BIOMASS YIELD AND COST ANALYSIS (4th YEAR) OF VARIOUS TREE SPECIES GROWN UNDER A SHORT ROTATION MANAGEMENT SCHEME IN EASTERN KANSAS[1]

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Abstract.--Biomass studies were established in 1976 to determine the feasibility of supplying the central steam plant at the University of Kansas with wood as a fuel source. Experimental tree plantings were established on fifteen acres of upland and bottomland soils near Lawrence, Kansas. Six species were tested at eight different spacings to determine the above ground dormant season biomass yield of intensively cultured, rapid-growing hardwood trees. Early results indicated biomass plantations specifically managed as an "energy forest" would appear to be one feasible source of wood. This report summarizes third- and fourth-year growth results, projects the fifth-year yield of fuel from a short-rotation energy forest and presents an economic analysis of the cost of plantation wood delivered at the steam plant.

Additional keywords: biomass, energy forests, energy, fuel wood, short rotation, forestry

Wood, along with municipal solid waste, can be used as a supplemental fuel to carry the peak load requirements of a proposed central-steam facility at the University of Kansas campus in Lawrence. While most available wood sources would be subjected to competitive pricing in the market at some future time, wood from plantations grown on University land would be free from supply-and-demand competition.

A management system maximizing biological potential while minimizing costs of plantation-grown wood is essential for properly evaluating this fuel alternative. Selecting the "best" system involves such factors as species selection, planting density (trees per acre), cultural practices, timing of harvest, method of harvest, and land costs.

A series of experimental tree plantings made in the springs of 1976, 1977, and 1978 on different sites in the Lawrence, Kansas area have provided base-line data on biomass production for evaluating the feasibility of fuelwood plantations, recently termed the "energy forest" concept (Szego and Kemp, 1973). Reported yields of intensively managed plantings have been high (Bowersox and Ward, 1976; Geyer, 1978; Kennedy, 1975).

Here we report on findings during four years of a multi-year project of plantation-growth trials and on the estimated delivered cost of wood fuel. Previously reported results (Naughton and Geyer, 1978) covered only 2nd-year and estimated 3rd-year data.

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METHODS

Site Description

Four sites of widely differing soil quality within 15 miles of the KU campus and under public ownership were available for plantation development: two upland prairie sites at the Sunflower Research Center and two lowland sites in agronomic crop production, one at Clinton Reservoir and one at Teepee Junction.

Sunflower Research Center: Approximately 13 miles east of KU campus on land owned by the University. This site is a gently rolling prairie upland with rich, loamy topsoil over clay loam subsoil in natural bluegrass pasture. It is typical of the upland areas available for planting east of Lawrence.

Site No. 1.--Pawnee-Woodson-Morrill Soil Association, Pawnee Series. Surface soil is 8-10" silt loam, well drained, 5-8" slope, pH 5.6, 17 ppm nitrogen, 22#/A phosphorous, 427#/A potassium.

Site No. 2.--Pawnee-Woodson-Morrill Soil Association, Morrill Series. Surface soil 10-16" silt loam, well drained, 3 to 5% slope, pH 5.6, 17 ppm nitrogen, 8#/A phosphorous, 378#/A potassium.

Clinton Reservoir: Approximately 4 miles southwest of the KU campus on land owned by the U.S. Army Corps of Engineers below the new dam. This site is a deep, loamy lowland soil, on retired cropland. The site is typical of bottomland available on the minor and major drainages west of Lawrence.

Site No. 3.--Wabash Kennebec-Reading Soil Association, Kennebec Series. Surface soil 22" silt loam to silty clay loam, well drained, flat, pH 7.6, 10 ppm nitrogen, 175#/A phosphorous, 522#/A potassium.

Teepee Junction: Approximately 5 miles north of the KU campus on land owned by the city of Lawrence, on the river side of the Kaw River levee. This site is sandy loam river alluvium, currently under crop lease to a local farmer; it is periodically flooded. It is typical of the 1/4-mile wide alluvial land running along the Kaw River.

Site No. 4.--Eudora-Kimo Soil Association, Sarpy Series. Surface soil deep fine sandy loam, excessively well drained, flat, pH 7.5, 6 ppm nitrogen, 79#/A phosphorous, 342#/A potassium.

Planting Design

Three field studies were incorporated in our evaluation -- 1) plant-density trials, 2) cultural-practice trials, and 3) an "energy forest" production trial.

