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An economic analysis of hardwood fiber production on dryland irrigated sites in the US Southeast ☆

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Abstract

Although there is renewed interest in intensively managed, short-rotation plantations as a source of hardwood for pulp mills, few have been established in the Southeast. Understanding all the costs associated with these plantations will help determine their feasibility. Using a model developed to summarize all the costs, a break-even analysis was completed to determine the delivered cost for plantations of eastern cottonwood (*Populus deltoides* Bartr.) from a hypothetical fiber farm in 2003. Using current yield from an experimental fiber farm, short-rotation cottonwood plantations were not cost effective, as delivered cost to a pulp mill averaged 78$ t^{-1}. If yield can be increased by 40% through improvements in genetics and silvicultural practices, delivered cost is reduced to 60$ t^{-1}. Thus, finding this additional yield is key to the cost feasibility of intensively managed, short-rotation hardwood plantations.

Keywords: Fiber farms; Hardwood plantations; *Populus deltoides*; Fertigation; Intensive management

1. Introduction

Growth and yield for poplar species has been studied for many years. Ek and Dawson [1] examined *Populus* '*Tristis #1*' grown under intensive culture in Wisconsin. Their findings indicated annual height growth of 2 m and diameter growth of 2.5 cm per year. A study conducted in the Southeast [2] yielded height growth of 3 m and diameter growth of 2.5 cm each year for 4-year-old plots of eastern cottonwood (*Populus deltoides* Bartr.), equating to nearly 84 m^3 ha^{-1} of volume. Sycamore species (*Platanus occidentalis* L.) and sweetgum species (*Liquidambar styraciflua* L.) trials at the same site were less productive. A recent 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 3 m y^{-1} of height and 2.5 cm y^{-1} of diameter.

When estimating the feasibility of short-rotation, intensively managed hardwood plantations, the costs to include in such an analysis are very site specific. A wet site (flat sites with good loamy and organic soils that typically have a high water table) 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 (sites with sandy soils and a low water table through much of the growing season) 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.

Utilizing a model to summarize costs allows the user to include only those practices 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 was developed in Excel™ and can be used as a tool to estimate the value that hardwood plantations may have to a southeastern pulp mill by

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calculating a net present value for an operational fiber farm investment. A fiber farm in this instance refers to a location where plantations will be established for maximum growth potential and any tree needs (water, fertilizer, herbicide, etc.) are monitored and supplied as necessary. Rotation length is generally kept under 10 years.

Validating the 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.

The US Department of Energy has also been investigating hybrid poplar for biomass production for many years. In a recent report on bio-energy crop production [3], hybrid poplar yield in the Southeast averaged 11 dry $\text{t ha}^{-1}\,\text{y}^{-1}$. From 3-year-old plantations in Mississippi, Stanturf et al. [4] estimated 10 year production of cottonwood to be 7.7 dry $\text{t ha}^{-1}\,\text{y}^{-1}$. In both cases, the sites were flood plains previously used for agriculture and did not require irrigation. Bar [5] used irrigation in an analysis, but gave little information to justify the high yield he used in determining his final unit costs. Pacific Northwest plantations are currently producing 12.5 dry $\text{t ha}^{-1}\,\text{y}^{-1}$ [6], but that analysis did not include any cost information. 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, our research objective was to use the best available component costs from literature and yield information from an industry trial to estimate wood costs for a typical eastern cottonwood plantation.

2. Material and methods

A break-even analysis was completed in 2003 that included all the costs associated with a fiber farm on dryland site. Yield for the plantation was obtained from a fiber farm in the Southeast and costs were estimated from several sources.

2.1. 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 the Southeast. 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 2–6. These are the oldest plantations in operation, so diameters and heights for years 7, 8, 9 and 10 were extrapolated out using Schumacher's [7] equation:

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

where b_0 is the y intercept, b_1 the slope of the line, ε the random error for the equation.

The height and diameter estimates by age was then used in the Krinard [8] formulas for yield from eastern cottonwood plantations. The two formulas are:

$$\text{TVOB} = 0.06 + 0.002221D^2H$$

and

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

where TVOB is the total tree volume outside bark in cubic feet from a 30 cm stump to the tree tip, MVIB the merchantable tree volume inside bark in cubic feet from a 30 cm stump to a 8 cm top, D the diameter at breast height (dbh) in inches, H the 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 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 8 cm diameter. 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 TVOB equation is likely to slightly overestimate the actual fiber yield.

