GROWTH AND YIELD OF *POPULUS* COPPICE STANDS GROWN UNDER INTENSIVE CULTURE[1/]

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Abstract.--Growth and survival data on the first three years of development of coppiced stands representing seven clones are described. The data were collected from small multispaced plots at the Rhinelander, Wisconsin, nursery. Sprout growth and mortality equations developed from this data were then integrated with growth and mortality equations developed for older trees of cutting origin to form a simulation model of coppice stand development. Model output suggests potential yields of 5-15 metric tons per hectare per year can be achieved at ages 5-15 years from a variety of spacing and clone combinations under intensive culture. However, there was evidence of considerable variability in results within clones.

Coppicing is a potentially attractive option for short rotation intensive culture (SRIC) of *Populus*. This study was an attempt to estimate that potential for seven clones. The primary objective was to quantify the relationship of coppice stand development to parent stand (before coppice) spacing.

Little information on coppicing was available for the clones considered in this study. Ek and Brodie (1975) presented results for natural aspen stands, primarily *Populus tremuloides* stands. They found site quality, parent and residual stand basal area, season of cutting and cutting treatment had important effects on aspen sucker density. DeBell and Alford (1972) found that stump height and angle of cut had no significant effect on the vigor, size, or number of sprouts produced by *Populus deltoides*. Season of cutting, however, had a significant effect on the number and sizes of sprouts. Stumps cut from September to March produced significantly more sprouts than those cut during the growing season. These authors also noted that stump age may affect vigor and mortality of the sprouts produced. Younger stumps tend to produce sprouts from dormant buds, while sprouts from advantitious buds were prevalent on older stumps. Sprouts from advantitious buds tended to be smaller and more susceptible to wind damage than those produced from dormant buds. Beck (1977) found similar results for *Liriodendron tulipifera* stump sprouts. He also pointed out that thinning sprouts to the expected number of crop trees was probably unnecessary because of the competition-induced mortality in such circumstances. In repeated harvesting of *Populus tricocarpa* cuttings planted in the Pacific Northwest, DeBell (1975) noted that spacing had a significant effect on yields for the first harvest, but subsequent coppice stands showed little difference in yields across initial plantings and spacings.

Factors found critical by these authors, when included in models for initial sprout frequency, growth and mortality, offer the opportunity for improved screening of superior clones. The specific

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objectives of this study were to analyze available *Populus* coppice stand growth data from the Rhinelander, Wisconsin, Nursery and: (1) compare clones on the basis of sprouting ability, stand yield, and the relationship of these to parent stand spacings; (2) develop expressions for coppice stand growth and yield components; and (3) develop a computer model integrating this information on coppice stand development with existing information on the development of older stands grown from cuttings.

METHODS

Data

The data for this study were collected from a study of various clones established at the Rhinelander nursery in 1973. Small multispaced plots were established from cuttings and then harvested at age 4 in December 1977. Each clone was represented by only one plot due to logistical considerations at the time. Sample stump locations were subsequently examined in April 1979, October 1979, and November 1980 to establish sprout height, dbh and frequency records. Observations were taken on all sprouts greater than 0.5 m tall and only sprouts within one meter of the parent stump were included. Nearly all sprouts were within 0.5 m of the parent stump. Sprout height and Dbh were observed to the nearest 0.1 m and mm, respectively. The number of stumps examined by spacing and approximate areas per tree were:

Spacing (m)	Stumps Observed	Area per tree (m^2)
.3048	3	.0929
.6096	3	.3716
1.2192	4	1.4864
.3048 x .6096	3	.1858
.3048 x 1.2192	4	.3716
.6096 x 1.2192	4	.7432

An additional one to four parent stand trees left uncoppiced in the northeast corner of the plot were also observed for height and dbh growth. These trees were dominant or codominant stems retained to suggest height-Dbh-age relationships for larger trees as a guide to model development. The parent stand plot and sample stump locations are noted in Figure 1. The clones studied are described in Table 1. Note that clones 5258 and 5266 died during the growing season following harvesting and are not considered further here. Also, 5260 *Populus Tristis* #1, is included in Table 1 for reference, but it was not among the clones coppiced for this study.

These plots were the same ones described by Meldahl (1979) and they continued to receive intensive culture fertilization and irrigation treatments (see Meldahl, 1979) following the 1977 coppicing.