Plant density trials: A relatively small circular plot was used following the Nelder (Namkoong, 1965) design which allows for a maximum number of species and spacing-variation tests on a minimum of land area. Each Nelder "cartwheel" tested 7 spacing subplots on a 51.6-ft. radius, 30 spokes per circle, 7 trees per spoke, 210 trees total per plot. Each cartwheel contains a different species of trees -- cottonwood (*Populus deltoides*), silver maple (*Acer saccharinum*), black

locust (Robinia pseudoacacia), Siberian elm (Ulmus pumila), or European black alder (Alnus glutinosa). All four sites were planted, except that the sandy loam site (No. 4) was planted the second year and black alder was eliminated because of its poor survival the first year. Thus, a total of 19 wheels were eventually established for the test. All plots were mechanically cultivated for two summers to provide an estimate of the best potential growth on each site and to avoid possible herbicide toxicity problems. Cultural care the third season consisted of mowing only. There was no treatment the fourth season because the plantings had sufficient crown closure to shade the sites and restrict mechanical operations.

Cultural-practice trials: Linear plantings at 4'x4' spacing and about 1/2 acre in size were planted at the Sunflower and Clinton sites during the first year, 1976. At Sunflower, one plot is cottonwood, another maple; the plot at Clinton was subdivided into 4 blocks, each with a different species. Eventually the plantings will be used to test mechanical harvesting equipment, fertilizers, pesticides, stump-management techniques for sprouting enhancement, and individual tree weights for determining nondestructive yield of the wheel plots.

An "energy forest" of 8 acres was established in 1977 and expanded in 1978 at the Sunflower site. Four species were planted at 8 1/2x4' spacing; rows being far enough apart to accommodate small farm tractors. This planting is our "operational scale model" for cost-analysis studies on time and motion (equipment) operation. During the first growing season it was cultivated chemically using an aqueous solution of dichlobenil (Casoron) at 8 to 10# a.i. per acre rate in 4'-wide strips. During succeeding years the strips were mowed 4 times for weed control. Blocks of silver maple, catalpa, and Siberian elm were planted the first year (1977); a block of black locust was planted the second year (1978).

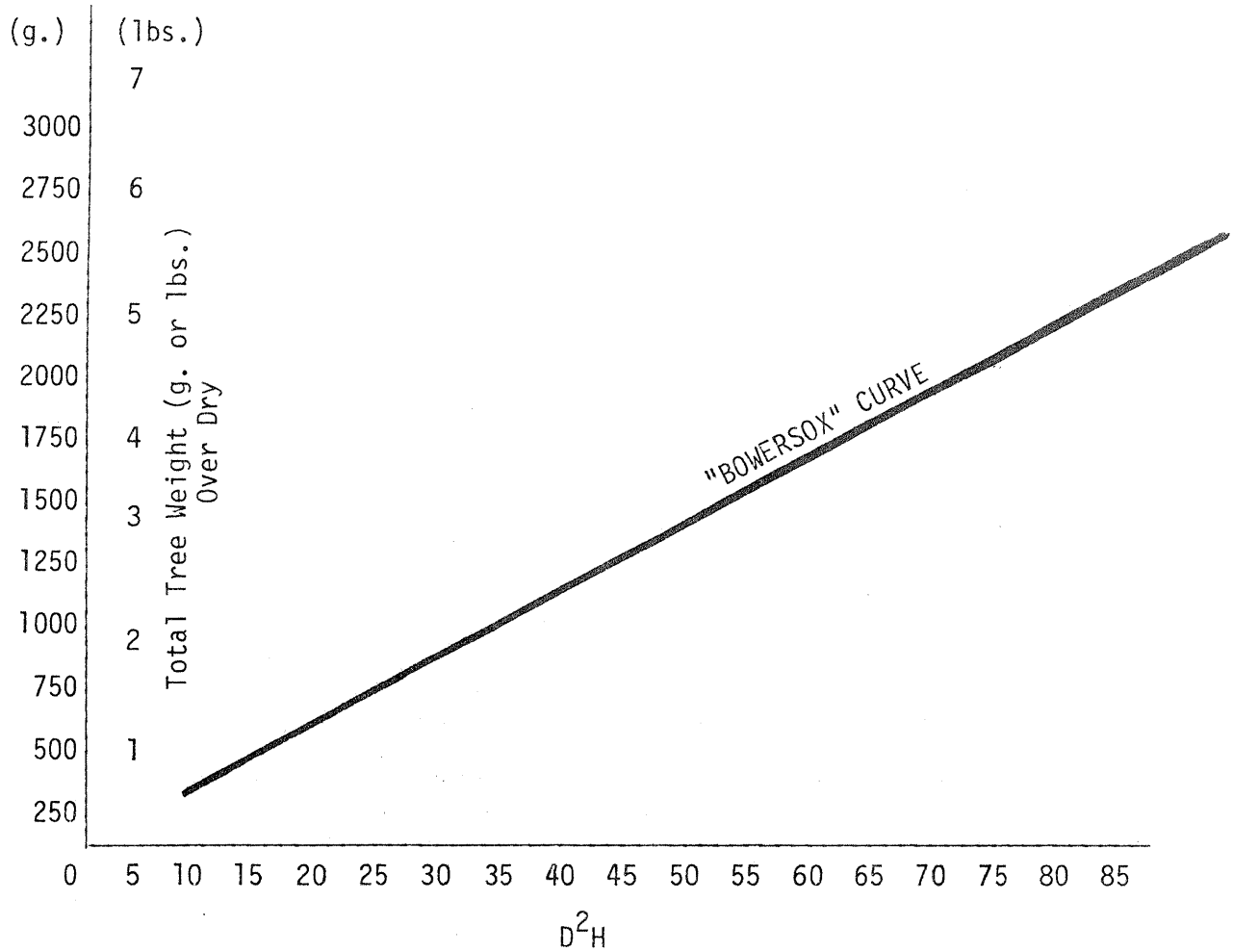
Species used were broad-leafed trees capable of rapid juvenile growth, relatively free of pest problems, and capable of vigorous resprouting. These species, naturalized to the Great Plains, were selected to take advantage of their adaption to the plains environment. European black alder was included because of its nitrogen-fixing capability and its reputation for fast juvenile growth.

