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Some Simulation Estimates of Mean Annual Increment of Douglas-Fir: Results, Limitations, and Implications for Management

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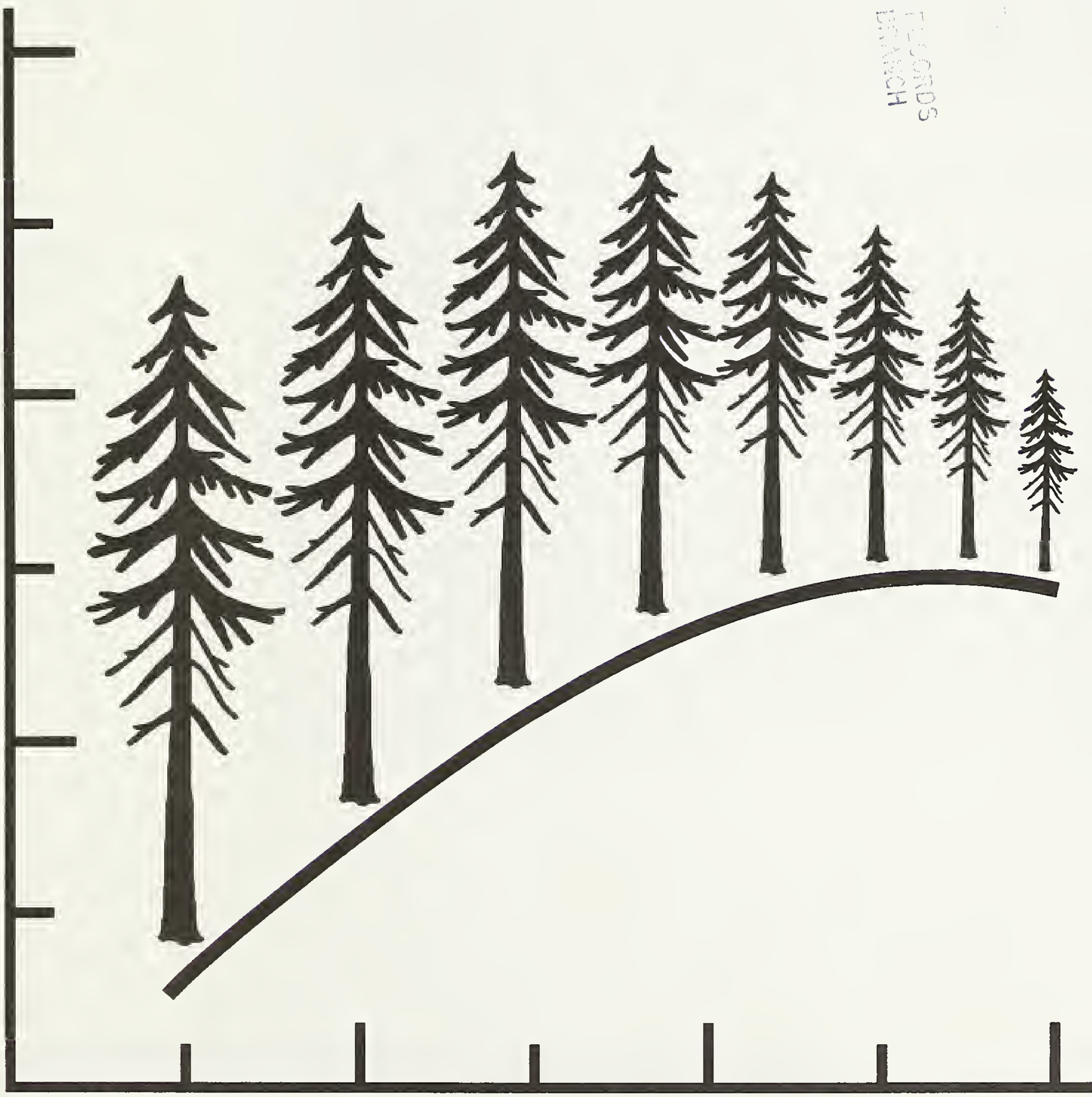

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Abstract

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Patterns of development of mean annual increment in relation to age predicted by the widely used DFSIM, SPS, TASS, and ORGANON simulators were examined. Although predictions differ considerably among simulators for portions of the range of sites, ages, and treatments, comparisons indicated that (1) culmination is relatively late, (2) the curve is relatively flat in the vicinity of culmination, and (3) systematic thinning tends to delay culmination. Harvest ages of 40 to 50 years reduce volume production relative to potential by amounts ranging from moderate to large according to site, treatment regime, and simulator. Within unknown upper limits, moderate extension of rotations to minimize conflicts among timber production and environmental, aesthetic, and wildlife values would not materially reduce long-term volume production and might increase value production.

Keywords: Growth and yield, mean annual increment, rotation, growth models, Douglas-fir, *Pseudotsuga menziesii*, new perspectives, alternative silviculture, ecosystem management.

Summary

Estimates of trends in mean annual increment produced by four widely used simulators (DFSIM, SPS, TASS, and ORGANON) were compared for several management regimes. Estimated ages of culmination differ considerably. Age of culmination is not well determined but is greater than often thought and near or beyond the upper age limits of most of the data used in construction of these simulators. Very short rotations (40 to 50 years) produce moderate to large reductions in mean annual volume production, differing with site and simulator. Estimates indicate that the mean annual increment curve is relatively flat near and beyond predicted culmination. Rotations could be extended beyond those now in common use to minimize conflicts between timber production and environmental, aesthetic, and wildlife values, without necessarily reducing long-term volume production. Timber value production might even increase. Simulator predictions agree generally for portions of the range well represented in the basic data used in model construction but diverge widely for low initial densities, poor sites, advanced ages, and extreme regimes. Some of these variations may represent differences in growth patterns and stockability associated with geographic diversity, but they also reflect weaknesses in the basic data used in simulator construction and assumptions regarding mortality and upper density limits.

Introduction

Estimates of mean annual increment (MAI = volume production/total age) and its culmination (maximum) point are important in forest management. The National Forest Management Act of 1976 (Public Law 94-588) specifies that rotations on National Forest lands shall approximate age of culmination. Although other owners use harvest ages based on financial and other factors, these criteria also are related to the shape of the MAI curve. And, MAI curves provide a part of the information needed for estimating the effects of alternative management regimes on long-term timber supply.

