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AN EXPERIMENT IN BIOMASS PRODUCTION: RESULTS FROM THREE CONSECUTIVE HARVESTS OF COTTONWOOD AND ALDER

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ABSTRACT

Experimental coppice yields of black cottonwood and red alder biomass ranged from 1.7 to 6.2 oven-dry tons per acre per year. Cottonwood substantially out-produced alder; this was in part due to the applications of pulp and paper mill sludge which increased cottonwood yields but depressed alder yields. Irrigation, the other cultural treatment in this experiment, increased growth of both species. The authors also discuss some of the opportunities and limitations associated with biomass farming in the Northwest.

precipitation (50 in) occurring as rain during winter. Soil is a silty clay loam of alluvial origin. Vegetation on the island includes black cottonwood, willow, teasel, Canada thistle, nettle, and several grass and other herbaceous species. Red alder does not occur naturally on the island but is very common in the general area.

Trees in the immediate vicinity of the study had been removed several years previously for a powerline right-of-way. The area was rototilled in the spring of the year before planting; developing herbaceous vegetation was sprayed with amitrol in early fall.

INTRODUCTION

Wood biomass farms were first proposed as a means of rapidly producing fiber for the pulp and paper industry (McAlpine et al., 1966). More recently it has been suggested that wood biomass farms could also be used to produce energy (Szego and Kemp, 1973). The biomass farm concept includes: (1) establishment of rapid-growing trees at close spacings, (2) application of intensive culture technology, (3) harvest on cutting cycles of 10 years or less, (4) regeneration of subsequent crops via sprouts or coppice arising from stumps, and (5) a high degree of mechanization. Recent assessments of this concept suggest little potential for large-scale production of energy or fiber by this means, especially in the next quarter century (Smith, 1978; Tillman, 1978). Principal limitations are: (1) the small amount of land that is both suitable and available, and (2) low values for end products of biomass farming. We recognize the validity of these points and agree with the general conclusions. On the other hand, we suspect that opportunities do exist in the Pacific Northwest for biomass farms to contribute as a supplemental source of energy or fiber. Such opportunities may occur when special circumstances obviate or lessen previously cited limitations.

Treatments

The study was designed to look at effects of pulp and paper mill sludge and irrigation on growth and yield of black cottonwood and red alder. Three levels of sludge (0, 100, and 200 oven-dry tons per acre) and two levels of irrigation (NO and YES) were used. There were two replications of each treatment for each species; assignment of species and treatment to the plots was random.

The sludge was composed primarily (~80%) of short wood fibers which had fallen through paper machine screens and were too small to be economically recovered from the mill's waste water. The other 20% of sludge composition included soil materials brought into the mill with logs and various additives used in making paper. Nitrogen fertilizer was added to the 100- and 200-ton sludge-treated plots in amounts equivalent to 1,300 and 2,600 lbs N per acre.¹ Phosphorous and potassium fertilizers were applied to low sludge plots in amounts equivalent to 100 lbs each of P₂O₅ and K₂O per acre; high sludge plots received the equivalent of 200 lbs each of P₂O₅ and K₂O. Plots without sludge were fertilized with the equivalent of 150, 200, and 200 lbs per acre of N, P₂O₅, and K₂O, respectively. Sludge and fertilizers were incorporated into the soil by rototilling prior to planting in March, 1973. No additional sludge or fertilizer was applied in subsequent years.

This paper describes an experimental biomass planting that illustrates one such set of special circumstances. The experiment was established on lands owned by and adjacent to Crown Zellerbach's pulp and paper mill at Camas, Washington. The mill was faced with problems associated with waste disposal and also was concerned about future fiber supplies. Using the same land to grow short-rotation fiber crops (albeit limited in quantity) and to dispose of mill wastes offered some promise of both environmental and economic benefit. The purpose of the biomass trial was to: (1) gain experience with and estimate yields from coppice plantings of two fast-growing native hardwoods, and (2) test effects of pulp and paper mill sludge and irrigation on growth of these plantings.

The plots receiving the irrigation treatment were watered three to four times per week during the first two growing seasons. Water was applied using overhead sprinklers. None of the plots were irrigated after the first 2 years.