Measurements: Annual nondestructive tree sampling was conducted each winter. Survival, ground-line diameter to the nearest 1/10 inch, and height to nearest 1/2 foot were taken to develop ovendry weight yield curves for individual trees and subsequently expanded to an acreage basis. Weight curves were prepared for each species and compared to those of Bowersox (1975) in Figure 1, for use in this analysis.

The usual theoretical value for the heat yield of all wood is 8,600 BTU per pound on the basis of ovendried (0% moisture content), bark-free, and resin-free wood fibre (U.S.D.A., 1976). The theoretical yield of bark is approximately 105% of the yield of wood, or 9,000 BTU per pound. In actual practice, fuels will not be ovendry at the time they are fed into an operating power plant. Our estimate is that most wood fuel to be used at the KU plant will have a 20-30% moisture content (5,000 to 6,000 BTU/lb. as fired).

With the assistance of the Chemistry Department at Kansas State University, heat of combustion analyses were made on immature plant materials (see Table 1)

FIGURE 1: ESTIMATION OF TOTAL DRY WEIGHT OF TREES



similar to those showing potential use in fuel plantations. We then made tables of the heat yield data, along with other available data found in the literature.

Tests made at KSU's Chemistry Department were on two-year old material including bark, wood, and buds combined. Usual values shown in the literature are for wood only. For our biomass area-yield calculations, we used 8,400 BTU/pound for black locust, 8,200 BTU/pound for cottonwood, and 8,100 BTU/pound for the other species (Table 1).

Cost analysis: Plantation management alternatives were analyzed using a systems matrix approach incorporating growing costs, land rent, harvesting, chipping, and hauling expenses to the Lawrence campus. The approach used in our preliminary analysis (Naughton and Geyer, 1978) using growth data from published reports (Ek and Dawson, 1976) proved adequate for our current analysis. Empirical data collected from Kansas studies were used to generate costs of wood fuel delivered to the University of Kansas at Lawrence.

Table 1.--Heating value of selected hardwood species.

Species	Reference[1/]	Heating Value Per Dry Pound, BTU's		
		Wood & Bark	Wood	Bark
Silver maple	1	8054	----	----
E. black alder	1	8122	----	----
Boxelder	1	8102	----	----
Sandbar willow	1	7982	----	----
Siouxland cottonwood	1	7876	----	----
Common cottonwood	1	8217	----	----
Sycamore	1	8230	----	----
Sugar maple	2	----	----	7301
Sycamore	2	----	----	7403
Black willow	2	----	----	7168
American elm	2,4	----	7414	6121
Quaking aspen	2	----	----	8433
Red alder	2,3	----	8000	7947, 8410
Black cottonwood	3	----	8800	9000
Sugar maple	2,4	----	7235	7301
Sweetgum	2	----	----	7450
White oak	2,4	----	7239	6995
Red oak	2,4	----	7235	8030
Shagbark hickory	4	----	7252	----
Red maple	4	----	7265	----
Reported mean	5	----	8300-8600	9000

[1/] Literature source is as follows: 1--small material calculations by KSU; 2--Tappi, 1955, Vol. 38(5), pp. 319; 3--Oregon State University, Bul. No. 14, 1973; 4--University of Wisconsin Forestry Facts, No. 6, 1966; 5--Forestry Handbook, 1956, pp. 14-73.

RESULTS AND DISCUSSION

Biomass Yield

Survival, growth, and development have been excellent, except for European black alder. At the end of the 1976 growing season, we discontinued consideration of alder because of its poor survival rate. In 1977 we added catalpa and used it in the large "energy forest" planting. Our three trials are summarized here.