Extended rotations are a possible way to minimize conflicts among timber production and other land uses (wildlife, recreation, and watershed values), reducing visual impacts of timber production operations, and enhancing production of non-timber values (Curtis 1992, Curtis and Marshall 1993, Newton and Cole 1987). Extended rotations combined with systematic repeated thinnings offer the prospects of (1) reduced fraction of the land in regeneration and early developmental stages—hence, aesthetically more appealing landscapes, less area treated annually with slash burning and herbicides, and associated hydrological benefits; (2) larger trees, higher quality wood, and higher values per unit of volume; (3) more naturally occurring snags and down material and enhanced development of understory vegetation—therefore, better habitat for some wildlife and perhaps improved long-term site productivity; and (4) increased carbon storage (a possible component of policies for mitigating climatic change).

Feasibility of longer rotations depends partly on their effect on timber yields, which can be expressed in terms of MAI. What would be the long-term effect on volume yields of adopting rotations for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) longer than those currently in common use?

One can attempt to answer this question by using estimates provided by existing stand simulation programs, extrapolating as necessary beyond the age range of the data used to construct the models. One also can examine existing experimental studies in older stands that have had some type of consistent management. Results of these two approaches will not necessarily agree because the databases for existing simulators often are outdated or restricted to limited geographic areas and existing data have not been adequately summarized and compared.

This paper compares some estimates obtained for Douglas-fir by using existing stand simulation programs. Because of limitations of these programs, estimates do not extend to the very long rotations now being discussed for some National Forest lands but do include harvest ages greater than those now in use on most private, industrial, and state ownerships.

Simulations are not reality. These comparisons necessarily involve questionable extrapolations beyond the range of ages and treatment regimes to which the programs can properly be applied, and different assumed initial conditions would produce somewhat different numerical values. But, to the extent that several simulation programs of different structure and derived from different data sets agree on the general nature of trends, one can have some confidence in the estimates. Conversely, radical differences in growth patterns predicted by different programs indicate either weaknesses in one or more of the programs or the basic data from which they were constructed, or differences between geographic areas.

The primary objective was to examine some characteristics of the MAI curve (especially culmination age) and their relation to site and management regime, as predicted by several widely used stand growth and yield models. A secondary objective was to make some limited comparisons of estimates provided by these different models and to identify some differences in model behavior.

Methods

The results presented are based on four yield models widely used in the Pacific Northwest:

1. DFSIM, vers. 1.3 (Curtis and others 1981, Fight and others 1984).
2. SPS, vers. 2.0 (Arney 1985, 1988).
3. TASS, vers. 2.05.12 (Mitchell 1975, Mitchell and Cameron 1985).
4. ORGANON, vers. 4.2 (Hann and others 1993, Hester and others 1989).

Regimes Compared

Most comparisons are based on parallel runs of comparable regimes for three sites, site index 125 (site II, good), site index 105 (site III, medium), and site index 85 (site IV, poor), base age 50 years at breast height (bh). (Site III was omitted from the TASS runs).

The basic regimes considered were as follows:

1. No treatment (NT).
2. Precommercial thinning (PCT) to:
   - a. 355 stems per acre (PCT355).
   - b. 200 stems per acre (PCT200).
3. Commercial thinning after:
   - a. No precommercial thinning (NT + CT).
   - b. Precommercial thinning to 355 stems per acre (PCT355 + CT).
   - c. Precommercial thinning to 200 stems per acre (PCT200 + CT).

Volumes given for ORGANON, SPS, and TASS results are in cubic feet per acre, to a 6-inch top. This approximates commercially usable volume. Those for DFSIM are for trees 7.6 inches and larger diameter at breast height (d.b.h.) to a 4-inch top, as the most nearly comparable figure available from that program. All values shown for MAI are net and include thinnings.

The number of possible combinations of initial conditions, sites, and management regimes is nearly infinite, and these regimes certainly do not provide an exhaustive comparison of the different simulators or of the predicted effects of management on MAI curves. They do, however, provide a range of sites and treatment options that bring out some of the major characteristics and differences.

Principal emphasis is on volume growth and age of culmination as expressed by the MAI curve, although some limited comparisons of other characteristics also are included.

Initial Conditions

Starting points for simulations were diameter distributions taken from the Sayward LOGS study (Arnott and Beddows 1981, Diggle 1972), a site III plantation with extensive natural fill-in. These distributions represent the initial conditions in that study before thinning and immediately after a late precommercial thinning to 355 stems per acre. Values were adjusted to site indexes 125 and 85 by assigning the ages at which equivalent top heights would have been attained on those sites, as predicted by the applicable height-growth curve; a procedure used in construction of TASS and justified by extensive use (under the name of Eichhorn's Rule) in the European literature (Assmann 1970).

The diameter distribution for 355 stems per acre was then thinned to 200 stems per acre by using procedures in the ORGANON model. Basal areas and quadratic mean diameters corresponding to these three distributions were calculated. Because of the large amount of natural fill-in, the stand was treated as either "natural origin" in simulations not including precommercial thinning, or as "planted" for simulations with precommercial thinning.

Default specifications in DFSIM produced initial values nearly identical to the Sayward observed values for the unthinned and 355-stems-per-acre conditions. Considerable differences from the derived values were evident at 200 stems per acre (which is outside the database for DFSIM), and the DFSIM default values seemed unrealistic for the initial distribution. The DFSIM as well as SPS runs, therefore, were begun by using the same calculated initial numbers, basal areas, and quadratic mean diameters. The TASS runs approximated these initial values. The ORGANON runs were made by using the initial diameter distributions.

In reality, diameter distributions differ among stands, and it is plausible to suppose that lower initial stocking, other site preparation or regeneration treatments, or earlier precommercial thinning (PCT) might produce somewhat larger residual diameters than those observed at Sayward. Some comparative DFSIM and SPS runs were therefore included in which residual diameters were arbitrarily increased 10 percent, thereby providing some indication of the possible direction and magnitude of the effects of such differences on estimates.

Thinning Treatments

Because of differences in program input and operation and in growth trends produced by the different simulators, it is not possible to specify identical commercial thinning regimes. Also, differences in thinnings obscure the differences of primary interest to some extent. Markedly different thinning regimes would presumably produce somewhat different results. The commercial thinnings included, however, are conservative and comparable. In general, stands were not allowed to grow past relative densities of about RD55-60 (Curtis 1982), except that no thinnings were made until the average diameter of cut trees in stands reached at least 9 inches. Thinnings had d:D ratios of about 0.9, except at first thinning in stands of small diameter. Residual relative densities were about RD35-40 at the first thinning and higher at later thinnings. In general, thinning approximated the default specifications in DFSIM.