Plot Establishment and Maintenance

Plots were 20 x 20 ft and were separated by 6-ft wide lanes. Trees were planted at 2- x 4-ft spacing; each plot

METHODS

Study Area

The study area was located on Lady Island in the lower Columbia River. Climate is humid with most of the annual

¹Previous work (Aspitarte et al., 1973) showed that this sludge had a carbon:nitrogen ratio (C/N) of more than 200:1 and that crop growth was best when the sludge was amended with sufficient nitrogen fertilizer to attain a C/N ratio of 100:1. Due to recent changes in waste treatment, sludge from most mills now has a much lower C/N ratio and thus can be used without such large fertilizer additions.

contained five rows of nine trees. Alder seedlings and cottonwood cuttings were planted in March, 1973. At time of planting, container-grown alder seedlings were 6 to 10 in tall and about 6 months old. Cottonwood cuttings were 25 in long and planted to a 15 in depth. Alder survival was excellent, but 1st-year mortality was high in some of the sludge-treated cottonwood plots. Therefore, all cottonwood were replanted in February, 1974. Plots were hoed and mowed to reduce weed competition during the first and second growing seasons. Coppice (i.e., sprout) growth was established by cutting all plots back to 6 in stumps after the 1974 growing season (hereafter referred to as the first harvest) and allowing them to sprout. Two-year-old coppice was harvested after the 1976 and 1978 growing seasons (hereafter referred to as the second and third harvests). Figure 1 depicts the development of a typical alder plant over time; except for replanting of cuttings in 1974, cottonwood development followed an identical pattern.

level was used as the cut-off in judging significance of the F statistic.

RESULTS AND DISCUSSION

The main purpose of the cut in 1974 was to establish coppice growth, and not to harvest substantial yields. For both species annual yields averaged less than 1 oven-dry ton per acre (t/acre). Stumps sprouted rapidly and uniformly; the second harvest was a coppice harvest. Yields averaged 4.2 t/acre per year for cottonwood and 2.4 t/acre per year for alder. Stumps again sprouted well. Yields in the third harvest averaged 4.8 t/acre per year for cottonwood and 2.3 t/acre per year for alder.

Tables 1 and 2 show height and diameter of the tallest stem per tree. This information provides an indication of type