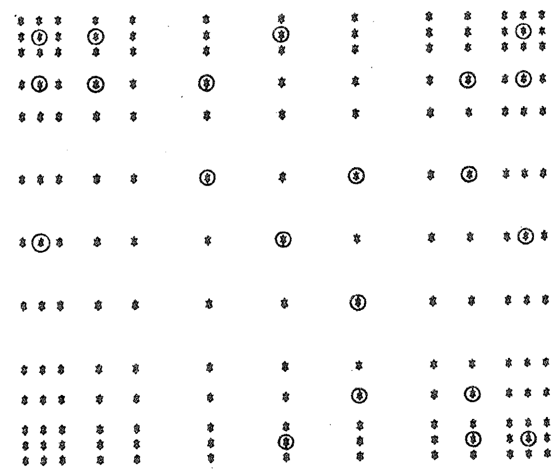

Figure 1.--Multispaced plot design. The narrowest spacing (at each corner) is .3048 m. The widest spacing is 1.2192 m (in the plot center). Parent tree stump locations sampled for sprout data are circled.

Data Analysis and Model Development

Sprout Component

Preliminary analysis of the coppice plot data suggested considerable variability in mortality between clones and years. Average mortality rates across spacings by clone are given in Table 2. The mortality rate of stumps and sprouts was similar and usually the highest for the narrowest spacings, but exceptions to this were frequent. Also, third year mortality (age 2-3) was frequently higher than that for the second year. Results were also confounded by a few small stems growing above the countable height (0.5 m) during the second and third years. Because of this lack of consistency in the pattern of mortality, no simple model fit the data well. Consequently, the mean rates in Table 2 were used for growth model development and projections for all spacings.

As a guide to management, it was noted that the number of sprouts per stump after coppicing was strongly related to the parent stand spacing. Table 3 indicates the number of live sprouts per stump at the end of the growing season following coppicing by clone area per tree.

Table 1.--*Populus* clones studied.

Percentage	Source number	Received from	Supplier's number(s)
Populus spp.	5258	Indian Head, Sask.1/	---
Populus tristis Fisch. x *P. balsamifera* L. cv. Tristis #1	5260	Indian Head, Sask.1/	---
Populus cv. Candicans x *P.* cv. Berolinensis	5262	Upper Darby, Pa.2/	NE-387
Populus cv. Candicans x *P.* cv. Berolinensis	5263	Upper Darby, Pa.2/	NE-386
Populus cv. Angulata x *P. tricho-* Torr. & Gray	5266	Upper Darby, Pa.2/	NE-372
Populus nigra L. x *P. laurifolia*	5272	Upper Darby, Pa.2/	NE-1
Populus x *euramericana* (Dode) Guinier cv. eugenii	5326	Maple. Ontario3/	DN-34
Populus cv. Betulifolia x *P. trichocarpa* Torr. & Gray	5331	Upper Darby, Pa.2/	NE-299
Populus cv. Betulifolia x *P. trichocarpa* Torr. & Gray	5332	Upper Darby, Pa.2/	NE-298
Populus x *euramericana* (Dode)	5377	Ames, Iowa4/	---

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Table 2. Average sprout mortality rates by clone for coppiced stands.

Clone	Sprout Mortality Rate: Age 1-2 years	Sprout Mortality Rate: Age 2-3 years
	- percent -	
5262	71	63
5263	77	54
5272	63	62
5326	50	64
5331	57	67
5332	17	53
5377	44	56

Table 3. Number of live sprouts per stump at age 1 year following coppicing by clone and parent stand area per stump.

Clone	Parent Stand Area per Stump - m^2				
	.0929	.1858	.6096	.7432	1.4864
5262	4.0	10.5	13.7	20.3	29.0
5263	6.3	5.0	11.3	26.0	27.0
5272	18.0	19.0	17.7	27.2	16.7
5326	1.0	6.8	5.1	6.3	11.8
5331	2.7	11.0	12.3	16.5	25.5
5332	0.7	8.0	11.7	6.2	13.5
5377	2.0	4.8	5.6	5.5	8.8

As a guide to management, it was noted that the number of sprouts per stump after coppicing was strongly related to the parent stand spacing. Table 3 indicates the number of live sprouts per stump at the end of the growing season following coppicing by clone and area per tree.

