of the year.
f. Yields from the fiber farm will likely increase over time above volumes previously reported by the limited operational trials in the Southeast. This is reasonable to expect, given the documented increase in yields realized from

existing, large-scale operations in the Pacific Northwest through genetic manipulation and optimization of cultural practices.

g. Wood from the fiber farm would not be needed or used *every* year, allowing substantial cost savings from reduced woodyard inventory to accrue and additional growth to occur during periods of the rotation. If (expensive) fiber farm had to be used too frequently, any woodyard inventory savings would likely be depleted.

The net present value analyses were all positive @ a 5% discount rate for the 3 pulp mills in the study. There are 94 pulp mills in the Southeast. At least 30 of those pulp mills are located in the coastal plain region, where weather often significantly hampers wood deliveries. These pulp mills store large volumes of wood in remote woodyards to prevent a mill curtailment due to a wood outage. If these 30 pulp mills could generate a similar savings from "green" inventory, wood cost across the south could be reduced substantially.

There are other potential advantages from "green" inventory that were not addressed in this study. Because a "before tax" net present value economic analysis was used, there were no tax implications involved; individual firms may determine greater benefit with an after-tax analysis. With possible impending legislation on carbon credits, fiber farms may provide a substantial benefit as markets to buy and sell these credits are established. Also, fiber farms located near urban centers may be useful to some municipalities as a location to disperse treated waste water.

Certain species of trees well-suited for fiber farms may also provide advantages in the pulping process. Because of the unique fiber characteristics, intensively-managed, short-rotation material may improve the quality of the final product (pulp or paper). However, benefits from any change in fiber qualities will likely be realized only if fiber farm material is processed separately in the pulping process.

In summary, wood from intensively-managed, short-rotation hardwood plantations is currently too expensive to become a regular source of furnish for southern pulp mills in the near future, but may, under certain circumstances, be strategically used in a limited capacity as "green" inventory to reduce overall wood cost through inventory savings for some mills.

RECOMMENDATIONS FOR FURTHER STUDIES

Very limited research has been done regarding intensively-managed, short-rotation, hardwood fiber farms as a supplemental source of raw material for the forest industry in the Southeast. Possible topics for future research in this area include:

1. A continuation of this study with additional data would strengthen the net present value analysis for these three pulp mills. That would allow the analysis to start with year 1 and include all the fiber farm establishment costs.
2. Further studies to document fiber farm management operational costs and yields in the Southeast under a range of conditions, including acreage involved, species employed, management regime, and physiographic region. It is likely that fiber farm costs and yields may be quite variable and site specific.
3. Further studies to assess the potential feasibility of the "green" inventory concept for a range of mill types (paper, OSB, engineered wood, etc.) and locations where regional/local differences in wood costs and expected yields may impact the analysis.

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Appendix A

The following pages were copied from the decision model developed as an Excel spreadsheet. It is presented here so a reader will be able to see some of the inputs into the model. For a copy of the actual spreadsheet, please contact the author.

"Green" Inventory Decision Model

This decision model will help a manager decide if short-rotation, intensively-managed hardwood plantations will help reduce wood cost for a pulp mill by supplementing woodyard inventory with "green" inventory.
This spreadsheet consists of four worksheets: general information, per acre values, system numbers and the NPV calculation. Most of the numbers automatically transfer to the necessary cells; occasionally they must be input manually. The following directions should assist a person with using this model. Some costs for plantation operations will need to be determined before running an analysis.

Directions to use each worksheet will be found at the top of each worksheet.

Info worksheet - there are several inputs that are generic to the entire model. They will be used to calculate the various costs associated with a plantation. Definitions for each input are found by paging down. There is also a section for plantation operations where costs are put in for a given year because they may change (fertilizer, weeding, etc.) For any given rotation length, enter values for all 10 years because some plantations may carry over if not harvested.

	Input	
Cost of Capital =	5.0%	(discount rate entered as a decimal - ex. - .05)
Accumulated Interest Rate =	5.0%	(discount rate entered as a decimal - ex. - .05)
Land Cost per Acre =	$600	(initial land purchase cost)
Total Number of Acres =	400	
Number of Rotation Years =	7	
Initial Irrigation System Cost =	$1,150	
Site Preparation Costs/Acre =	$300	
Seedling and Planting Costs/Acre =	$171	
Total Labor Cost per Year =	$66,000	

The following are operational costs that may vary from year to year. Therefore, they are entered by year

Year	1	2	3	4	5	6	7	8	9	10
Irrigation electric/Acre =	40	40	40	40	40	40	40	40	40	40
Weed Contol/Acre =	93	62	18							
Fertilizer/Acre =	54	72	90	90	90	90	90	90	90	90
Insecticide/Acre =	27	27	27	27	27	27	27	27	27	27

The following are associated with "green" inventory savings.