Fertilization was not included because of the weakness or absence of fertilization functions in these simulators.

Table 1—DFSIM: predicted values of mean annual increment (MAI) at culmination, and related stand values, based on projection of assumed initial stand statistics

Site	Treatment	MAImax[a]	Age at which MAImax first reached[b]	Lower and upper age limits, 95% of MAImax: Lower 95%[c]	Upper 95%[d]	QMD age 45[e]	N age 45[f]	QMD age 80[g]	N age 80[h]	MAI age 45/MAImax[i]
		Ft[3]	*Years*			*Inches*		*Inches*		
II	NT	197	74	52	103	9.9	454	16.0	219	0.89
(125)	NT+CT	198	82	54	120+	10.0	316	16.8	145	.87
	PCT355	209	75	59	102	12.0	284	18.4	174	.83
	with QMD+10%	226	65	52	90	12.7	254	19.2	171	.88
	PCT355+CT	207	88	62	120+	12.7	193	21.2	99	.81
	PCT200	198	82	63	120+	13.9	183	20.8	132	.78
	with QMD+10%	197	86	65	120+	14.1	177	21.0	128	.77
	PCT200+CT	205	92	70	120+	13.9	183	24.1	83	.75
III	NT	148	74	58	108	8.3	589	13.6	280	.78
(105)	NT+CT	149	94	65	120+	8.3	386	14.5	171	.76
	PCT355	159	82	63	120+	10.5	315	16.0	215	.75
	with QMD+10%	161	79	64	111	11.0	294	16.8	196	.76
	PCT355+CT	160	95	67	120+	11.0	208	17.9	123	.75
	PCT200	151	92	70	120+	12.2	193	18.3	155	.69
	with QMD+10%	151	92	71	120+	12.4	190	18.7	148	.70
	PCT200+CT	156	108	75	120+	12.2	193	20.1	117	.67
IV	NT	103	84	70	120+	6.5	771	11.1	379	.50
(85)	NT+CT	106	92	76	120+	6.5	771	11.8	196	.49
	PCT355	109	93	75	120+	8.6	340	13.1	271	.54
	with QMD+10%	118	81	69	114	9.2	339	13.7	274	.61
	PCT355+CT	111	100	82	120+	8.6	340	14.3	181	.54
	PCT200	108	106	83	120+	10.1	197	15.8	175	.50
	with QMD+10%	108	101	83	120+	10.4	197	16.5	163	.55
	PCT200+CT	112	114	90	120+	10.1	197	18.4	97	.49

[a] MAImax = maximum mean annual increment.
[b] MAImax frequently remains constant for a period of some years, and the midpoint of this range is often considerable later than AgeL.
[c] Earliest age at which MAI attains 95 percent of the maximum.
[d] Oldest age at which MAI ≥95 percent of the maximum.
[e] QMD (quadratic mean diameter) at age 45.
[f] N (number of trees per acre) at age 45.
[g] QMD at age 80.
[h] N at age 80.
[i] Ratio of MAI at age 45 to MAImax (fraction of potential volume production obtained if harvested at age 45).

Results

Results for DFSIM are presented in table 1. Similar results for SPS (version 2.0) are presented in table 2. Some irregularities in estimates result from the use of estimates by 5-year intervals in SPS, ORGANON, and TASS.

Table 3 gives similar results for ORGANON. As pointed out by David Hann,[1] these predictions are somewhat questionable because ORGANON is derived from data collected by a different sampling procedure in an ecologically different area; the initial diameter distribution from the Sayward LOGS study is probably not representative of conditions common in southwest Oregon. This was supplemented, therefore, by a series of runs starting with actual data supplied by Hann for young stands in southwest Oregon.

[1] Personal communication. 1993. David Hann, professor, Oregon State University, Corvallis, OR 97331.

Table 2—SPS: predicted values of mean annual increment (MAI) at culmination and related stand values, based on projection of assumed initial stand conditions[a]

Site	Treatment	MAImax	Age at which MAImax first reached	Lower and upper age limits, 95% of MAImax: Lower 95%	Upper 95%	QMD at age 45	N at age 45	QMD at age 80	N at age 80	MAI age 45/ MAImax
		Ft^3	---------- Years	----------		Inches		Inches		
II	NT	171	71	52	91	9.6	503	13.6	292	0.83
(125)	NT+CT	171	66	52	98	9.5	297	14.1	178	.86
	PCT355	216	74	58	97	12.8	259	17.8	210	.78
	with QMD+10%	231	68	54	85	13.5	259	18.8	196	.82
	PCT355+CT	189	74	53	98	13.6	179	20.6	111	.83
	PCT200	181	84	61	103	15.2	150	21.6	121	.76
	with QMD+10%	200	73	59	100	16.2	148	22.8	121	.79
	PCT200+CT	176	84	58	96	15.2	146	22.4	97	.78
III	NT	127	86	64	104	7.9	670	11.8	365	.61
(105)	NT+CT	122	76	63	101	7.9	535	12.0	215	.67
	PCT355	158	87	66	108	10.9	284	15.3	242	.66
	with QMD+10%	179	75	61	92	11.9	283	16.6	234	.72
	PCT355+CT	140	76	62	101	11.5	193	17.4	125	.73
	PCT200	130	87	68	110	12.6	158	18.5	136	.66
	with QMD+10%	141	87	64	110	13.6	158	19.4	136	.70
	PCT200+CT[b]									
IV	NT	78	92	75	120+	6.4	898	9.5	512	.32
(85)	NT+CT	78	77	74	120+	6.4	898	9.4	346	.32
	PCT355	95	92	76	117	8.8	308	12.7	273	.47
	with QMD=10%	108	92	74	112	9.4	309	13.4	277	.58
	PCT355+CT	82	87	69	116	8.8	316	13.8	160	.54
	PCT200	77	92	76	120+	9.8	171	14.9	152	.49
	with QMD+10%	88	92	73	120	10.7	172	15.9	153	.54
	PCT200+CT[b]									

[a] Column headings are as defined in table 1.
[b] Density insufficient for a reasonable CT.

A partial set of comparable results are presented in table 4 for TASS. Similar though not exactly comparable results are available from the TIPSY program (Mitchell and others 1992) for those regimes that do not involve commercial thinning.

Estimates were truncated at age 120 for DFSIM, SPS, and TASS and at 130 for ORGANON. These ages represent extrapolations considerably beyond the range of ages of the data on which these are based. Likewise, regimes involving PCT200 are extrapolations beyond the range of real data used in constructing these simulators.

