Opportunities for short rotation culture and complete utilization of seven northwestern tree species

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L'auteur fournit les données sur la croissance, le rendement et la répartition de la composition des jeunes peuplements de sept espèces ligneuses d'importance. On y discute également des aspects économiques et de ceux de l'aménagement qui s'avèrent essentiels à l'évaluation adéquate d'une courte révolution et d'une utilisation totale de l'arbre.

Two innovative concepts — short-rotation culture and complete tree utilization — have appeared on the North American forestry scene during the past decade. The possibility of growing increased amounts of wood fibre by intensive culture of sycamore on rotations of 2 to 5 years was suggested by McAlpine *et al.* in 1966. The concept is now being tested at several locations in the Southeastern United States (Steinbeck *et al.* 1972). Potential advantages of short rotation forestry in the Northeastern United States have been illustrated by Schreiner (1970). Our interest has centred on the fast-growing hardwood species — red alder and black cottonwood — of the Northwestern United States and Canada as compared with hybrid poplars, aspen, and fast-growing conifers.

The concepts of total tree and complete stand utilization have been advanced enthusiastically by Young (1964, 1968). More recently, Young (1972) has combined the possibilities of complete stand utilization and short rotation culture in his concept of woody fibre farming. Much of the literature on complete tree utilization has been summarized in five comprehensive reports by Keays (1971), who also directs a substantial program of evaluation of pulp- and paper-making properties of various tree components.

The purpose of our paper is to summarize available data which are pertinent to these new concepts for major tree species in the Pacific Northwest. Also, we will discuss some of the management and economic aspects of short rotation culture and complete tree utilization.

Yield data for juvenile stands of seven species

To evaluate applicability of the new concepts, it is necessary to know the yield relationships of juvenile stands of various species and also the composition in terms of percentage of stem, branches, and leaves. Some yield data are available for black cottonwood (Heilman *et al.* in press, Smith and Blom 1970), red alder (Warrack 1949 and 1964, DeBell 1972, Smith 1972, Zavitkovski and Stevens 1972), western hemlock (Osborn 1968), lodgepole pine (Lee 1967), and aspen (Bella 1970). Additional data have been obtained in unpublished spacing studies of Douglas-fir, western hemlock and western red cedar on the UBC Research Forest. Many biomass studies also are in progress throughout the continent (e.g. see Young 1971).

It is often difficult to compare and interpret the results of various biomass, spacing, and conventional yield studies in terms of forest practice. Therefore, Table 1 contains factors which facilitate conversions between volume and weight for seven northwestern tree species. Total cubic foot volume can be estimated from diameter and height (Smith and Breadon 1964) or from basal area per tree or per acre and height (Smith 1967). The calculated volume can be multiplied by the number of pounds (oven-dry) per cubic foot (green volume) to determine weights of wood and bark (Smith 1968, Smith and Kozak 1971). In Table 2, we have attempted to harmonize data of several studies in a summary of the distribution of weight among above-ground components for the same species. These values should be considered only as indicators of approximate composition and should be refined by intensive studies.

Estimates of the size of trees of average basal area which were growing rapidly on good sites are given in Table 3. Most data were collected in

TABLE 1. Factors for estimating tree volume and weight

	Total cubic foot volumes from			Volume (green): weight (oven-dry) relationships		
	$V = a + bD^2H$	b	$V = b'HBA$	Bark (lb/ft ³)	Wood (lb/ft ³)	Bark plus wood*
Douglas-fir	0.18	0.220	0.33	30.8	28.1	38.0
Western redcedar	0.31	0.234	0.34	24.3	19.5	22.9
Western hemlock	0.02	0.243	0.39	30.6	25.5	31.0
Lodgepole pine	0.07	0.251	0.44	28.1	25.0	28.1
Black cottonwood	0.05	0.209	0.36	36.6	18.4	26.5
Red alder	0.02	0.246	0.45	39.9	23.3	28.9
Aspen	0.05	0.228	0.42	31.0	23.0	27.8

*These values indicate the weight of bark plus wood associated with one cubic foot of wood as shown in published yield tables.

studies on the UBC campus, UBC Research Forest, and in the Lower Fraser River Valley, but values for lodgepole pine and aspen were determined in stands of the Interior. The values for height, dbh, and basal area represent averages for fully-stocked, but well-spaced trees. Coniferous species occupy at least 3 x 3 ft whereas minimal spacing for hardwoods is 6 x 6 ft. By comparing relative tree sizes at ages 5, 10, and 15 one can see that hardwoods — especially red alder and black cottonwood — are much superior to conifers in growth rate at young ages. Faster growth rate and the ability of hardwoods to sprout or coppice makes them more attractive than conifers for short rotation culture. Until complete stand utilization concepts became of interest, few researchers thought that trees less than 6 inches dbh would ever have value in the Pacific Northwest; therefore, little work was done at closer spacings. The limited data available are presented in the next section.