However, using the MVIB equation will likely underestimate total recoverable volume. If the stand is harvested by a roundwood operation, the 8-cm 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 were 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 short tons is the common unit used to measure pulpwood, so the cubic foot volume was converted to short tons for cost comparison in today's market using 46 pounds per cubic foot of wood [9]. Lastly, it was assumed there are 1210 trees per hectare at year 5 (a 10% mortality rate from planting through year 5) and a loss of 1% each year over the remaining life of the stand.

2.2. Determining hardwood plantation silvicultural costs

The costs associated with a hypothetical short-rotation, intensively managed hardwood plantation are grouped into two categories: (1) capital (initial) costs such as land, irrigation system, site preparation and planting. The other category is annual costs such as weed control, fertilizer, insecticides, irrigation and supervision.

Land costs were summarized from a survey of consulting foresters from the Southeast. Fifteen consultants were sent a survey to estimate land cost in their respective regions for both cleared farm land and bare land value for a forested site. Irrigation costs were estimated from bids by two companies that install systems. Site preparation and planting costs were taken from the biannual *Forest Landowners* magazine report; all other costs were estimated after communications with field managers of some current trial fiber farms in the Southeast.

The costs over the rotation were summarized and added with the yield estimated above to determine the stumpage cost for fiber farm material. Lastly, an average cut and haul cost was established to give an estimate of the delivered cost of the fiber farm material to a pulp mill, which could be compared by a procurement manager to current resources of wood.

3. Results and discussion

3.1. Short-rotation plantation costs

The following section explains how the costs were developed. These costs will vary greatly depending on the site, so any manager looking to establish a fiber farm will need to consider their own special circumstances.

3.2. Initial costs

3.2.1. Land costs

Of the 15 forestry consulting firms contacted across the Southeast, 11 responded. Values reported for forestland (bare land cost only, excluding timber value) varied from a minimum of 741$ ha^{-1} to a high of 2470$ ha^{-1}, with an average of 1462$ ha^{-1}. For farmland in the same area, only eight of the same consultants responded and estimated an average land cost of 2470$ ha^{-1}, with a low of 1482$ ha^{-1} and a high of 4446$ ha^{-1}.

For this analysis, the more expensive farmland was used along with the lower site preparation costs because it resulted in a lower capital investment. An added benefit to agricultural land is it 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 it has the lowest investment. 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 2470$ ha^{-1} purchase cost for forestland is carried forward by the 5-year average corporate bond rate of 5% [10] to produce an annual land rent of 124$ ha^{-1}.

3.2.2. 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 2225 to 3460$ ha^{-1} for a system installed on a 240 ha 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 2840$ ha^{-1}, the example system will have two pump houses that can be run individually or simultaneously to supply 3 cm of water per week to the entire plantation during the growing season [11]. 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 1 m. Only the drip hoses and the taps they connect to are left on the surface. Given the 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. Water from a deep well tends to have a high mineral content, primarily iron, and may clog the drip lines, therefore, 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.

Total cost for this system was estimated at 2840$ ha^{-1}. This value is in line with Bar's [5] 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) of 142$ ha^{-1} using the corporate bond rate of 5%.

3.2.3. 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. Logging debris removal, site preparation and burning should clear the site and allow for disking, but at a cost of 740–1000$ ha^{-1} [12].

Sites will require at least two passes of disking [13]. Disking to establish a hardwood plantation will require a heavier plow than is used for most agriculture applications.

The top half meter or so must be thoroughly mixed to allow good root growth. Earlier field studies in 1995 estimated disking costs at 37$ ha^{-1}. In the Dubois report [12], 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 54$ ha^{-1} for each pass. Since farmland is being used, total site preparation cost is 108$ ha^{-1}.

Determining the lowest capital investment 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 a manager.

3.2.4. Planting

For this analysis, rows were planted every 3 m with 2.4 m between trees, resulting in 1350 tree ha^{-1}. 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. A wider spacing such as 4 m × 4 m might be used if sawtimber were the objective. Planting cost for a site prepared tract is 100$ ha^{-1} [12]. 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, 100$ ha^{-1} was used.

Cutting cost for genetically improved eastern cottonwood is 24¢ tree^{-1}, or 324$ ha^{-1} [14]. Cutting 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.

3.3. Annual costs

The silvicultural treatments used in this analysis are described in Table 1.