Discussion

Background Knowledge and Expectations

Shape and level of the MAI curve are not fixed species characteristics. It is well recognized that both shape (and culmination age) and level differ among site qualities, but less generally recognized that these also are influenced by measurement standards and by the management regime applied. Estimates also are affected by assumptions made in the process of constructing yield tables and stand simulation programs.

Table 3—ORGANON: predicted values of mean annual increment (MAI) at culmination and related stand values, based on projection of assumed initial stand conditions[a]

Site	Treatment	MAImax	Age at which MAImax first reached	Lower and upper age limits, 95% of MAImax: Lower 95%	Upper 95%	QMD at age 45	N at age 45	QMD at age 80	N at age 80	MAI age 45/ MAImax
		*Ft*³	*Years*			*Inches*		*Inches*		
II	NT	214	90	72	130+	8.6	570	13.7	297	0.61
(125)	NT+CT	218	105	80	130+	8.6	570	16.3	148	.60
	PCT355	236	95	73	127	11.4	311	17.0	193	.68
	PCT355+CT	239	90	75	130+	11.8	226	20.0	103	.63
	PCT200	234	100	74	130+	13.4	197	19.9	139	.63
	PCT200+CT	243	100	79	130+	14.0	139	21.7	93	.60
III	NT	168	109	85	130+	7.3	676	11.9	364	.43
(105)	NT+CT	169	119	90	130+	7.3	676	14.1	173	.43
	PCT355	179	109	84	130+	9.9	322	15.3	212	.56
	PCT355+CT	192	114	85	130+	10.6	201	17.7	128	.53
	PCT200	180	104	83	130+	11.4	197	17.8	156	.45
	PCT200+CT	187	119	88	130+	11.4	197	19.3	113	.43
IV	NT	126	123	98	130+	6.3	865	10.0	469	.29
(85)	NT+CT	126	133	108	130+	6.3	865	12.1	172	.29
	PCT355	133	118	93	130+	8.5	350	13.6	247	.36
	PCT355+CT	141	128	97	130+	8.5	350	15.0	151	.34
	PCT200	131	123	94	130+	9.3	198	15.8	174	.29
	PCT200+CT	144	128	103	130+	9.3	198	16.4	145	.26

[a] Column headings are as defined in table 1.

Height Growth Pattern

Height growth is one of the basic factors involved in volume growth, and the height-growth curve used has a strong influence on the level and shape of volume-growth curves. It has long been known that the height-growth curve, as expressed by site index, is strongly related to volume production. It is less generally recognized that differences in shape among height-growth curves passing through the same height at the site index reference age are reflected in differences in shape of volume-growth curves. These differences can be quite substantial and can result in considerably different estimates of age of culmination; prolonged height growth is associated with late culmination of volume growth (Curtis 1992).

Units of Measure

Shape of the MAI curve and time of culmination also are influenced by measurement standards. Measurement of volume in total cubic feet gives a smooth curve with origin at the point where trees pass 4.5 feet in height. If cubic volume is measured to a 6-inch top, there is no volume until trees pass a diameter of somewhat over 6 inches. For small merchantable tops, the main effect is on shape of the curve at young ages; for a sufficiently large merchantability limit, age of culmination also will be extended.

The effect is accentuated when volumes are expressed in board feet rather than cubic feet, because board-foot volumes are influenced not only by the merchantable diameter limit but also by the increase in the board foot per cubic foot ratio as trees increase in size. Board-foot volumes will always show later culmination than cubic volumes measured to the same minimum top diameter, although differences decrease and may become negligible with increasing average tree size, and use of Scribner scale rather than Scribner formula rule can introduce irregularities in growth trends.

Table 4—TASS: predicted values of mean annual increment (MAI) at culmination and related stand values, based on projection of the assumed initial condition[a]

Site	Treatment	MAImax	Age at which MAImax first reached	Lower and upper age limits, 95% of MAImax: Lower 95%	Upper 95%	QMD at age 45	N at age 45	QMD at age 80	N at age 80	MAI age 45/ MAImax
		Ft³	*Years*			*Inches*		*Inches*		
II	NT	236	75	60	92	10.8	454	19.8	197	0.78
(125)	NT+CT	221	80	65	120	11.7	454	20.7	116	.82
	PCT355	238	75	60	93	12.7	313	20.6	185	.77
	PCT355+CT	220	80	60	120	13.1	204	22.2	91	.80
	PCT200	242	75	64	100	15.6	187	22.6	159	.71
	PCT200+CT	227	85	68	120+	16.1	116	25.9	79	.70
III	These runs not made for TASS									
(105)										
IV	NT	102	90	68	120+	7.2	666	10.9	446	.68
(85)	NT+CT	98	80	63	120+	7.2	666	11.3	293	.68
	PCT355	102	85	75	120+	9.1	342	12.4	319	.72
	PCT355+CT	99	90	74	120+	9.1	342	13.7	201	.71
	PCT200	99	95	77	120+	10.6	196	15.2	191	.61
	PCT200+CT	94	110	70	120+	10.6	196	16.1	117	.63

[a] Column headings are as defined in table 1.

Initial Density

The pattern of MAI development also is markedly affected by initial density.

With low initial stocking, the site is only partially occupied for some period of time, with resulting low early volume growth and later culmination of total cubic volume growth (Mitchell and Cameron 1985). For merchantable volume, any extension due to initial reduced site occupancy may be offset by earlier attainment of merchantable sizes.

High initial densities, without later stocking control, reduce culmination age for total net cubic volume (for example, Reukema 1979, fig. 19) because high initial density produces both early site occupancy and heavy mortality as the stand approaches the upper density limit. This is consistent with the fact that in well-stocked stands, gross increment culminates later and at a higher level than net increment, as shown by comparison of Staebler's (1955) gross yield tables with the net yield tables from which they were derived (McArdle and others 1949, 1961).

When measurement is in merchantable rather than total volume, this effect may be offset by the longer time required to reach merchantable size.

Stocking Control

Early stocking control (precommercial thinning) has effects similar to those of low initial stocking.

Stocking control (thinning) applied at intermediate ages has several effects, with net results that are not obvious and may differ depending on initial condition and thinning regime. One immediate effect is usually a reduced total volume-growth rate (due to incomplete site occupancy) combined with accelerated diameter growth. Over time, total volume-growth rate usually increases to levels more or less comparable to unthinned stands. Because the merchantable:total volume ratio increases with increasing diameter, however, merchantable volume-growth rate and yield may increase.