Woodyard Premium =	$10
Roundwood harvesting cost =	$12
Chip harvesting cost =	$18

This is the per acre worksheet. The cost numbers are generated from the info worksheet. All 10 years are completed because sometimes a plantation may be carried over an additional year.
The only input on this worksheet is yield in row 45. Yield is tons/acre and will vary with species.

Annual Total is all the cost added together for that specific year. Rotation Total is the cummulative cost to date.

Stumpage cost per ton is the total rotation cost to date divided by the yield.
Delivered Cost is the stumpage cost plus a harvesting cost.

Costs per acre for short-rotation, intensively-managed plantations

	year	1	2	3	4	5	6	7	8	9	10
Initial ($/Acre)	Land Rent	30	30	30	30	30	30	30	30	30	30
	Irrigation Rent	58	58	58	58	58	58	58	58	58	58
	Site Prep & Tillage	300									
	Planting	171									
Annual ($/Acre)	Irrigation electric	40	40	40	40	40	40	40	40	40	40
	Weed Control	93	62	18	0	0	0	0	0	0	0
	Fertilizer	54	72	90	90	90	90	90	90	90	90
	Insecticide	27	27	27	27	27	27	27	27	27	27
	Supervision	165	170	175	180	186	191	197	203	209	215
	Annual Total	938	458	438	425	430	436	442	447	454	460
	Interest Cost	47	72	98	124	151	181	212	245	280	317
	Rotation Total	984	1515	2050	2599	3180	3797	4450	5143	5876	6653
	Yield (tons)	0	0	0	0	49.7	65.5	79.1	91.1	100.8	109.2
	Stumpage Cost per Ton					63.99	57.97	56.26	56.45	58.29	60.92
	Delivered Cost as Roundwood					75.99	69.97	68.26	68.45	70.29	72.92
	Delivered Costs as Chips					81.99	75.97	74.26	74.45	76.29	78.92

This worksheet covers the entire "green" inventory system. Most of the numbers are transferred from the previous worksheets. New inputs to this worksheet include mill hardwood inventory by month for each year. This section assumes a fully operation fiber farm evenly spread across all age classes. It does require the user to move acreage from year to year depending on whether plantatons were harvested. The decisions on this worksheet will impact the NPV outcome. The specific inputs are:

Acreage - the first year acreage comes from the info worksheet where fiber farm total acreage and rotation length were input. It evenly distributes the acreage across all age classes. The figure representing the number of acres will have to be manually transferred from year to year depending on whether acres are harvested. If no acreage is cut, move all the acres up one year in age class. Whenever plantations are harvested, take those acres from the oldest age class and put the same acres in year one the following year. Move all the remaining acres up one year.

Inventory info - the inventory is put in so a user can make a decision whether to harvest plantations. Inventory includes the total target and actual. Neither is "required" to run this model, but they are helpful to make a decision. The last column is percentage of goal. **Note**: the analysis assumes that all the available "green" inventory is part of the actual inventory numbers. The percentage column is based on the (actual inventory minus the "green" inventory) over the goal inventory. This is because the "green" inventory is standing and can be left that way. The decision to harvest plantations will vary from mill to mill and with the season. A 50% of goal in December may signal that plantations should be harvested - a 50% of goal in April when weather is improving and the goal number is coming down may not require harvesting plantations.

Example:		Month	Total Goal	Total Actual	"green" inv.	in storage	% Diff.
green inventory =	10,000	1	100,000	80,000	10,000	70,000	70%
		2	90,000	60,000	10,000	50,000	56%
		3	80,000	40,000	10,000	30,000	38%
		4	70,000	50,000	10,000	40,000	57%

In this example, a manager may have decided to harvest some plantations in month 3.