Silvicultural considerations

The effects of spacing are extremely important in any consideration of short-rotation culture. Planting should be much closer than is done in conventional forestry so that the stand will attain full growth capacity or leaf area index at an earlier date. Unfortunately, data regarding effects of spacing on yield and mortality for various rotation lengths are limited at this time. Some information, however, is available for black cottonwood (Heilman *et al.* in press), and selected conifers planted at a 1 x 1 ft spacing (Smith *et al.* 1968, Behm 1970). Yield data for unfertilized plots are presented in Table 4 along with average data on growth response to fertilizer applications. For details on types and amounts of fertilizers, the reader should refer to papers cited.

Mortality has been considerable for all species planted at the 1 x 1 ft spacing. In the black cottonwood plots, 78% survived to the first harvest at age 2; however, only 47% remained to the second harvest at age 4. For Douglas-fir, only 58% of the trees survived to age 12. Obviously, yields could be greatly increased by reducing mortality through control of stand density or growing space. Other

problems associated with excessive crowding include irregular mortality, loss of capacity to respond to release, and the high cost of planting unnecessary trees which may even have detrimental effects on stand yield.

Although difficult to achieve, biological returns from extremely dense stands can be very high. Among 28 small plots in dense, natural thickets of red alder, DeBell (1972) found one plot which had mean annual increments of 11 oven-dry tons or 560 ft³ of stem wood per acre at age 11. Using the upper limits of stand density reported for red alder by Zavitskovski and Stevens (1972), Smith (1972) estimated that maximum yields could be obtained with an 8-year rotation on good sites (120 ft at age 50). Based on graphical analysis of tree and stand data, Smith also suggested that nearly 100 ft² of basal area, 1700 ft³, or 25 tons of oven-dry stem wood could be produced per acre in very dense stands. On such good sites, however, even the average mean annual increments are impressive — 12.5 ft² of basal area and 226 ft³ of stem wood.

The possibility that complete tree utilization will lead to site deterioration has been suggested because additional amounts of organic matter and mineral nutrients will be removed during harvest. Depleted inorganic nutrients can, of course, be replenished by fertilizer applications. Replacement of organic matter is a more difficult proposition. Work by Crown Zellerbach's Environmental Sciences Division, however, has shown that application of pulp mill sludge to agricultural soils can improve yield of certain vegetable crops (Amberg, personal communication¹). Rather than burning such material and adding to the air pollution load, it is estimated that such material could be hauled to lands within a short distance of existing mills. Because most companies view short rotation culture only as an additional source of wood to be grown on lands near their mills, sludge and other by-products (e.g.,

¹Unpublished data from cooperative research project involving Fed. Water Qual. Admin. (now Environmental Protection Agency) and Crown Zellerbach. Project title: A demonstration plant evaluation of four methods of pulp and paper mill sludge utilization and disposal.

TABLE 2. Distribution of above-ground weight by size class and species

Species	Size class ^a	Stem wood	Tree components		
			Stem bark (Percent composition)	Branches	Foliage
Douglas-fir.....	Small	53	21	16	10
	Average	71	13	11	5
Western redcedar.....	Small	57	19	14	10
	Average	73	10	11	6
Western hemlock.....	Small	55	18	14	9
	Average	77	11	7	5
Lodgepole pine.....	Small	—	—	—	—
	Average	61	10	16	9
Black cottonwood ^b	Small	55	18	27	N.A.
	Average	—	—	—	—
Red alder.....	Small	56	13	17	14
	Average	66	10	16	8
Aspen.....	Small	58	15	13	14
	Average	—	—	—	—

^aDbh classes vary by species, but generally small trees are in the 2- to 6-inch dbh class whereas average trees range from 12 to 16 inches in diameter.

^bFoliage was not included for black cottonwood because data was collected during the dormant season; percentages are based on stem and branch weights only.

TABLE 3. Average tree size at 5, 10 and 15 years for several species grown rapidly on good sites

Age	Variable and units	Douglas-fir	Western redcedar	Western hemlock	Lodgepole pine	Black cottonwood	Red alder	Aspen
5	Height (ft.)	5	7	6	3	25	29	15
	Dbh (in.)	0.1	0.2	0.1	0	3.5	2.7	0.8
	Basal area (ft ²)	0	0	0	0	0.067	0.040	0.003
10	Height (ft.)	15	13	12	9	50	47	23
	Dbh (in.)	3.0	1.3	1.8	0.7	7.0	6.3	1.2
	Basal area (ft ²)	0.049	0.009	0.018	0.003	0.267	0.216	0.008
15	Height (ft.)	31	28	29	15	75	63	30
	Dbh (in.)	4.4	3.4	4.2	2.0	10.5	8.2	1.7
	Basal area (ft ²)	0.106	0.063	0.096	0.022	0.601	0.367	0.016

bark or treated effluent) might also be used to ameliorate soil conditions on such fibre-growing lands.