3.3.1. Weed control

Controlling vegetation is critical to establishing a short-rotation plantation to eliminate competition for the water and nutrients being supplied to the planted trees. Mechanical and/or 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. In wide spacing situations, additional years of weed control should be budgeted.

Table 1
Summary of hardwood plantation silvicultural treatments

Treatment	Material
Irrigation	Deep water well
Weed control	Combination cultivation and chemical (Gramoxone® PDQ)
Fertilization	Potassium nitrate 10-1-6
Insecticide	Dimethoate

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 25$ ha^{-1} [14]. Another report had cultivating between rows at 22$ ha^{-1} [15]. Applying the same 5.4% annual inflation factor from the Dubois paper [12], the current cost would be 32$ ha^{-1} 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 3 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 (active ingredients: paraquat (Gramoxone) and diquat (Reglone)—Syngenta Crop Protection Canada, Inc.) was chosen for this analysis because the managers interviewed indicated it achieves superior weed control results. 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 (32$ ha^{-1}). Gramoxone PDQ is normally applied at 1.7 L ha^{-1}. The cost for Gramoxone PDQ is 7$ L^{-1}, or 12$ ha^{-1}; thus, the total cost per chemical application is 44$ ha^{-1}.

The amount of weed control will vary with each site, and while chemical is usually required, the mechanical passes may become unnecessary. For this cost study, both treatments will be utilized at the recommended levels. Adding the scheduled mechanical and chemical treatments produces a first year weed control cost of 230$ ha^{-1}.

Second year cost declines to 153$ ha^{-1}, and third year cost to 44$ ha^{-1}. No additional weed control costs were included in this analysis.

3.3.2. Fertilization

Fertilizer is applied regularly in small amounts during the growing season, usually 3 times per 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 55 kg ha^{-1} the first year, 74 kg ha^{-1} the second year, and 92 kg ha^{-1} 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 [11].

Current cost for potassium nitrate fertilizer is 180$ t^{-1}. Assuming that 92 kg ha^{-1} of nitrogen is needed, a 10% formulation would require 1.25 t ha^{-1} for a cost of 222$ ha^{-1} for year three and beyond. The 55 kg application in the first year would cost 134$ ha^{-1} and the second year 74 kg application cost is 178$ ha^{-1}.

3.3.3. Insecticides

Various defoliators, borers and miners of intensively cultivated poplars require treatments to prevent losses [16]. 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* F.). While the cottonwood pests have several natural predators, chemical treatments are the most economical and effective means of eliminating outbreaks [17].

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. There are two options for deciding when to apply insecticides: (1) on a schedule to prevent any infestation; or (2) when an insect problem has been detected. Option 1 is a planned annual cost, option 2 will depend on insect activity in the area.

For this analysis, option 1 will be used and included as an annual cost. 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 [18]. Each treatment consists of applying 4.6 kg ha^{-1} of chemical through the drip irrigation system. Chemical cost for a 4.6 kg treatment is approximately 22$ ha^{-1}. Three treatments per season would cost 66$ ha^{-1}.

3.3.4. Daily irrigation

The daily irrigation cost in this analysis is primarily due to the electricity cost. Survey of the system and 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 h 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-h 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-h 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 $24,000. For a hypothetical 240 ha fiber farm, that amounts to 100$ ha^{-1} per year.

3.3.5. 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, survey the lines to ensure uniform coverage, identify and repair leaks caused by various animals, 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 48k$ y^{-1}. This estimate includes a pay rate of 12.50$ h^{-1}, 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.

3.4. Total costs

Total costs for each year are illustrated in Table 2 on a per hectare basis for a hypothetical 240 ha 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 1000$ ha^{-1} or more, but during a planting year, they are over 1600$ ha^{-1}.

3.5. Growth and yield volumes

A graphical representation of the curves for diameter and height data for eastern cottonwood supplied from a fiber farm operation is found in Fig. 1. The average diameter and height for each age class were used to determine the average volume per tree. It was assumed that there are 1210 trees per hectare at year 5 (a 10% mortality from planting through year 5) and a loss of 1% of the 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 hectare for a given year. Total yield per hectare is presented in Table 3.

Analysis indicates that the plantations are growing just over 20 t ha^{-1} year of green fiber. This yield per acre is less than one-half what Bar [5] used in his analysis (147 t ha^{-1} versus 350 t ha^{-1}) and only about one-half of typical Pacific Northwest operations (300 t ha^{-1}) [6]. 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.