Year 1 Information

Age Class	Acres	Total Cost/Acre	Costs/ Age Class	Tons/ Acre	Tons/ Age Class
1	57	938	53,571		
2	57	458	26,197		
3	57	438	25,003		
4	57	425	24,274		
5	57	430	24,583	49.7	2,840
6	57	436	24,902	65.5	3,743
7	57	442	25,230	79.1	4,520
8	0	0	0	0.0	0
9	0	0	0	0.0	0
10	0	0	0	0.0	0
Totals	400		203,760		11,103

Pulp Mill Hardwood Inventory Information

Month	Total Goal	Total Actual	"green" inv.	in storage	% Diff.
July	33,000	29,555	11,103	18,452	56%
August	40,000	33,369	11,103	22,266	56%
September	50,000	40,172	11,103	29,069	58%
October	60,000	44,587	11,103	33,484	56%
November	78,000	53,459	11,103	42,356	54%
December	78,000	73,930	11,103	62,827	81%
January	65,000	72,339	11,103	61,236	94%
February	60,000	63,864	11,103	52,761	88%
March	55,000	39,187	11,103	28,084	51%
April	40,000	34,569	11,103	23,466	59%
May	33,000	39,957	11,103	28,854	87%
June	33,000	55,237	11,103	44,134	134%

0 = Number of Acres to be Harvested.
(Any acres in year 10 must be harvested)

Year 2 Information

Age Class	Acres	Total Cost/Acre	Costs/ Age Class	Tons/ Acre	Tons/ Age Class
1		0	0		
2	57	458	26,132		
3	57	438	24,940		
4	57	425	24,214		
5	58	430	24,952	49.7	2,883
6	57	436	24,839	65.5	3,734
7	57	442	25,167	79.1	4,509
8	57	447	25,503	91.1	5,193
9		0	0	0.0	0
10		0	0	0.0	0
Totals	400		175,747		16,318

Pulp Mill Hardwood Inventory Information

Month	Total Goal	Total Actual	"green" inv.	in storage	% Diff.
July	33,000	33,983	16,318	17,666	54%
August	40,000	45,946	16,318	29,629	74%
September	50,000	66,395	16,318	50,078	100%
October	60,000	67,006	16,318	50,689	84%
November	78,000	61,987	16,318	45,670	59%
December	78,000	65,203	16,318	48,886	63%
January	65,000	53,743	16,318	37,426	58%
February	60,000	32,332	16,318	16,015	27%
March	55,000	32,275	16,318	15,958	29%
April	40,000	21,555	16,318	5,238	13%
May	33,000	31,546	16,318	15,229	46%
June	33,000	67,001	16,318	50,684	154%

57 = Number of Acres to be Harvested.
(Any acres in year 10 must be harvested)

Year 3 Information

Age Class	Acres	Total Cost/Acre	Costs/ Age Class	Tons/ Acre	Tons/ Age Class
1	57	938	53,438		
2		0	0		
3	57	438	24,940		
4	57	425	24,214		
5	57	430	24,522	49.7	2,833
6	58	436	25,275	65.5	3,799
7	57	442	25,167	79.1	4,509
8	57	447	25,503	91.1	5,193
9		0	0	0.0	0
10		0	0	0.0	0
Totals	400		203,059		16,333

Pulp Mill Hardwood Inventory Information

Month	Total Goal	Total Actual	"green" inv.	in storage	% Diff.
July	33,000	71,675	16,333	55,342	168%
August	40,000	63,848	16,333	47,515	119%
September	50,000	40,172	16,333	23,839	48%
October	60,000	39,767	16,333	23,434	39%
November	78,000	48,459	16,333	32,126	41%
December	78,000	73,930	16,333	57,597	74%
January	65,000	72,339	16,333	56,006	86%
February	60,000	63,864	16,333	47,531	79%
March	55,000	36,187	16,333	19,854	36%
April	40,000	22,407	16,333	6,074	15%
May	33,000	39,957	16,333	23,624	72%
June	33,000	55,237	16,333	38,904	118%

114 = Number of Acres to be Harvested.
(Any acres in year 10 must be harvested)

This is the net present value worksheet. It requires wood cost savings to be input by the user. Plantation costs and savings from "green" inventory are transferred from previous worksheets. The plantation costs are all the costs for managing the fiber farm for that year. Annual inventory savings is calculated by multiplying the amount of "green" inventory times the woodyard cost premium from the Info worksheet. The final input is wood cost savings when a plantation is harvested.

Wood cost savings are calculated during any year plantations are cut. The plantation wood should be included at the price of the average harvesting cost for the distance you anticipate the plantation being located from the pulp mill. The harvested volume at the harvest cost is then subtracted from the highest price deliveries arriving at the pulp mill during the similar period of time.