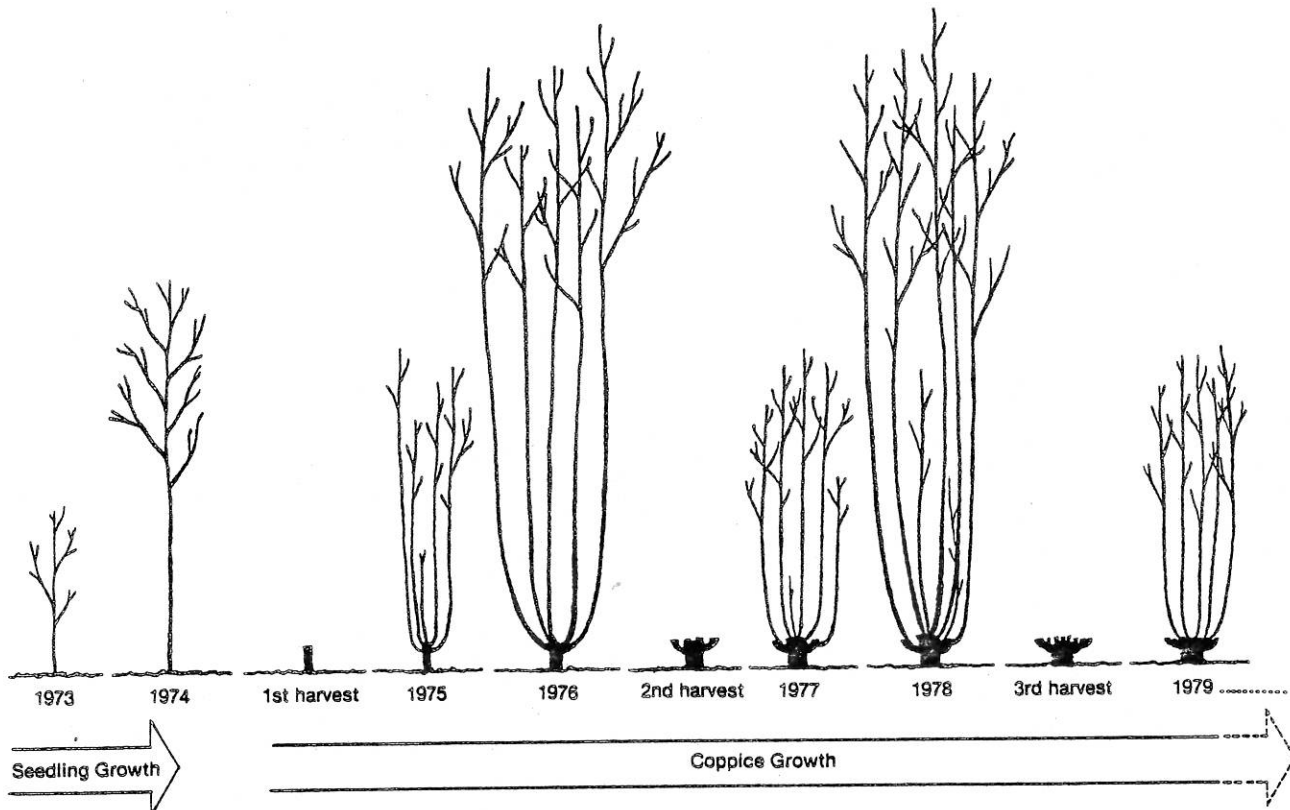


Fig. 1. Development of a typical alder plant.

Growth and Yield Measurements

The 21 interior trees on each plot were measured at each harvest. Height and diameter of the tallest sprout were tallied for each plant. Trees were then cut and fresh yield weights were obtained for each plot. Subsamples were taken to determine the relationship between fresh and oven-dry yields; all harvest yield information is given in units of oven-dry tons per acre. In 1976, samples were also collected and analyzed for bark content, specific gravity, and amount of stem material greater than 1/2 inch in diameter.

Statistical Analyses

Data collected at each harvest—height, diameter, and yield—plus the 1976 data on yield characteristics (e.g., bark content) were analyzed using 2-way analysis of variance. Analyses were performed separately for each species; as appropriate, either the total (e.g., yield) or the average (e.g., height) for a plot was used as data input. The 10%

and size of harvested material. Effects of treatments on height and diameter were similar to effects on yield, and therefore, will not be individually discussed. In the following paragraphs we will first discuss effects of irrigation and sludge treatments on yield. We will then examine differences between the two species.

Treatment Effects

Irrigation applied during the first rotation had surprisingly long-lasting effects on plot yields (Table 3). For cottonwood, average yield on irrigated plots was significantly higher than on non-irrigated plots at both the first (0.9 vs. 0.6 t/acre, respectively) and second (4.8 vs. 3.7 t/acre, respectively) harvests. The difference between irrigated and non-irrigated plots at the third harvest was not statistically significant.

Table 1. HEIGHT AND DIAMETER OF BLACK COTTONWOOD BY HARVEST AND TREATMENT

Irrigation	Sludge (t/acre)	Height ¹ (feet)			Diameter ¹ (inches)		
		Harvest			Harvest		
		1st	2d	3d	1st	2d	3d
NO	0	4.6	10.8	14.2	0.44	1.19	1.23
NO	100	6.0	14.9	15.4	.62	1.48	1.60
NO	200	6.3	15.4	14.0	.64	1.59	1.21
YES	0	6.0	14.5	15.7	.63	1.45	1.34
YES	100	7.0	15.0	13.8	.76	1.69	1.26
YES	200	7.1	16.6	16.4	.74	1.60	1.32

¹Height and corresponding diameter of the tallest stem per plant.

Table 2. HEIGHT AND DIAMETER OF RED ALDER BY HARVEST AND TREATMENT

Irrigation	Sludge (t/acre)	Height ¹ (feet)			Diameter ¹ (inches)		
		Harvest			Harvest		
		1st	2d	3d	1st	2d	3d
NO	0	8.2	12.3	12.5	1.12	1.14	1.07
NO	100	7.0	12.2	11.9	1.02	1.22	1.16
NO	200	5.1	10.4	10.6	.76	1.02	.94
YES	0	9.9	12.0	12.6	1.38	1.10	1.16
YES	100	7.7	12.1	11.2	1.14	1.12	1.02
YES	200	6.2	12.0	10.8	.96	1.22	.96

¹Height and corresponding diameter of the tallest stem per plant.