Some management and economic considerations

Both concepts — short rotation culture and complete tree utilization — offer a means of increasing present supplies of wood fibre. In actual practice, use of the short rotation concept must be closely associated with and, in fact, is dependent upon improved utilization. Opportunities exist for the complete tree concept through increased utilization within the framework of present silvicultural and harvesting operations — for example, tops, branches, stumps, and roots of large trees as well as smaller trees cut in pre-commercial thinnings could be chipped and hauled from the site. As is the case with most new developments, proponents of these concepts tend to be very optimistic regarding advantages as well as successful solution of some of the problems. Many foresters, on the other hand, view such radical concepts with much skepticism. Therefore, we will discuss some of the factors that we think are essential for proper evaluation of these concepts.

Advocates of short rotation culture emphasize increased yields per acre, shorter investment periods, and savings due to mechanization. The doubters cite high costs and suggest economic infeasibility of such management. One of the primary reasons for disagreement is lack of silvicultural knowledge regarding interactions of spacing, rotation length, and yield. Moreover, the extremely high costs of establishing dense plantations by conventional methods would surely be prohibitive. There are several alternative methods for plantation establishment (i.e., seeding, short ("potato bud") cuttings, horizontal placement of long cuttings, etc.), but the success of such methods and their costs have yet to be determined. It is also assumed that other costs of growing and harvesting cellulose fibre will be reduced, but such methods remain to be developed and evaluated.

If stands are to be regenerated by coppicing, another problem exists for short rotation culture. In most hardwood species, the growth and vigor of subsequent sprouts are considerably reduced when tops are cut in the growing season. For best sprouting, stands may not be amenable to harvesting

throughout the year and either additional chip sources or storage methods will be needed.

Complete tree utilization is generally deemed desirable, but it too has cost problems. The harvesting and processing of smaller pieces are much more costly per unit weight than is the "merchantable bole." However, landowners having other interests (e.g. fire control, aesthetics, ease of future cultural operations) can do much to allay costs and encourage more complete utilization. The U.S. Forest Service in the Pacific Northwest has, for example, a number of methods to absorb costs of falling, bucking, and yarding of non-merchantable wood. In some cases, where removal of such material from the site is required, allowances for loading and hauling costs also are considered in the timber sale appraisal. Still, most suggested schemes for utilization rely upon chipping in the woods and blowing chips into trucks for hauling to mills. Unfortunately, the volume-weight ratio of chips is much greater than for logs and trucking costs sky-rocket for harvesting sites located at considerable distances from mills. Where possible, barge or rail transport of chips would substantially lower costs. A pneumatic pipeline also may be, as some have suggested, a solution to the problem; chips could be piped to distant mills from various points in the forest.

Complete tree utilization will also require additional fibre preparation — chip debarking, pulp cleaning, and possibly more bleaching — to make finished products. Technology is currently available to take care of these matters, but additional costs will be incurred.

To sum up, both concepts offer possibilities for increasing present supplies of wood fibre. A number of advantages and disadvantages are associated with each, but costs of additional wood will undoubtedly be higher than that currently being used. As demand for fibre-based products increases, industrial processors may have to look to these innovative methods for additional wood as well as to more conventional alternatives (e.g. the harvesting of trees in areas which are more remote and less accessible, and increasing growth and subsequent harvest of currently managed stands by intensive cultural practices).

The economic criterion for selection of one or a combination of the above alternatives must be the

TABLE 4. Effect of spacing and fertilization on dry weight yields of black cottonwood, Douglas-fir, western hemlock, and western redcedar

	Rotation length (years)	Spacing (ft)			Addition increment due to Fertilization (percent)
		1 x 1 (o.d. tons/acre/year)	2 x 2	4 x 4	
Black cottonwood (initial).....	2	3.0	2.1	1.0	33
Black cottonwood (coppice).....	2	4.1	5.2	3.6	—
Douglas-fir.....	7	3.3	—	—	27
Douglas-fir.....	12	3.5	—	—	—
Western hemlock.....	7	2.1	—	—	67
Western redcedar.....	7	0.9	—	—	—

total cost involved in growth, harvest, transportation, and processing. Factors other than economic ones will influence choices to some degree. More complete utilization may be encouraged by certain landowner objectives, especially on public land where aesthetics and recreation visits during fire season are prime considerations. Although costs and returns of short rotation culture are subject to much speculation, Dutrow's (1971) economic analysis indicated that some wood processors will find the growing of silage sycamore rather profitable. Non-industrial owners, however, face bleak prospects due to present lack of an established market for silage cellulose and high costs of establishing plantations. In a recent article in *The Forestry Chronicle*, Zivnuska (1972) predicted that solid wood products will decline whereas durable and non-durable fibre-based products will dominate markets during the next fifty years. Short rotation, highly intensive management on better sites is suggested as the key to meeting future demands. In addition, Zivnuska foresaw the need for sawlogs and veneer logs being met by growth and harvest of large trees on land where timber production will be a secondary objective. Although no unanimity of opinion exists today, it is clear that forest managers and forest product industries will face some interesting choices in the years ahead.

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