Example: Harvesting 50 acres in January at 59.3 tons/acre is 2965 tons. This should be included in the analysis at $12/ton for roundwood (average harvest cost). If the highest price 2965 tons of roundwood in January cost the company $38/ton, then a wood cost savings for that year is $77090. If chips are used in the analysis, then you should use the average harvest cost for chips.

NPV analysis

	plantation costs	inventory savings	wood cost savings
year 1	203,760	111,029	
year 2	175,747	163,175	102697
year 3	203,059	163,333	185214
year 4	0	0	
year 5	0	0	
year 6	0	0	

analysis area

year	NPV
1	-92,732
2	90,125
3	145,488
4	0
5	0
6	0

Net Present Value = $119,108

Appendix B

Scenario 3. Three years of plantation costs, yield available and harvested material from the low yield short-rotation hardwood fiber farm for pulp mill 2.

Year 1	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	86	650	55,700				
	2	86	425	36,449				
	3	86	403	34,520				
	4	86	388	33,286				
	5	86	392	33,605	37.3	3,193		
	6	86	396	33,933	49.1	4,208		
	7	86	400	34,271	59.3	5,084		
	Total	600		261,764		12,484		

Year 2	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	0	0	0				
	2	86	425	36,570				
	3	86	403	34,233				
	4	86	388	33,397				
	5	86	392	33,717	37.3	3,204	86	3,204
	6	86	396	33,650	49.1	4,173	86	4,173
	7	86	400	34,385	59.3	5,101	86	5,101
	8	86	404	34,734	68.3	5,876	86	5,876
	Total	600		240,686		18,352	343	18,352

Year 3	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	343	650	222,893				
	2	0	0	0				
	3	86	403	34,635				
	4	86	388	33,009				
	5	86	392	33,717	37.3	3,204		
	6	0	0	0	0	0		
	7	0	0	0	0	0		
	8	0	0	0	0	0		
	Total	600		324,254		3,204		

Scenario 4. Three years of plantation costs, yield available and harvested material from the high yield short-rotation hardwood fiber farm for pulp mill 2.

Year 1	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	86	650	55,700				
	2	86	425	36,449				
	3	86	403	34,520				
	4	86	388	33,286				
	5	86	392	33,605	49.7	4,260		
	6	86	396	33,933	65.5	5,614		
	7	86	400	34,271	79.1	6,780		
	Total	600		261,764		16,654		

Year 2	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	0	0	0				
	2	86	425	36,570				
	3	86	403	34,233				
	4	86	388	33,397				
	5	86	392	33,717	49.7	4,274	86	4,274
	6	86	396	33,650	65.5	5,568	86	5,568
	7	86	400	34,385	79.1	6,803	86	6,803
	8	86	404	34,734	91.1	7,835	86	7,835
	Total	600		240,686		24,479	343	24,479

Year 3	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	343	650	222,893				
	2	0	0	0				
	3	86	403	34,635				
	4	86	388	33,009				
	5	86	392	33,717	49.7	4,274		
	6	0	0	0	0	0		
	7	0	0	0	0	0		
	8	0	0	0	0	0		
	Total	600		324,254		4,274		

Scenario 5. Three years of plantation costs, yield available and harvested material from the low yield short-rotation hardwood fiber farm for pulp mill 3.

Year 1	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	86	650	55,700				
	2	86	425	36,449				
	3	86	403	34,520				
	4	86	388	33,286				
	5	86	392	33,605	37.3	3,193		
	6	86	396	33,933	49.1	4,208		
	7	86	400	34,271	59.3	5,084		
	Total	600		261,764		12,484		

Year 2	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	0	0	0				
	2	86	425	36,570				
	3	86	403	34,233				
	4	86	388	33,397				
	5	86	392	33,717	37.3	3,204		
	6	86	396	33,650	49.1	4,173		
	7	86	400	34,385	59.3	5,101	86	5,101
	8	86	404	34,734	68.3	5,876	86	5,876
	Total		600	240,683		18,340	172	10,977

Year 3	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	172	650	111,771				
	2	0	0	0				
	3	86	403	34,635				
	4	86	388	33,009				
	5	86	392	33,717	37.3	3,204		
	6	86	396	33,650	49.1	4,173		
	7	86	400	34,385	59.3	5,101		
	8	0	0	0	0	0		
	Total	600		281,168		12,477		

Scenario 6. Three years of plantation costs, yield available and harvested material from the high yield short-rotation hardwood fiber farm for pulp mill 3.