Table 3. YIELDS OF BLACK COTTONWOOD AND RED ALDER BY HARVEST AND TREATMENT

Irrigation	Sludge (t/acre)	Cottonwood Yields (O.D. t/acre per yr)			Alder Yields (O.D. t/acre per yr)		
		Harvest			Harvest		
		1st	2d	3d	1st	2d	3d
NO	0	0.4	2.6	4.6	0.8	2.5	3.2
NO	100	.6	3.7	4.3	.6	2.4	2.3
NO	200	.7	4.8	4.3	.2	1.9	1.9
YES	0	.6	3.8	5.8	1.4	2.9	2.8
YES	100	.9	4.4	4.7	.8	2.3	1.7
YES	200	1.1	6.2	5.4	.4	2.8	2.1

Effects of initial irrigation on growth of alder were of shorter duration. Irrigated plot yields (0.8 t/acre) were significantly higher than alder yields from non-irrigated plots (0.5 t/acre) at the first harvest). Differences associated with the early irrigation treatment, however, were not significant in the second and third harvests of alder.

Sludge treatments (mill sludge plus fertilizer) had very different effects on the two species. As mentioned above, cottonwood mortality was very high on some of the sludge plots. Some trees were replaced three or four times during the first growing season. All cottonwood was replanted the second year and no mortality occurred. Apparently whatever caused sludge treatments to be toxic to cottonwood cuttings was no longer present after a year of weathering. On the other hand, early survival on alder plots was excellent and was not affected by the sludge treatments.

Once cottonwood was established, the sludge treatments were very effective in increasing yields. Cottonwood yields were significantly higher on sludge plots than on non-sludge plots at the first two harvests (0.8 vs. 0.5 t/acre and 4.8 vs. 3.2 t/acre). Yields of cottonwood on the non-sludge and sludge-treated plots at the third harvest, however, did not differ significantly.

The sludge treatments significantly depressed growth and yield on the alder plots. Yields from sludge-treated plots were 0.5, 2.3, and 2.0 t/acre in the first, second, and third harvests, respectively; yields from plots without sludge additions were 1.1, 2.7, and 3.0 t/acre for these same harvests.

We do not know if the sludge effects seen on both cottonwood and alder plots were caused by the mill sludge itself, the fertilizer applied as part of the sludge treatment, or the combination of sludge and fertilizer. Since alder is a nitrogen-fixing plant, it is possible that its nodule development was reduced by high nutrient or chemical concentrations. Poor nodule development (whatever the cause) would help explain the long-term poor performance on alder plots with sludge additions.

Species Effects

Mortality rates, both initial and long term, differed by species. As mentioned above, cottonwood cuttings planted in 1973 had a very high mortality rate and were all replaced with new cuttings in 1974. After replanting, cottonwood survival was high. No trees were dead at the time of the first or second harvests. At the third harvest, 6% of the cottonwood plants were dead. Initial survival of alder was excellent; however, mortality since then has increased rapidly. At the first harvest, one tree was reported dead. By the second harvest, 8% of the alder plants were dead; by the third harvest, 24% were dead. Perhaps a longer cutting cycle is necessary for repeated coppicing of alder.

Characteristics of the harvested material, in addition to total yield, are also important in evaluating problems and opportunities associated with conversion of biomass to energy, fiber products, or combinations thereof. Moisture content directly influences weight and, thus, ease of handling of the harvested material; more importantly, moisture content affects the amount of net energy gained in conversion processes. Specific gravity is another important factor; it is the single most useful indicator of potential pulp or energy yields of a given volume of biomass--the higher the specific gravity, the higher the potential yield. Bark content and percent of material greater than 1/2 inch are of particular importance in fiber industries. Most pulp products have a low tolerance level for bark; materials with high bark content must be mixed with materials of low bark content to attain specified bark levels, or additional energy must be expended to remove bark during processing. Conventional chippers at many mills can effectively chip material down to 1/2 inch; material smaller than that size would probably be burned.