The average height and dbh of sprouts over all clones was only weakly correlated (positively) with area per stump at the end of the first year, but the correlation increased greatly the second and third years. The correlation of the maximum observed height and diameters with area per stump was consistently higher than that for mean values. Average heights, and Dbh of sprouts observed the first three years are shown with stems per hectare and biomass values in Table 4. Biomass values were developed from equations given by Ek (1980) for *Populus Tristis* #1 and adjusted for the average specific gravity of stem and branch components of each clone.3/

Note that the per acre values given in the table assume tree growth was representative of the nominal spacing. In fact, the small plot size and especially the close proximity of the narrowest spacings to the plot edge suggest the yields are

3/ Average specific gravity values were drawn from personal communication of a draft manuscript by J. E. Phelps, J. G. Isebrands and D. Jowett.

Table 4.--Three year development of coppiced *Populus* clones under intensive culture at selected spacings.

Clone-age (square spacing (m))	Height (m)	Dbh (cm)	Number of trees (thousand per ha)	Stem and branch wood dry weight (t per ha)
5262 - age 1				
(.3)	1.3	.46	431	5.6
(.6)	1.1	.36	260	2.1
(1.2)	1.3	.42	195	2.0
- age 2				
(.3)	3.1	1.46	72	13.0
(.6)	3.3	1.10	9	.7
(1.2)	2.9	1.50	62	12.9
-age 3				
(.3)	6.3	3.50	36	49.9
(.6)	dead			
(1.2)	5.8	3.29	17	21.1
5263 - age 1				
(.3)	1.4	.34	682	4.2
(.6)	1.3	.45	278	3.4
(1.2)	1.5	.55	182	3.3
- age 2				
(.3)	3.0	1.50	72	12.5
(.6)	4.0	2.10	9	3.5
(1.2)	3.2	1.61	62	14.5
- age 3				
(.3)	3.8	1.90	72	21.8
(.6)	5.6	2.80	9	7.0
(1.2)	5.6	3.46	20	29.2
5272 - age 1				
(.3)	1.3	.42	1,938	20.3
(.6)	1.3	.41	413	4.0
(1.2)	1.5	.45	109	1.3
- age 2				
(.3)	2.8	1.18	466	58.6
(.6)	2.9	1.23	170	22.2
(1.2)	2.6	1.27	740	11.3
- age 3				
(.3)	3.8	2.35	251	181.5
(.6)	4.8	2.56	72	54.3
(1.2)	5.5	2.74	20	17.4
5326 - age 1				
(.3)	1.4	.29	108	.4
(.6)	1.1	.50	81	1.3
(1.2)	1.1	.32	79	.4
- age 2				
(.3)	1.7	.50	36	.4
(.6)	3.3	1.84	36	11.6
(1.2)	2.2	1.25	49	7.0
- age 3				
(.3)	dead			
(.6)	5.5	3.22	27	32.4
(1.2)	5.2	2.93	18	18.2

Table 4.-- continued

Clone-age (square spacing (m))	Height (m)	Dbh (cm)	Number of trees (thousand per ha)	Stem and branch wood dry weight (t per ha)
5331 - age 1				
(.3)	1.6	.47	287	3.7
(.6)	1.6	.54	179	3.5
(1.2)	1.6	.62	172	4.6
- age 2				
(.3)	2.2	.65	73	1.8
(.6)	3.5	1.50	27	5.2
(1.2)	2.7	1.46	103	22.4
- age 3				
(.3)	2.6	.70	36	1.1
(.6)	4.5	2.10	18	8.0
(1.2)	5.7	3.26	30	40.9
5332 - age 1				
(.3)	1.6	.35	72	.4
(.6)	1.6	.60	278	6.2
(1.2)	1.6	.56	91	1.7
- age 2				
(.3)	1.9	.58	72	1.4
(.6)	2.5	1.18	224	26.7
(1.2)	2.5	1.30	86	13.6
- age 3				
(.3)	2.6	.80	36	1.3
(.6)	4.6	2.42	81	49.2
(1.2)	4.4	2.52	35	25.2
5377 - age 1				
(.3)	1.0	.43	215	2.2
(.6)	1.1	.50	108	1.7
(1.2)	1.3	.55	59	1.1
- age 2				
(.3)	dead			
(.6)	4.0	3.40	9	12.4
(1.2)	2.8	1.45	44	8.0
- age 3				
(.3)	dead			
(.6)	6.0	4.20	9	19.1
(1.2)	5.0	3.15	20	22.5

overestimates of what might be attained for large regularly spaced stands (see for example Zavitkovsky, 1981).