Year 1	Age	Acres	Management Cost		Available Tons		Harvested	
	Class		Acre	Age Class	Acre	Age Class	Acres	Tons
	1	86	650	55,700				
	2	86	425	36,449				
	3	86	403	34,520				
	4	86	388	33,286				
	5	86	392	33,605	49.7	4,260		
	6	86	396	33,933	65.5	5,614		
	7	86	400	34,271	79.1	6,780		
	Total	600		261,764		16,654		

Year 2	Age	Acres	Management Cost		Available Tons		Harvested	
	Class		Acre	Age Class	Acre	Age Class	Acres	Tons
	1	0	0	0				
	2	86	425	36,570				
	3	86	403	34,233				
	4	86	388	33,397				
	5	86	392	33,717	49.7	4,274		
	6	86	396	33,650	65.5	5,568		
	7	86	400	34,385	79.1	6,803	86	6,803
	8	86	404	34,734	91.1	7,835	86	7,835
	Total		600	240,683		24,463	172	14,638

Year 3	Age	Acres	Management Cost		Available Tons		Harvested	
	Class		Acre	Age Class	Acre	Age Class	Acres	Tons
	1	172	650	111,771				
	2	0	0	0				
	3	86	403	34,635				
	4	86	388	33,009				
	5	86	392	33,717	49.7	4,274		
	6	86	396	33,650	65.5	5,568		
	7	86	400	34,385	79.1	6,803		
	8	0	0	0	0	0		
	Total	600		281,168		16,644		

Scenario 7. Three years of plantation costs, yield available and harvested material from a 200-acre high yield short-rotation hardwood fiber farm for pulp mill 3.

Year 1	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	29	877	25,043				
	2	29	659	18,820				
	3	29	643	18,377				
	4	29	636	18,172				
	5	29	647	18,491	49.7	1,420		
	6	29	659	18,819	65.5	1,871		
	7	29	670	19,157	79.1	2,260		
	Total	200		136,878		5,551		

Year 2	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	0	0	0				
	2	29	659	18,820				
	3	29	643	18,377				
	4	29	636	18,172				
	5	29	647	18,491	49.7	1,420		
	6	29	659	18,819	65.5	1,871	29	1,871
	7	29	670	19,157	79.1	2,260	29	2,260
	8	29	683	19,504	91.1	2,603	29	2,603
	Total	200		131,340		8,154	87	6,734

Year 3	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	85	877	74,503				
	2	0	0	0				
	3	29	643	18,653				
	4	29	636	17,809				
	5	29	647	18,768	49.7	1,441		
	6	29	659	19,101	65.5	1,900		
	7	0	0	0	0	0		
	8	0	0	0	0	0		
	Total	200		148,833		3,341		

Scenario 8. Three years of plantation costs, yield available and harvested material from a 400-acre high yield short-rotation hardwood fiber farm for pulp mill 3.

Year 1	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	57	707	40,371				
	2	57	484	27,634				
	3	57	463	26,449				
	4	57	450	25,729				
	5	57	456	26,048	49.7	2,840		
	6	57	462	26,376	65.5	3,743		
	7	57	467	26,714	79.1	4,520		
	Total	400		199,321		11,103		

Year 2	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	0	0	0				
	2	57	484	27,634				
	3	57	463	26,449				
	4	57	450	25,729				
	5	57	456	26,048	49.7	2,840		
	6	57	462	26,376	65.5	3,743		
	7	57	467	26,714	79.1	4,520	57	4,520
	8	57	474	27,062	91.1	5,206	57	5,206
	Total	400		186,011		16,309	114	9,726

Year 3	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	114	707	80,541				
	2	0	0	0				
	3	57	463	26,383				
	4	57	450	25,665				
	5	57	456	25,983	49.7	2,833		
	6	57	462	26,771	65.5	3,799		
	7	57	467	26,647	79.1	4,509		
	8	0	0	0	0	0		
	Total	400		211,990		11,141		

Scenario 7: Summary of all cash flows ($) for a net present value analysis of 200-acres of green inventory for pulp mill 3 with high yield plantations.

	Plantation costs	Inventory savings	Wood cost savings	Annual cash flow
Year 1	136,878	55,514	0	-81,364
Year 2	131,340	81,543	192761	+142,964
Year 3	148,833	33,408	0	-115,425
	Net present value =	($47,525)		-17,942

Scenario 8: Summary of all cash flows ($) for the net present value analysis of 400-acres of green inventory for pulp mill 3 with high yield plantations.