Plant density trials: Except for black alder, survival has remained sufficiently high for evaluation of biomass yield comparisons at different spacings. Height growth increased dramatically the 2nd year, presumably because of good weed control, juvenility, and aided by abundant precipitation that summer. Currently, cottonwood and locust are the tallest (Table 2) at sites 1, 2, and 3 -- after four growing seasons.

Table 2.--Four year survival percentage and height.

Species	1st Year[1/] Survival	Ht.	2nd Year Survival	Ht.	3rd Year Survival	Ht.	4th Year Survival	Ht.
Cottonwood	97	5	99	15.4	99	16.8	94	22.5
Black locust	97	3	98	13.2	98	16.2	96	21.1
Siberian elm	89	2.5	100	8.3	100	10.7	100	14.0
Silver maple	85	2	100	8.6	100	12.6	99	18.4
Black alder	57	1	100[1/]	5.0	94	7.2	94	14.3

[1/] All replanted to insure sufficient survival for growth data.

Each species of tree has a different biological potential; fast-growing trees usually have low wood density and thus yield less fuel per cubic foot than do slow-growing trees. Likewise, some species perform better on one soil than on another. In terms of costs, however, all trees are about equal in price per seedling, cost for planting, and cost of cultivation and management.

We expected tree growth to be best on the lowland, silty clay loam of Site 3 and to be poorest on the upland prairie silty loam of Site 1. After 4 years of growth, trees in the test plots did not conform to our expectations--and perhaps never would in a "short rotation" system. The "best" soil so far has proven to be the most difficult to handle in terms of weed control, and to date the growth of trees has been less on that soil (Site 3) than on upland Site 2. The traditional concept of site quality used by foresters may need some new interpretations for "short rotation" forestry.

Growth after three years was best on Site 4 for all species except silver maple. A comparison may not be justified, however, because Site 4 was planted a year later (1977) than the three other sites and had three good growing seasons as a result of precipitation patterns. The first growing season (1976) applicable to the three other sites, was very dry and hot.

At the end of the 1977 growing season, trees on all plots were still expressing accelerated growth characteristics but by 1978 cottonwood was decelerating while the others were continuing to accelerate.

During the 4th growing season (1979), cottonwood growth began to increase; the trees grew at the same rate as black locust and silver maple. Though we do not understand the decelerated growth of cottonwood during the 3rd year, a partial explanation may be that cultivation was terminated after two years. Cottonwood is known to be quite sensitive to competition from weedy vegetation and thus it may be under stress.

Crown closure, an important factor in weed control, after 4 years was complete for all but the outer two rings in cottonwood, black locust, and maple "wheels"; and for the first four rings (narrow spacing) in elm. The columnar crown shape of elm makes it the least desirable species for quick crown closure and natural weed control obtained from shading. Where the crowns touched, the weeds were greatly suppressed, thus allowing the trees more soil moisture and nutrients. Total biomass production was also greater where crowns had closed because more sunlight was intercepted.

The cottonwood has exhibited moderate leaf rust, but not enough to reduce tree growth. Insect damage has been nominal in all species; the only measurable amounts have been caused primarily by grasshoppers. Some black locust suffered nominal wind breakage but recovered rapidly.

We can approximate five different test spacings using average radial and chord distances and excluding rings No. 1 and 7 as buffers. Total production for the remaining spacings shows (Figure 2) that Siberian elm produces substantially less wood than do any of the three species on the loamy sites. On the sandy soil elm grows well, but cottonwood grows better.

For the three sites (Sites 1, 2, 3) that have had four full growing seasons, all trees in each of the "cartwheel" spacing trials were measured and the total yield on a per-acre basis was calculated from the composite curves (Figure 1) to determine the variations in production among sites, spacings, and species.

Because the trees are still so young that they have just begun to show competition stress even at high population densities, the general result in all situations is that the highest population (i.e., closest spacing) shows the greatest gross BTU production.

We anticipate that the production curves shown for all species will tend to flatten out over time. But the information gathered thus far is not clearly definitive. In our plots, production of cottonwood may flatten out sooner than does production of any of the three other species because cottonwood is not expected to withstand competition as well.

Initial data in 1977 (2 years' growth) indicated that cottonwood (at 199,000 BTU per cubic foot) and black locust (at 354,000 BTU per cubic foot) were the most likely species to produce substantial quantities of fuel economically (Figure 3). These species have remarkably different heat values, but because of natural differences in growth patterns, they could yield about the same quantities of fuel (BTU) per acre under intensive management.

By 1978 (3rd year), however, black locust yields were greater than cottonwood, and silver maple was close to cottonwood. Potential BTU yield from elm was still substantially below that of the three other species being tested.