The results shown in Table 4 indicates clone 5272 was the most productive at all three ages. Clones 5262, 5331 and 5332 were next best and produced yields similar to each other at all three ages. Unfortunately, the small plot and stump sample sizes and associated variable mortality obscurred the relationship of yields to spacing. Table 5 suggests that parent stand densities of 25,000-50,000 stems per ha were most productive to coppice age 3. Conversely, Table 5 may simply indicate those stumps where survival and growth was high--perhaps due to mortality of nearby stumps. It was thus apparent that meaningful interpretations would require analysis of all of the data. This was done by consideration of models described below.

Table 5. Maximum stem and branch wood yields by clone and spacing for ages 1, 2 and 3 years following coppicing.

Clone	Age 1 - (spacing)	Age 2 - (spacing)	Age 3 - (spacing)
5262	8.7 (.3x.6)	33.5 (.3x1.2)	69.6 (.3x1.2)
5263	8.2 (.3x1.2)	33.4 (.3x1.2)	122.1 (.3x1.2)
5272	20.3 (.3x.3)	58.6 (.3x.3)	181.5 (.3x.3)
5326	2.9 (.3x.6)	11.6 (.6x.6)	32.4 (.6x.6)
5331	12.0 (.3x.6)	40.6 (.3x.6)	94.2 (.3x.6)
5332	7.5 (.3x.6)	41.1 (.3x.6)	92.4 (.3x.6)
5377	4.2 (.3x.6)	19.0 (.3x1.2)	52.2 (.3x1.2)

Given the above data on the coppice plots, the following models were fitted to describe mean sprout height and diameter growth

$$H_s = b_1 (1 - e^{-b_2 A_c})^{b_3} T^{b_4}$$

maximum SE = .76
minimum R^2 = .80

and

$$D_s = b_0 + b_1 H^{b_2} A_c^{b_3} T^{b_4}$$

maximum SE = .23
minimum R^2 = .96

where H_s is mean total height of sprouts (m), A_c is coppice stand age (years), T is stems per hectare in the parent stand, D_s is quadratic mean Dbh of sprouts over 1.37 m tall, and the b_is are constants that differ for each equation. The maximum standard error (SE) and minimum R^2 values across the seven clones from model fitting are also given. Note that although the H_s and D_s observations used for these fits were actually mean values, in later simulation, these models were applied to individual sprouts. Also, the close relationship of sprout height to D_s for the first three years after coppicing precluded the need for an explicit diameter growth equation. The coefficients for these and other models noted below are given by Lenarz and Ek (1983, Appendix 3). Subsequently, these data and equations are refered to as those for <u>sprout</u> growth.

Tree Component

The next step in model development was to synthesize, in equation form, the growth projections to age 20 made for the same *Populus* clones by Meldahl (1979). Meldahl's projections were based upon calibration of the FOREST distance dependent individual tree based stand growth simulation model for trees of cutting origin planted at regular spacings (see Ek and Monserud, 1975, for a general description of the FOREST model). It was felt that the general relationships of growth to density and age in these projections would provide a first approximation of post age three relationships for the development of sprouts from coppiced stands. The projection data used was drawn from Meldahl's tables of 20 year plot interior projections results for each clone for various spacings. Specific tables used were his Appendix 3 Tables 32-39, 45-52, 58-65, 71-78 and for clone 5260, Tables 28, 41, 54 and 67. The following models were then used to describe table values.

$$\Delta H = b_1 (H^{b_2} - b_3 H) A^{b_4} N^{b_5}$$

maximum SE = .17
minimum R^2 = .91

$$\Delta D = b_1 (D^{b_2} - b_3 D) A^{b_4} N^{b_5}$$

maximum SE = .26
minimum R^2 = .95

$$\frac{\Delta N}{N} = b_1 (H^{b_2} + b_3 N^{b_4})$$

maximum SE = .02
minimum R^2 = .88

where ΔH is mean height growth (m), A is stand age, N is current stems per hectare, and the b_is are constants that differ for each equation. Unfortunately, Meldahl's tables included only clones 5258, 5260, 5262, 5263, 5266, 5326, 5331, 5332 and 5377. Such tree growth data was not available for clone 5272. Conversely, no sprout data was available for clones 5258, 5260, and 5266. Study of growth patterns and suggestions by J. Zavitkovski[4/] then led to the assumption of tree growth model

[4/] Personal communication, August 30, 1982.

fits from clone 5377 as a first approximation of the growth of 5272.