A second effect is a reduction in competition-related mortality, which tends to offset the initial reduction in gross growth rate due to thinning. In unthinned stands, the onset of competition-related mortality contributes to culmination in MAI. To the extent that thinning forestalls such mortality, it will delay culmination of net volume MAI (Worthington and Staebler 1961).

Fertilization

Fertilization accelerates stand growth. Thus, one might guess that consistent fertilization over the life of a stand would produce a growth pattern comparable to that of a stand of higher site class, and hence earlier culmination; whereas fertilization late in stand life might accelerate growth and delay culmination.

There are few if any actual data available to confirm or disprove these hypotheses, and given the known weaknesses of fertilizer-effect predictions from the existing simulators, the question is not addressed here.

Upper density limit

One last factor, less a matter of biological fact than of assumptions made by modelers in the absence of precise information, is the upper limit of stand density as represented in the various growth models. Because approach to this upper limit triggers the onset of competition-related mortality, which has a major effect on culmination of MAI in net volume, the level at which this limit is set is related to predicted age of culmination for stands of a given initial stocking without later density control. Consistent thinning regimes that do not allow stands to approach this limit will not be affected.

This is illustrated in figure 1, which compares MAI estimates from DFSIM by using a relative density limit of RD70, with corresponding estimates with the relative density limit specified as RD80. In the former case, culmination occurs earlier and the decline after culmination is more rapid.

The value RD70 was originally selected as the approximate mean of unthinned plots in the DFSIM database. Many observed stands, however, do reach greater densities (for example, fig. 13 in Curtis and Marshall 1986), and both ORGANON and SPS use higher limiting densities. Comparisons in this paper consider only DFSIM predictions made with RD80 as the upper density limit, as this is more nearly comparable to those used in other simulators being compared.

Although the mechanisms employed and the upper limits differ among simulators, all involve either some explicit specification of allowable maximum density or implicit upper limits determined by the mortality and growth functions used. Differences in mortality assumptions and general uncertainty in mortality estimates are major causes of differences in predictions among simulators.

In summary—The ages and levels at which net MAI culminates are influenced to some extent by shape of the height growth curve, site quality, units of measure and merchantability limits, initial stocking, later stocking control, and fertilization (as well as by differences in data distribution and assumptions incorporated in the model). The net results in any comparison among possible regimes are not intuitively obvious.

Results obtained in these comparisons seem generally consistent with the expectations discussed above.

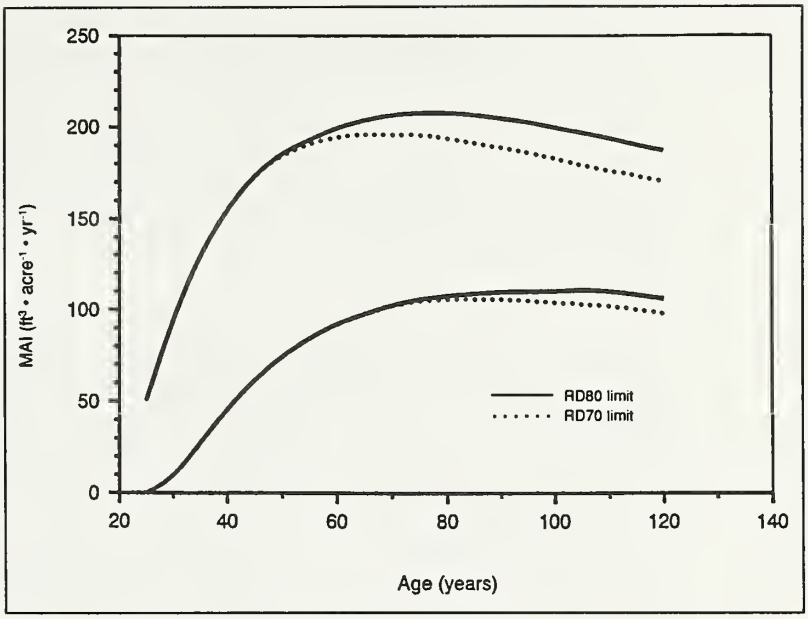

Figure 1—Effect of specified density limits on DFSIM mean annual increment predictions for PCT355 regime, sites II and IV.

Discussion of Comparisons

Differences between ORGANON and other predictions are influenced by differences in the height-growth curves used, which are related to geographic area. The Hann and Scrivani (1987) curves used in ORGANON have slower early growth and more sustained growth at older ages than do the Bruce (1981) curves used in DFSIM and TASS and the very similar King (1966) curves used in SPS.

Those comparisons involving commercial thinning (CT) contain incompletely controlled differences in that the thinnings made, though similar, are not and cannot be made identical. Hence, little significance should be attached to small differences in predicted thinning response.

Data used to construct these models represent different geographic areas. DFSIM was constructed with data that came mainly from western Washington and northwestern Oregon and some data from Vancouver Island. SPS was constructed from a subset of the DFSIM data. TASS is based primarily on data from coastal British Columbia. ORGANON data came from a limited area in southwestern Oregon generally considered to be ecologically different from the others.

The underlying data also differ in plot size and heterogeneity. SPS contains specific provision for adjustment for clumping differences, and it is common practice to apply subjective percentage reductions when applying research plot-based estimates to operational areas (Mitchell and others 1992).

These simulators are still evolving, and other versions may give somewhat different results. Thus, the Willamette Valley version of ORGANON produces MAI curves intermediate between those from the southwest Oregon version used here and those from DFSIM; and estimates from the current version of TASS differ from those given by Mitchell and Cameron (1985).

Despite these reservations, the comparisons made lead to useful generalizations and questions. Comparisons of curve shapes are probably more meaningful than direct comparisons of curve levels. Although there are differences in early growth patterns, most estimates of net MAI are fairly close at ages 50 to 60 years (corresponding to current harvest ages on many private and industrial ownerships). Notable exceptions are the SPS estimates for site IV, which are considerably lower than those from ORGANON, DFSIM, and TASS; and the TASS estimates for unthinned stands on site II, which show densities, volumes, and diameters much greater than the other simulators do.

It is not surprising that the range of reasonable agreement corresponds roughly to the range of actual data used in model construction. DFSIM and SPS included few data over 70 years; ORGANON extended to age 100 or more. Most DFSIM and SPS data were from sites II and III; few data from site IV had a history of active management or a sufficiently long period of observation to show management effects. Data for ORGANON were mainly from natural stands on sites III, IV, and V. There were virtually no data from stands with early PCT to very low densities, and the PCT200 regime estimates are gross extrapolations beyond the data. Agreement seems best for medium sites and medium stand densities (PCT355 and PCT355+CT regimes) and for ages under about 60 to 70 years (figs. 2-7).