	Plantation costs	Inventory savings	Wood cost savings	Annual cash flow
Year 1	199,321	111,029	0	-88,292
Year 2	186,011	163,086	274,303	+251,377
Year 3	211,990	111,406	0	-100,584
	Net present value =	$57,031		+20,834

Scenario 9. Three years of plantation costs, yield available and harvested material from an 800-acre high yield short-rotation hardwood fiber farm for pulp mill 3.

Year 1	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	114	622	71,029				
	2	114	396	45,263				
	3	114	373	42,592				
	4	114	357	40,844				
	5	114	360	41,162	49.7	5,680		
	6	114	363	41,490	65.5	7,486		
	7	114	366	41,828	79.1	9,040		
	Total	800		324,207		22,206		

Year 2	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	0	0	0				
	2	114	396	45,263				
	3	114	373	42,592				
	4	114	357	40,844				
	5	114	360	41,162	49.7	5,680		
	6	114	363	41,490	65.5	7,486		
	7	114	366	41,828	79.1	9,040	114	9,040
	8	114	369	42,176	91.1	10,411	114	10,411
	Total	800		295,354		32,617	228	19,451

Year 3	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	228	622	141,702				
	2	0	0	0				
	3	114	373	42,485				
	4	114	357	41,099				
	5	114	360	41,059	49.7	5,666		
	6	114	363	41,749	65.5	7,533		
	7	114	366	41,723	79.1	9,017	114	9,017
	8	0	0	0	0	0		
	Total	800		349,818		22,216		

Scenario 10. Three years of plantation costs, yield available and harvested material from a 1000-acre high yield short-rotation hardwood fiber farm for pulp mill 3.

Year 1	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	143	605	86,357				
	2	143	379	54,077				
	3	143	355	50,663				
	4	143	339	48,401				
	5	143	341	48,719	49.7	7,100		
	6	143	343	49,047	65.5	9,357		
	7	143	346	49,385	79.1	11,300		
	Total	1000		386,650		27,757		

Year 2	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	0	0	0				
	2	143	379	54,077				
	3	143	355	50,663				
	4	143	339	48,401				
	5	143	341	48,719	49.7	7,100		
	6	143	343	49,047	65.5	9,357	143	9,357
	7	143	346	49,385	79.1	11,300	143	11,300
	8	143	348	49,733	91.1	13,014	143	13,014
	Total	1000		350,026		40,771	429	33,671

Year 3	Age Class	Acres	Management Cost Acre	Management Cost Age Class	Available Tons Acre	Available Tons Age Class	Harvested Acres	Harvested Tons
	1	428	605	258,726				
	2	0	0	0				
	3	143	355	50,714				
	4	143	339	48,449				
	5	143	341	48,768	49.7	7,107		
	6	143	343	49,096	65.5	9,367		
	7	0	0	0	0	0		
	8	0	0	0	0	0		
	Total	1000		455,753		16,474		

Scenario 9: Summary of all cash flows ($) for the net present value analysis of 800-acres of green inventory for pulp mill 3 with high yield plantations.

	Plantation costs	Inventory savings	Wood cost savings	Annual cash flow
Year 1	324,207	222,057	0	-102,150
Year 2	295,354	326,171	528,548	+559,365
Year 3	349,818	222,157	246,467	+118,806
	Net present value =	$512,705		+192,007

Scenario 10: Summary of all cash flows ($) for the net present value analysis of 1000-acres of green inventory for pulp mill 3 with high yield plantations.

	Plantation costs	Inventory savings	Wood cost savings	Annual cash flow
Year 1	386,650	277,571	0	-109,078
Year 2	350,026	407,714	698,514	+756,203
Year 3	455,753	164,736	0	-291,017
	Net present value =	$330,623		+118,703

VITA

The author was born June 25, 1957 in Freeport, New York. He received an AAS degree from the New York State Ranger School in 1977 and went to work for Georgia-Pacific in Woodland Maine. He returned to school at the University of Maine at Orono and received a BS in Forestry in 1981 and then a MS in Forestry from Virginia Tech in 1984. He spent 14 years in NC and SC with Federal Paperboard and International Paper as a research forester, a procurement forester and as a procurement analyst, where he coordinated wood flow for a pulpmill and sawmill. He joined the faculty at Virginia Tech in the fall of 1998 and completed his PhD in 2003.

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