Subsequently, the data and equations are referred to as those for tree growth. The tree model coefficients are given by Lenarz and Ek (1983, Appendix 3).

The above equations were then assembled in the form of a small distance independent individual tree based stand growth model called POPGROW (see Lenarz and Ek (1983) for details of this model; Ek and Dudek (1980) describe this type of model in detail). This program reflects coppicing practice and short rotation intensive culture in that it allows input of a list of stems (sprouts), each associated with a particular stump. The sprouts are then grown (projected) to age three by the above equations for coppice stems. Subsequently, their growth is projected by the tree growth equations derived from Meldahl (1979). Growth and yields are described by annual output of mean projected height, Dbh, numbers of trees, basal area, biomass by tree component, total biomass and stem wood volume. The biomass equations used were those by Ek (1980) with adjustments noted earlier for differing specific gravities between clone. The stem volume output is based on a fit of Table 3 from Gevorkiantz and Olsen (1955).

The first projections with POPGROW identified a problem noted by Isebrands *et al.* (1982) and Zavitkovsky (1981, 1982). Comparisons of Meldahl's projections with observed plot values at ages 5, 9 and 10 indicated overestimation of height by approximately 4-6 percent. Diameter estimates from Meldahl were close to an actual value at age 5 but overstimated an actual value by up to 91 percent at age 10. Conversely, Meldahl's model underestimated survival by 4 to 7 percent at ages 5 and 10, respectively. These results were incorporated in POPGROW by reducing predicted sprout and tree height growth by 6 percent and reducing tree Dbh growth (post age 3) by 58 percent. Other adjustments incorporated after trial runs included constraining tree growth at wide spacings and at high basal areas. The first was accomplished by constraining the trees per hectare term in the tree height and Dbh growth to no less than 4445 (corresponding to a spacing of 1.5 m). This was necessary since there was no growth data for spacings beyond 1.2 m and because wider spacings were expected to have near maximum diameter growth that would not increase with further spacing. The other adjustments altered tree Dbh growth for stands with greater than 50 m^2 of basal area by the expression $1 - B/200$ and mortality rates by $1/[1 - B/200]$ where B = basal area - 50. In effect, 250 m^2 was considered a maximum possible stand density for SRIC. Further adjustments including constraining height and Dbh growth to maximum values expected for open grown trees were redundant, i.e., they had little or no effect after the adjustments noted above.

The adjustments to prediction models for Meldahl's growth data were considered appropriate because his original model fit allowed excessive and almost linear extrapolation of early diameter growth. Although the adjustments produced a more realistic pattern of growth, they should still be considered quite speculative, especially beyond age ten years. In particular, the lack of data on the long term diameter growth-density relationship made the adjustment process very subjective.

Analysis of Projections

Projections for the seven coppiced clones to age 15 are given in Table 6. Note that these projections are from observed initial conditions at age one and that they utilize average rather than spacing specific mortality for each clone. Also, they incorporate the model adjustments described in the previous section. Complete tables of projections for each clone and spacing are given in a supplement to this paper.[5/]

Table 6 indicates maximum mean annual increment values for stems and branch wood from 4.6 to 15.6 tons per hectare per year (6.4 - 15.6 excluding clone 5377). It is further significant that such yield projections were obtained for a variety of clones and spacings and that the mean annual increment curves appear to stay near their maximum for several years. It appears that these yields could be obtained early at narrow spacings, but that wider spacings would eventually catch up and usually surpass the narrow. For interpretation, it should be emphasized that there is much variability between spacings in the original data and in the projections. For example, projected yield values for clone 5272 at age 3 are possible, but unlikely for large plots.

These projections should be considered another step in the refinement of earlier reports on SRIC yields by Ek and Dawson (1976) and Meldahl (1979). Present values agree roughly with maximum temperate zone short rotation yields suggested by Cannell and Smith (1980). For clarification, however, it should be understood that the present study projects yields for SRIC populus coppice stands under carefully (but not perfectly) controlled experimental conditions. That is also what was intended by Ek and Dawson (1976) and Meldahl (1979). For large scale operations yields per unit area would likely

5/ Ek, A. R., J. E. Lenarz and A. Dudek. 1983. Supplemental Growth and Yield Tables for "Growth and Yield of *Populus* Coppice Stands Grown Under Intensive Culture." University of Minnesota, College of Forestry. Mimeo. 29 p. Available upon request.

be at least 15-20 percent lower. That shortfall would be due to variability in environmental factors and greater difficulty in applying cultural practices uniformly. Without intensive culture, the yields would be substantially lower.