The high level of the TASS estimates for NT regimes on site II corresponds to very high relative densities, basal areas, and diameters; ORGANON, DFSIM, and SPS are in much closer agreement (figs. 8, 9). At least a part of the differences represent somewhat arbitrary decisions on maximum density levels and mortality functions, which have little influence on comparisons for managed stands maintained at lower density levels and which are subject to user control when the TIPSY interpolation program (Mitchell and others 1992) is used to derive estimates for operational use. The high TASS estimates for site II unthinned stands are apparently associated with a recent recalibration; the older estimates given in Mitchell and Cameron (1985) are closer to estimates from the other simulators. Unadjusted TASS estimates for the lower density levels are in much closer agreement with other simulators (figs. 10-11).

Culmination ages—Tables 1-4 present estimated ages of culmination of MAI, here defined as the age at which MAI *first* reaches its maximum estimated value (which frequently remains the same for several projection periods). Some minor anomalies appear in these values and in the corresponding curves (figs. 12-19) because of the use of 5-year projection periods in ORGANON and TASS summaries and because of the timing of individual commercial thinnings).

Several generalizations can be made:

1. There are considerable differences among simulators in shape of the MAI curve at advanced ages and in estimates of culmination age. Culmination age is much later with ORGANON, a difference associated with geographic differences and a known difference in the height-growth curves.

2. Precommercial thinning to successively lower numbers of stems produces successively later estimated culmination ages in DFSIM; the trend is unclear in the other simulators (figs. 20-23).

Text continues on page 22.

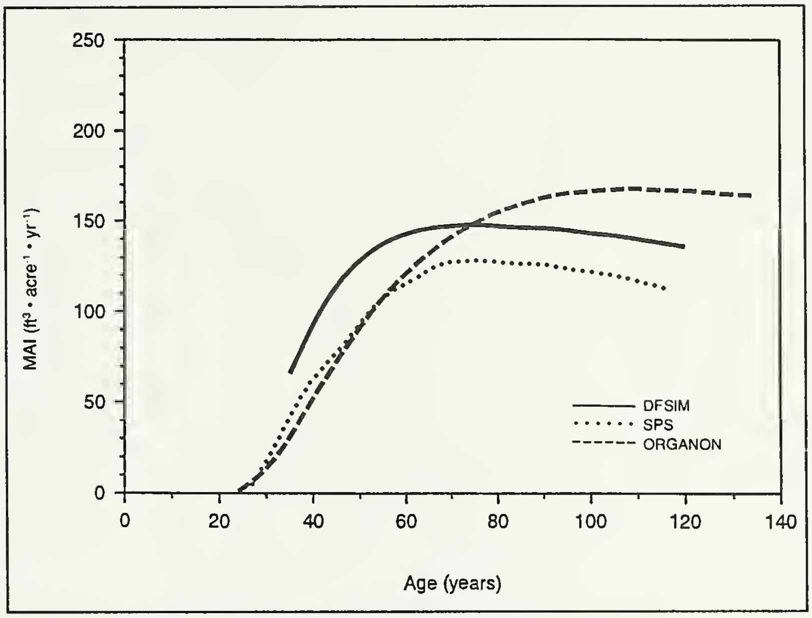

Figure 2—Comparison of DFSIM, SPS, and ORGANON predictions for site III, NT regime.

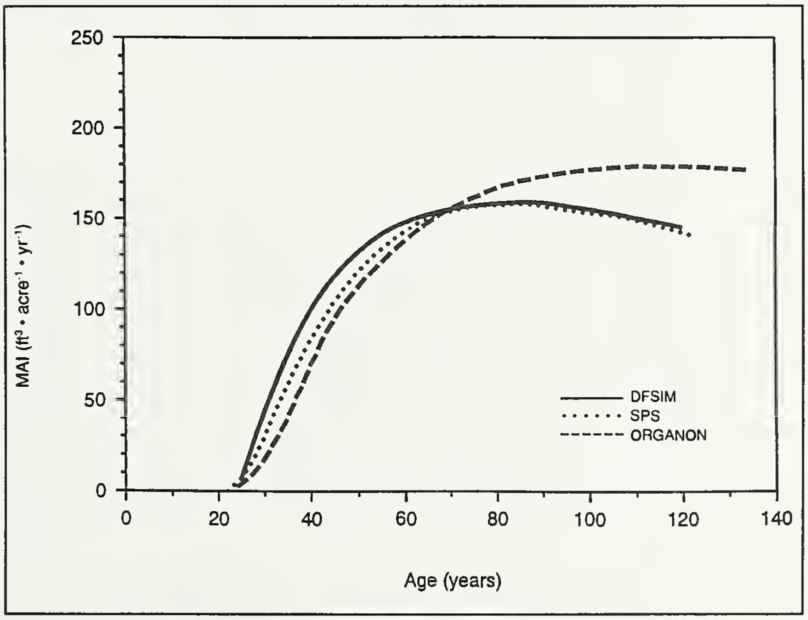

Figure 3—Comparison of DFSIM, SPS, and ORGANON predictions for site III, PCT355 regime.

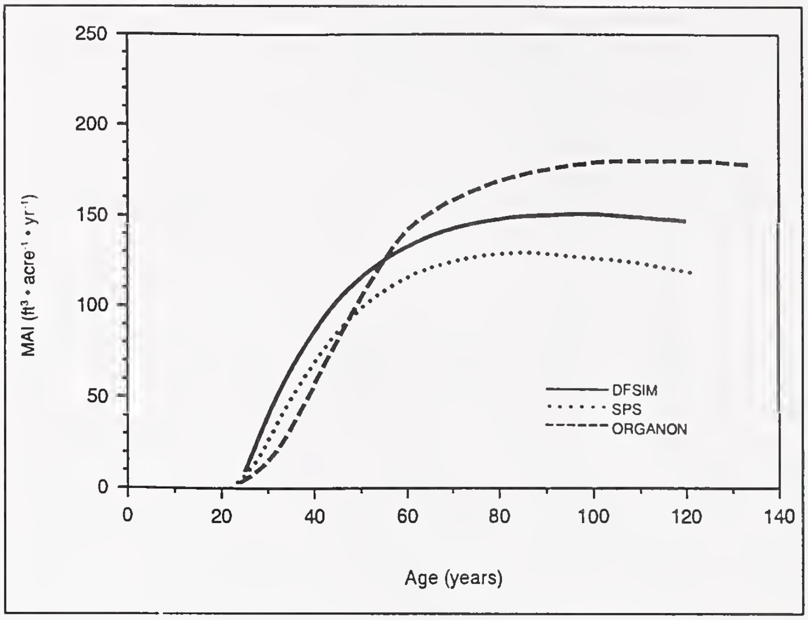

Figure 4—Comparison of DFSIM, SPS, and ORGANON predictions for site III, PCT200 regime.