The analyses performed on moisture content, bark content, specific gravity, and percent of material >1/2 in, showed no consistent treatment effects. The average values of these characteristics are given in Table 4 for each species. Cottonwood, in addition to producing higher annual yields than alder, has a larger percent of total yield in material that could be chipped (i.e., stems >1/2 in). The material from the cottonwood plots was, however, higher in both moisture content and bark content than material from alder plots. The specific gravity values for the two species were quite similar. High harvest yields were associated with low specific gravity for cottonwood; there was apparently no relationship between harvest yields and specific gravity for alder.

Table 4. CHARACTERISTICS OF 1976 YIELDS BY SPECIES

Characteristic ¹	Species	
	Cottonwood	Alder
Moisture content (percent)	110	101
Bark content (percent)	21	16
Stems >1/2 in (percent)	61	46
Specific gravity	.39	.38

¹All values are expressed in terms of oven-dry weight of wood plus bark; volumes for specific gravity determined using green samples.

IMPLICATIONS

Yields in this study were similar to those previously reported for black cottonwood (Heilman et al., 1972) and other species planted at similar spacings (Belanger and Saucier, 1975; Dawson et al., 1976). Even with irrigation and sludge-fertilizer amendments, the highest annual yield obtained was 6.2 tons per acre. Although annual yields might be somewhat higher using different management practices, future expectations of annual yields of 10 tons or more per acre (Fege et al., 1979) may be overly optimistic.

Black cottonwood yields in this study were substantially higher than those of red alder. We do not think, however, that the differential yields obtained from one trial, limited to one location, should lead to the general supposition that cottonwood is the more promising candidate for biomass farming. In another study² on an upland site, alder was twice as tall as cottonwood 4 years after planting. Thus, the relative performance of the two species may be quite site specific. The sludge treatments used in the present experiment had opposite effects on growth of the two species; in addition, the 2-year cutting cycle may have reduced the vigor of alder root stocks more than those of cottonwood. Moreover, the data indicated that control plots of the two species were more comparable in yield than plots of any given treatment, especially in the second harvest. Finally, the potential advantages associated with the nitrogen-fixing capacity of red alder were not effectively assessed in this study. This capability is important in fuel plantations; eliminating the need for nitrogen fertilizer application substantially reduces the energy inputs needed and increases the net energy gained.

²Unpublished data of authors on file at Forestry Sciences Laboratory, Olympia, Washington.

CLOSING THOUGHTS

Limited availability of suitable land is an important obstacle to biomass farming. There are lands, however, which are set aside for necessary but low value uses that may be compatible with biomass farming. Examples include: (1) lands used for disposal of wastes, (2) powerline rights-of-way, (3) buffer or protective zones surrounding military bases or nuclear plants, and (4) areas in need of rehabilitation (e.g., mining spoils).

Many reviewers of the biomass farming concept recognize the economic advantages of integrated utilization (Tillman, 1978) or "adaptive systems" as Lipinsky (1978) has termed those systems in which each portion of a harvested crop is used for the highest value product. Such operations are not new to the northwestern forest products industry; residuals from sawmills and plywood plants have been the primary raw materials for pulp mills for decades. Integration provides not only optimum use of resources and products, but lower value products are, in essence, partially subsidized by the production of those having higher value; that is, most of the necessary costs of management and harvesting operations are charged primarily against the principal products. Incremental costs of obtaining the low value products in integrated operations are therefore usually much less than the unit costs when resources are devoted to producing a crop used solely for low value products. This relationship between incremental and average or unit costs is paralleled by the relationship between incremental and average energy inputs needed for wood production and utilization. Thus, net energy gained as well as the profitability of the operation are likely to be more favorable in integrated operations.

Unlike many other energy alternatives, biomass farming offers a renewable source of raw material. The total land area that can be devoted exclusively to biomass production is limited, and therefore the amount of energy that can be produced is not great when compared with national needs. Nevertheless, biomass farming is an option deserving consideration when small-scale operations can meet or effectively supplement energy needs in a given locale.

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