Table 6. Fifteen year projections of coppice stand development and mean annual stem and branch wood yield for selected *Populus* clones and parent stand spacings.

	Parent Stand Spacing (m)[1/]												
	.3 x .3				1.2 x 1.2				2.4 x 2.4				MAI
Age	H	Dbh	N	MAI	H	Dbh	N	MAI	H	Dbh	N	MAI	Range
Clone 5262													
3	4.4	2.2	47	7.5	4.4	2.2	22	3.1	4.4	2.2	5	0.8	
5	6.2	3.0	34	6.8	6.6	3.2	18	4.2	7.3	3.9	5	1.9	
10	10.2	5.2	19	7.2	11.3	5.9	13	6.6	14.0	8.8	5	6.0	
15	13.4	7.5	13	8.2	14.9	8.8	10	8.8	18.2	13.6	4	10.5	8.2-10.5
Clone 5263													
3	4.3	2.1	74	10.2	5.1	2.9	20	5.7	5.5	3.2	5	1.9	
5	6.0	2.9	46	7.9	7.6	4.2	17	7.5	8.4	5.6	5	4.2	
10	9.7	4.8	23	7.1	12.5	7.6	12	11.0	15.1	11.6	4	10.7	
15	12.9	7.0	15	7.5	16.0	10.6	9	12.5	19.0	16.8	4	15.6	7.5-15.6
Clone 5272													
3	4.0	1.8	272	39.5[2/]	4.9	2.3	15	2.7	5.4	2.6	4	0.9	
5	5.0	2.3	80	8.8	7.2	3.4	14	3.7	8.4	4.1	4	1.6	
10	8.1	4.1	33	7.3	12.4	6.3	11	6.5	14.6	8.1	3	3.8	
15	11.0	6.2	20	8.0	15.6	9.4	8	9.3	18.3	12.2	3	6.4	6.4-9.3
Clone 5326													
3	3.9	2.0	19	2.3	4.1	2.2	14	2.1	4.4	2.4	4	0.7	
5	5.9	2.8	17	3.0	5.4	3.2	13	3.0	7.4	4.0	3	1.4	
10	10.2	5.1	13	4.8	11.1	5.8	10	5.2	13.7	8.6	3	4.1	
15	13.5	7.6	10	6.7	14.6	8.6	8	7.5	17.6	13.2	3	7.3	6.7-7.5
Clone 5331													
3	4.4	2.0	41	5.6	5.0	2.5	25	5.8	5.3	2.8	6	1.8	
5	6.2	2.9	31	5.8	7.2	3.6	20	7.0	8.3	4.7	6	3.7	
10	10.1	5.2	18	7.6	11.6	6.6	14	10.3	14.4	9.8	5	9.5	
15	13.3	7.9	13	9.6	14.9	9.7	10	12.8	18.3	14.7	4	15.1	9.6-15.1
Clone 5332													
3	4.2	1.9	28	2.8	4.5	2.1	35	4.7	4.7	2.2	9	1.3	
5	6.3	2.9	23	3.9	6.6	3.1	27	5.5	7.6	3.8	8	2.7	
10	11.0	5.6	15	6.7	11.1	5.7	17	8.0	13.7	8.2	7	7.5	
15	14.7	8.6	11	9.5	14.6	8.6	12	10.3	17.7	12.7	6	12.4	9.5-12.4
Clone 5377													
3	4.0	2.0	53	6.4	4.3	2.2	15	2.2	4.3	2.2	4	0.6	
5	5.6	2.7	39	6.1	6.6	3.3	13	3.1	7.3	3.6	4	1.0	
10	9.2	4.8	23	6.8	11.4	6.1	10	5.4	13.5	7.3	3	2.6	
15	12.3	7.0	16	8.1	15.0	9.1	8	7.8	17.5	11.2	3	4.6	4.6-8.1

[1/] Definition of terms:

H = mean total height (m)
Dbh = mean Dbh (cm)
N = stems per ha (thousands)
MAI = mean annual stem and branch wood increment (metric tons per hectare per year)

[2/] An extreme example of data and projection variability.

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