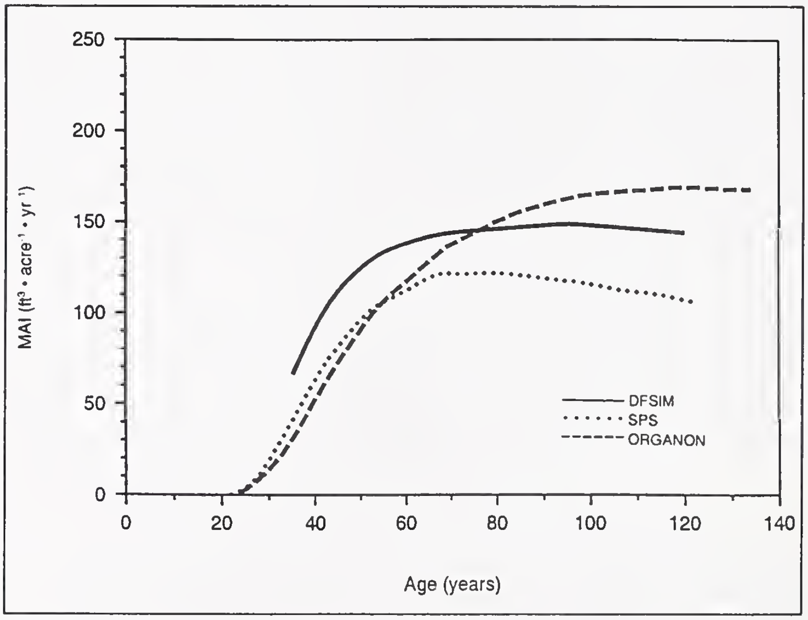

Figure 5—Comparisons of DFSIM, SPS, and ORGANON predictions for site III, NT+CT regime.

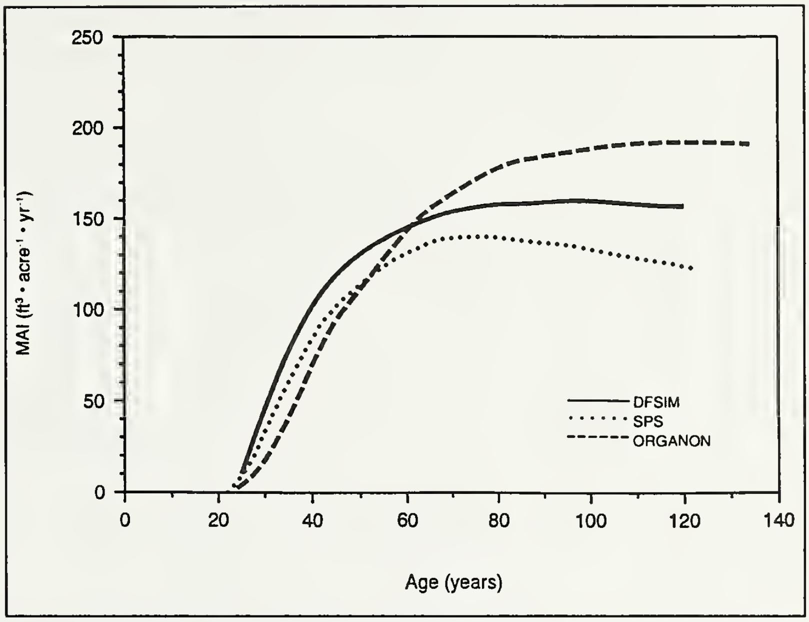

Figure 6—Comparisons of DFSIM, SPS, and ORGANON predictions for site III, PCT355+CT regime.

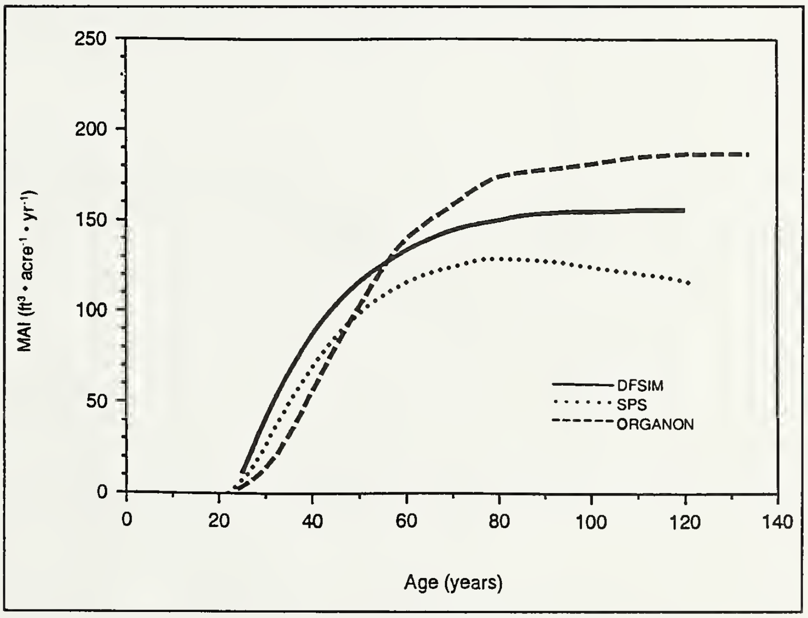

Figure 7—Comparisons of DFSIM, SPS, and ORGANON predictions for site III, PCT200+CT regime.