3.6. 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 50 km. For the roundwood, a 12$ t^{-1} harvest and transport rate was assumed. For clean chips, the harvest and transport rate was 18$ t^{-1}, due to the cost of chipping on site.

Table 4 summarizes all the costs and yields for the hypothetical 240 ha fiber farm, as well as a delivered short ton cost estimate for both roundwood and chips. Material from the fiber farm delivered to the mill as roundwood averaged 78$ t^{-1}, with the seventh year of the first rotation being lowest cost at 75.58$ t^{-1}. Chip deliveries from the fiber farm fell in the 84$ t^{-1} range.

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 3 shows that the average fiber farms currently yield approximately 147 t ha^{-1} in year 7. Discussions about yield with supervisors from West Coast operations indicate that through improved genetics and better cultural practices, they have

Table 2
Summary of all costs ($ ha^{-1}) determined in 2003 of a 240 ha fiber farm in the southeastern coastal plain growing eastern cottonwood

	Year									
	1	2	3	4	5	6	7	8	9	10
Initial										
Land rent	124	124	124	124	124	124	124	124	124	124
Irrigation rent	142	142	142	142	142	142	142	142	142	142
Site prep and tillage	108									
Planting	424									
Annual										
Irrigation electric	100	100	100	100	100	100	100	100	100	100
Weed control	230	153	4	0	0	0	0	0	0	0
Fertilizer	134	178	222	222	222	222	222	222	222	222
Insecticide	66	66	66	66	66	66	66	66	66	66
Supervision	280	288	297	306	315	325	334	344	355	365
Annual total	1608	1051	995	960	969	979	988	998	1009	1019
Interest cost	80	137	194	251	312	377	445	517	594	674
Accumulated total cost	1688	2877	4065	5277	6558	7914	9347	10863	12465	14158