At the end of the 4th growing season in 1979, cottonwood production appeared to be levelling-off at the closer spacings while maple and locust were continuing to grow rapidly. At the two closest spacings (1,894 and 2,833 trees/acre), locust and maple had the highest yield, while locust surpassed cottonwood at all five test spacings.

After 4 years, it is still too early to evaluate properly the optimum production yield from these test plantings. A levelling off in yield is likely to occur between 6 and 8 years. Growth still appears to be in its exponential stage and rates should increase during the 5th growing season, assuming normal precipitation. We can expect at best a doubling of the field biomass between the 4th and 5th years with increased yield at the close spacing to be less and at the wider spacing to be more than that rate (Figure 3).

Figure 2: MEAN YIELD OF ALL SPACINGS COMBINED FOR SITES 1, 2, & 3

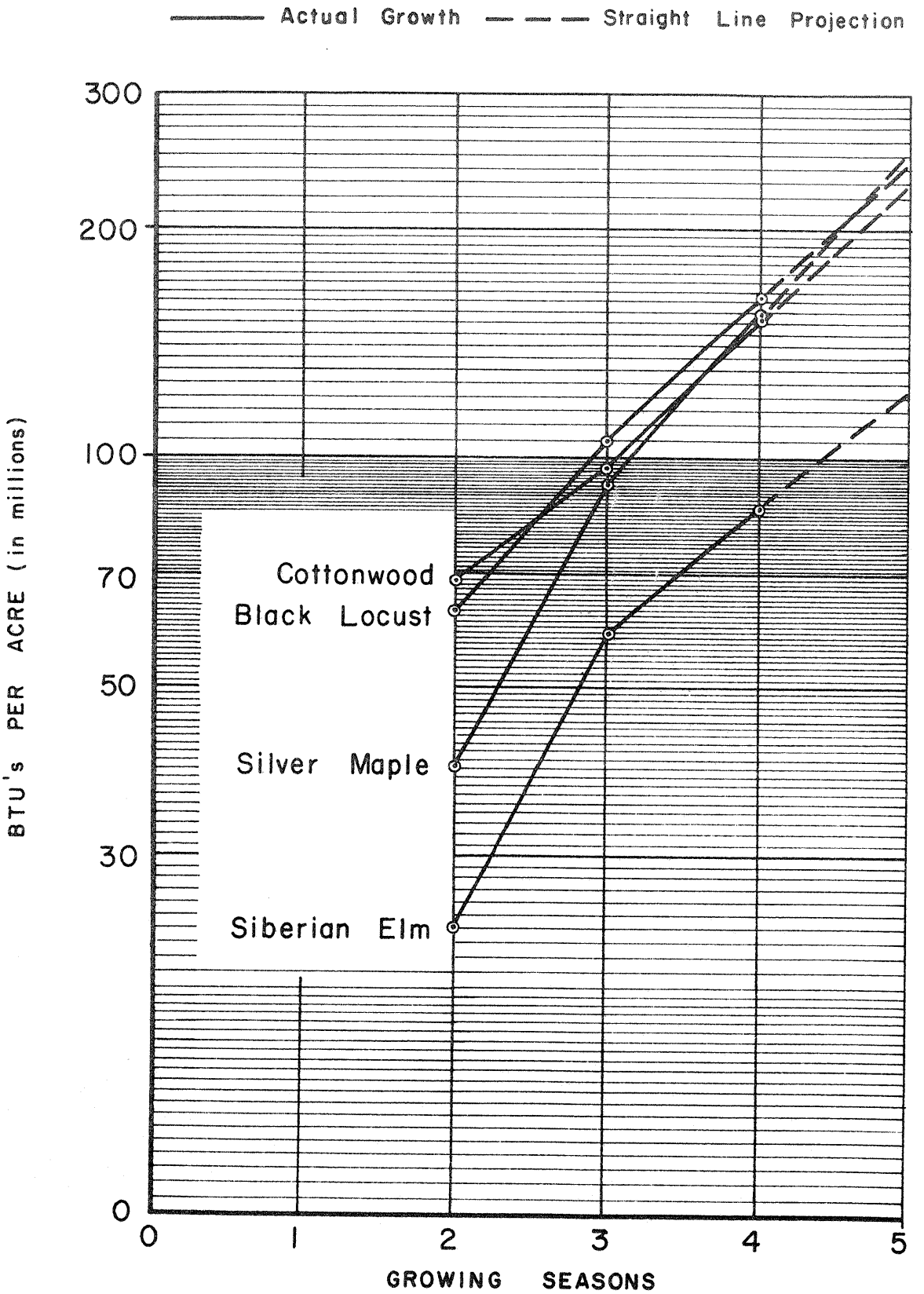
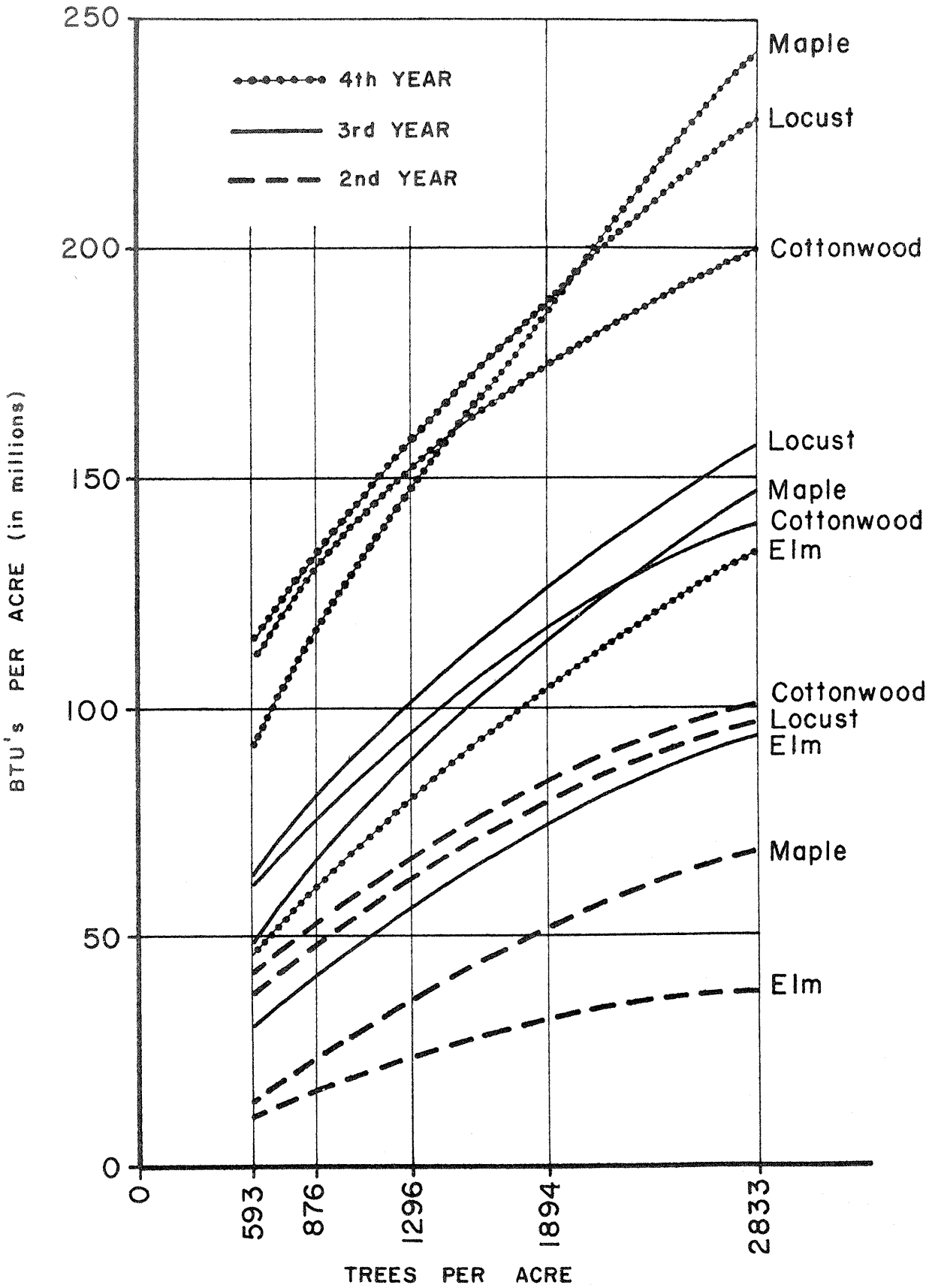