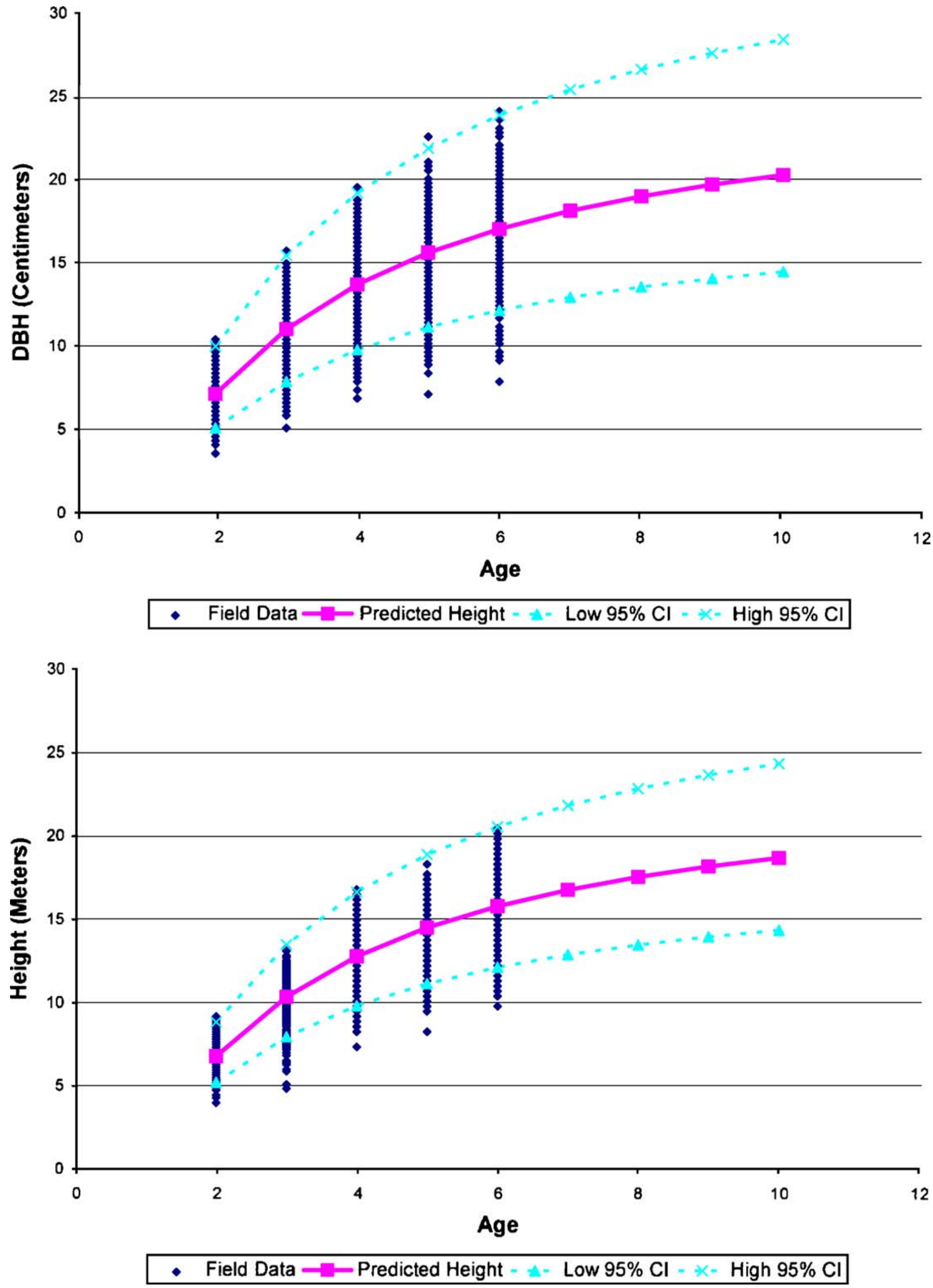

Fig. 1. Projected DBH and height by year for eastern cottonwood plantations in the southeast. At each age measurement, $n = 485$.

successfully increased yield nearly 60% over the past 10 years. Similar increases have been found in many intensively managed plantations [19]. 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 can take advantage of genetic and cultural improvements and gain two-thirds of the increase the Pacific Northwest accomplished, yield would improve by 40%. Yield would then conceivably approach 206 t ha^{-1} by year 7, thus providing the potential to reduce delivered costs by as much as 18$ t^{-1}. Attaining this level of yield improvement could result in fiber farm delivered costs of approximately 60$ t^{-1} for roundwood and 66$ t^{-1} for chips.

Table 3
Estimated per hectare yield by year for eastern cottonwood plantations growing in the southeast

Age	Yield (green) kg tree^{-1}	Trees ha^{-1}	Total t ha^{-1}
5	76	1210	92
6	101	1198	121
7	124	1186	147
8	144	1174	169
9	161	1162	187
10	176	1150	202

Table 4
Costs per hectare and delivered cost per ton for alternative rotation lengths of intensively managed eastern cottonwood plantations in the southeast with current yield and improved yield

	Year									
	1	2	3	4	5	6	7	8	9	10
Accumulated total cost ($)	1688	2877	4065	5277	6558	7914	9347	10863	12465	14158
Current yield (ton)					92	121	147	169	187	202
Stumpage cost per ton ($)					71.28	65.40	63.58	64.28	66.66	70.09
Delivered cost as roundwood ($)					83.28	77.40	75.58	76.28	78.66	82.09
Delivered cost as chips ($)					89.28	83.40	81.58	82.28	84.66	88.09
Improved yield (ton)					129	169	206	237	262	283
Stumpage cost per ton ($)					50.92	46.72	45.42	45.91	47.61	50.07
Delivered cost as roundwood ($)					62.92	58.72	57.42	57.91	59.61	62.07
Delivered costs as chips ($)					68.92	64.72	63.42	63.91	65.61	68.07

Delivered costs represent the cost for the fiber farm material for that given year based on a 2003 analysis.

4. Conclusions

The objective of this paper was to determine the costs for short-rotation, hardwood, fiber farm plantations. Using costs from literature and yield from an ongoing industry fiber farm, a hypothetical eastern cottonwood plantation was analyzed in the model. 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. These costs will vary greatly and any site being considered should be evaluated independently.

The use of estimated costs and yields to develop delivered costs to a pulp mill from these hypothetical plantations indicates that when current costs for all operations along with current yields from industry trials are attributed to determine a stumpage price, hardwood fiber farm plantations seem to be cost prohibitive for Southeastern pulp mills, based on input assumptions. 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 some 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. Great increases can be achieved through the use of transgenic trees—herbicide resistance, insect resistance, growth genes and pulping genes could greatly reduce costs and influence mill products.

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

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