Figure 3: BIOMASS YIELD OF SITES 1, 2, & 3 COMBINED



Cultural Practice Trials: Visually, growth on these 4'x4' spaced plantings has appeared to be lower than that found on the cartwheel plantings. Initially, the trees were planted a month later than were the wheel plantings, and thus had a shorter growing season. In addition, weed control was difficult because of close spacing, so tree growth was reduced. Survival has been high, at best 90%, and will provide a base planting for future studies of cultural-practice investigations.

Thirty elm trees were cut in 1978 at the Clinton site for single tree biomass calculations. Some black locust and maple were also cut from the wheels after they had been partially destroyed during October, 1978 because they were on the line of a municipal water main right-of-way. Altogether we lost 38 trees from the black locust wheel, 17 trees from the silver maple wheel, and 3 trees from the cottonwood wheel. The cut trees were used in the laboratory for calculating BTU yield data and the weight data.

The following formula eventually will be used to generate weight-regression equations; a preliminary graphic analysis showed some variance from the Bowersox curve (Figure 1) used in our analysis. For given D^2H dimensions, we found our cottonwood weighed less and the other species weighed more.

$$\text{Ovendry weight} = a + b\ D^2H,$$

where ovendry weight was determined by drying the entire above-ground biomass in an oven for 3 days at 100-105°C, D is the stem diameter 3 inches above the ground, and H is the total height of the tree in feet.

Energy Forest Trial: Because survival of all trees was high the first year after planting -- all species over 90% (see Table 3) -- no interplanting was done. Height growth was equivalent to that for the same species on the wheel plantings (Table 2). Even though herbicides were not applied the 3rd year, survival has remained high, but with substantially reduced tree growth. Mowing weeds between tree rows has not been sufficient for good tree growth. The ground was too wet for us to apply herbicides in the spring before the weed seed germinated.

Table 3. First and second growing season growth characteristics of "energy forest" plantation at Sunflower.

	First Year		Second Year	
Species	Survival (%)	Ht. (ft.)	Survival (%)	Ht. (ft.)
Maple	95	3.3	95	5.2
Catalpa	91	2.4	91	3.5
Siberian elm	99	4.6	99	5.8

Cost Analysis

The cost of delivered plantation-grown wood makes it competitive as a supplemental fuel with solid waste refuse. The price is 1/2 that of No. 5 fuel oil and the same as that of natural gas at January, 1980 prices (Naughton, 1980), on the basis of input BTU.

Growing Costs: In-as-much as the variables involved in a management scheme of this nature are infinite, we looked at the continuum of input data covering all planting densities and numerous planting ages. The "best" may be several closely related alternatives of stocking rate and time. Black locust was used in our analysis because it gave the best 4-year-yield results in our studies. The highest population density and the longest rotation gave the highest BTU yield per acre (Table 4). But high plant populations require high input costs per acre (Table 5). Growing costs (Table 6) were thus derived by the following formula:

$$GC = \frac{C}{Y} (1+i)^n;$$

where: GC = Growing costs
C = Cost of establishment per acre
Y = Yield at harvest in million BTU
i = Interest rate of 7.0%
n = Number of years between harvests

Table 4. Yield in million BTU per acre.

	Trees per acre				
Age	2833	1894	1296	876	593
2	99	69	62	49	36
3	170	112	101	91	67
4*	235	189	162	128	112
5	310	260	240	200	180
6	400	350	320	300	260
7	510	470	460	415	390
8	640	600	580	570	530

*Yield through year 4 are actual averages from three separate sites; years 5 through 8 are graphically projected logrithmic functions.

Table 5. Estimated establishment costs per acre*

	Trees per acre				
Item	2833	1894	1296	876	593
Seed preparation	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00
Weed control	87.00	87.00	87.00	87.00	87.00
Seedlings	283.30	189.40	129.60	87.60	59.30
Planting	84.99	56.82	38.88	26.28	17.79
Total	$473.29	$351.22	$273.48	$218.88	$182.09

*Based upon empirical data gathered at time of establishment of the "energy forest" study. Site preparation includes fall plowing and spring disking; weed control includes application @ $7.00 per acre plus 10# Casoron per acre @ $8.00 per pound; seedlings are 1 year old commercial stock costing $100 per thousand; planting is a machine rate of 4,000 per day per 4-man crew; approximately 3 cents per tree.

Table 6. Growing cost per million BTU (@ 7%).

Years (Cutting cycle)	Trees per acre 2833	1894	1296	876	593
3	3.24	3.84	3.31	2.94	3.32
4	2.64	2.44	2.21	2.24	2.13
5	2.14	1.89	1.60	1.53	1.42
6	1.77	1.51	1.28	1.09	1.05
7	1.49	1.20	.95	.85	.75
8	1.27	1.01	.82	.66	.60

Land Costs: Compounding total production over time yields a rate of production function that must be carefully judged. Adding to that the consideration of land rent (or return to land capital) further complicates the manager's decision process.

There is some argument against including land costs in such an analysis on the assumptions that: (1) the use of public land can be obtained for this "public" project at little or no cost; and (2) the land is not destroyed or "used up" by growing trees on it, and normal appreciations in value over the period of use will offset the cost of charging rent. However, when the public uses money (or land) in a project, it denies the use of that capital to the private sector and should, therefore, pay something for that use.

On the basis of an interest rate of 7% (the approximate average of the prime lending rate for the last decade), land averaging $500 per acre market value would need to earn $500 x .07 = $35.00 per acre per year as rent. Assuming that all rent and interest would be paid at the time the plantations are harvested, we have:

$$R_n = \frac{a \quad (1+i)^n - 1}{i};$$

where: R_n = Rent due at the end of a particular year
a = The simple annual payment
i = The interest rate of 7%
n = Number of years between harvests

Harvesting Costs: There are no empirical data available from this study to indicate what can be reasonably predicted for harvesting costs. Although several companies are developing mechanical equipment to harvest trees efficiently, none has been available for testing in our situation. Thus, we have assumed that harvesting would be a hand-labor operation (separate from chipping and hauling).

We also have assumed that a two-man crew with one chainsaw would cut 50 trees per hour. The cost is estimated at $9.00 per hour (including crew labor and saw operations), or 18 cents per tree. On a per-acre basis, the costs would be:

Trees Per Acre				
2,833	1,894	1,296	876	593
$450.85	$320.80	$228.96	$163.30	$116.23

where the median level of 1,296 trees per acre is the base for calculations. We allowed 5% greater efficiency for 1,894 trees per acre and a 10% greater efficiency for 2,833 trees per acre (the lower density plantings are penalized 5% and 10% respectively), the major variable here would be the time spent walking between trees. Thus, harvesting costs would range from a high of $2.65 to a low of $0.22 per million BTU (Table 8), if the variable has a linear function.

Table 8. Harvesting costs per million BTU.

	Trees per acre				
Years	2833	1894	1296	876	593
3	2.65	2.86	2.27	1.79	1.73
4	1.92	1.68	1.41	1.27	1.04
5	1.45	1.23	.95	.82	.65
6	1.13	.92	.72	.54	.45
7	.88	.68	.50	.39	.30
8	.70	.53	.39	.39	.22

Chipping and Hauling: Finally, the costs of chipping the trees to fuel size and hauling to the plant site storage area must be considered. Chipping would be done in the field as a separate operation behind the harvesting, by using a field-portable chipper, which would be moved along the rows of felled trees. The chipper would be pulled by a tractor, and a truck or trailer would move with the unit to take the chips blown from the unit.

Chipping costs with a portable field unit have been separately estimated at about $4.50 per ton ($.50 per million BTU at field moisture). Quoted hauling costs are at 10 cents per ton mile, and the average haul is assumed to be 20 miles or less. Thus, to cover these charges, we should add 70 cents per million BTU to all values given in these tables.

Total Delivered Costs: Considering all costs involved -- growing, land, chipping, and harvesting (Tables 6, 7, and 8) -- plantings with the widest spacing and longest rotation would have the lowest cost at $2.20 per million BTU (Table 9). Because many of the variables are indefinite, a cutting age of 7 or 8 years and a plant population of 876 to 1,296 trees per acre would be the likely combination to be selected on the basis of this data.

Table 7. Land costs per million BTU.

Years	Trees per acre 2833	1894	1296	876	593
3	.66	1.00	1.11	1.24	1.68
4	.66	.82	.96	1.21	1.38
5	.65	.77	.84	1.00	1.12
6	.63	.72	.78	.83	.96
7	.59	.64	.66	.73	.78
8	.56	.60	.62	.63	.68

Table 9. Total delivered cost per million BTU*.

Years	Trees per acre 2833	1894	1296	876	593
3	7.42	8.40	7.39	6.67	7.43
4	5.92	5.64	5.28	5.42	5.45
5	4.94	4.59	4.03	4.05	4.06
6	4.23	3.85	3.48	3.16	3.16
7	3.66	3.22	2.81	2.67	2.53
8	3.23	2.84	2.53	2.28	2.20

*Growing + land + harvesting + chipping and hauling.

Another consideration is the amount of land available for planting. High plant densities yield the most BTU/acre, and require the least land to produce given total BTU production; thus, the additional cost involved in high-density planting might be offset by the smaller acreage required (compared with that for plantings at wider spacings).

CONCLUSION

The "best" case cited here is to plant 593 trees per acre on $500/acre land and harvest the trees at the end of every 8-year growing cycle.

If land becomes more expensive, it follows that we should consider either planting more trees per acre, or shortening the production cycle by one or two years. The values as given in our tables imply that we have indeed substantially reduced the number of possibilities with regard to spacing, production cycle, and investment alternatives. For example, any of the plantation designs considered could compete favorably with current fuel oil prices if the production cycle is at least 5 years.

In the case of natural gas, the current price at Lawrence of $2.40/MCF is 9% higher than our projected cost of $2.20/million BTU of wood from 8-year-old black locust plantations spaced 8.5'x8.5' (593 trees per acre). This is equivalent to $37.84 per O.D. ton or $24.20 per field moisture ton of wood chips delivered to the boiler (production costs).

Even if we assume that natural gas prices will not rise further, then we may still consider growing energy forests as a means of energy independence for situations similar to the one presented here. However, conversion to wood-fired boilers will require additional capital costs to be charged off against the wood fuels.

Future growth of these plantations will show when the biological potential will be reached. But the economic potential can only be reached in light of what we are willing to pay for alternative fuels.

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