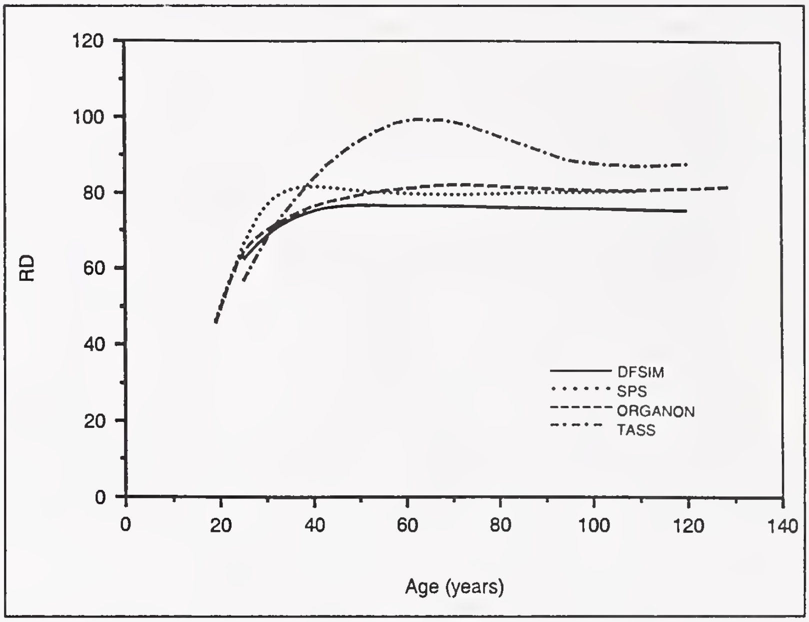

Figure 8—Relative density (RD) values predicted for site II by DFSIM, SPS, ORGANON, and TASS for NT regimes with the same initial conditions.

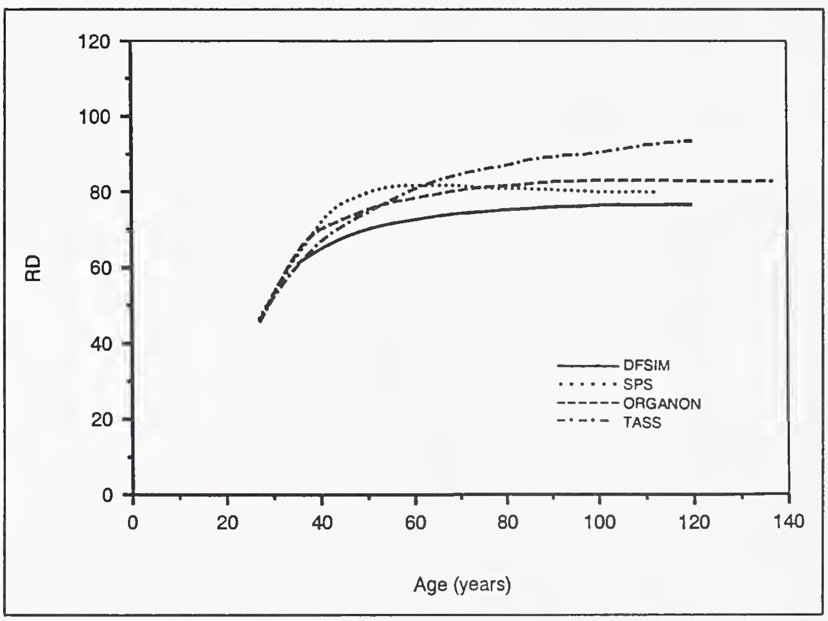

Figure 9—Relative density (RD) values predicted for site IV by DFSIM, SPS, ORGANON, and TASS for NT regime with the same initial conditions.

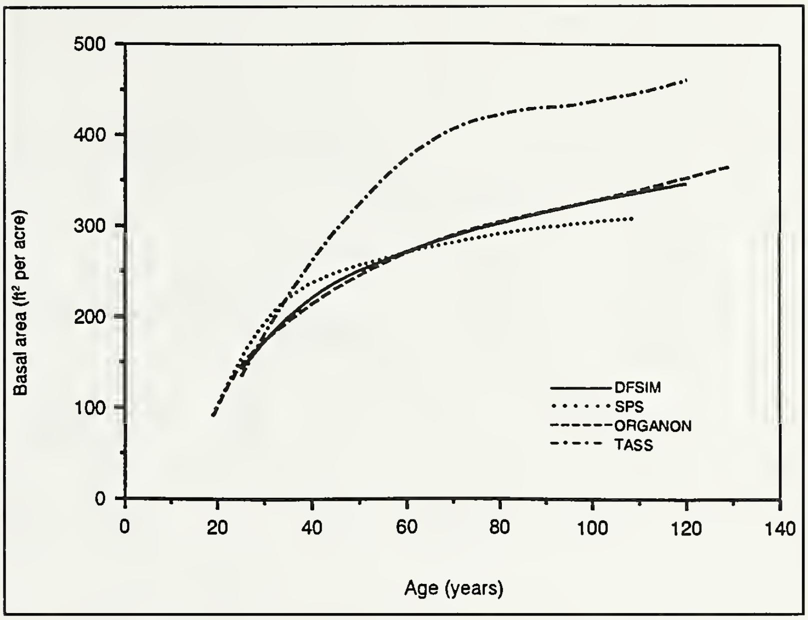

Figure 10—Basal area values predicted for site II by DFSIM, SPS, ORGANON, and TASS for NT regime from the same initial conditions.

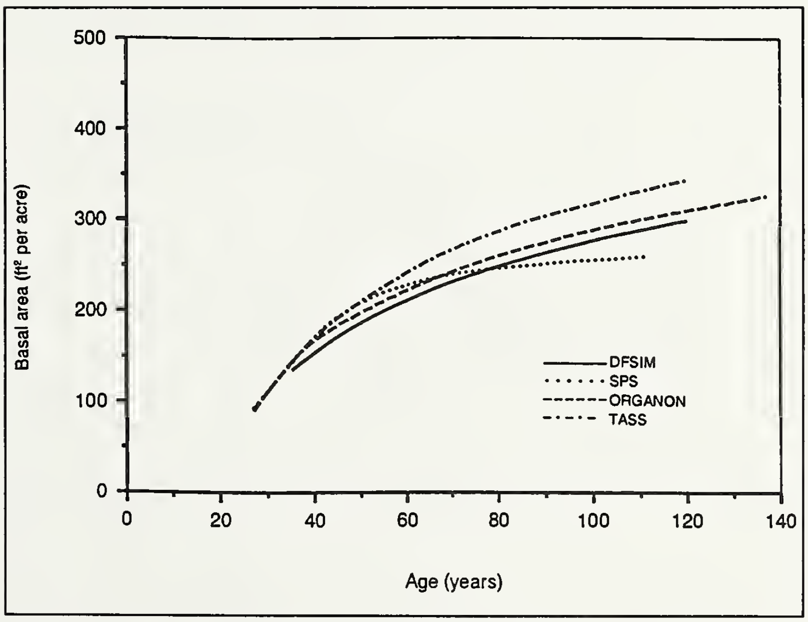

Figure 11—Basal area values predicted for site IV by DFSIM, SPS, ORGANON, and TASS for NT regime from the same initial conditions.

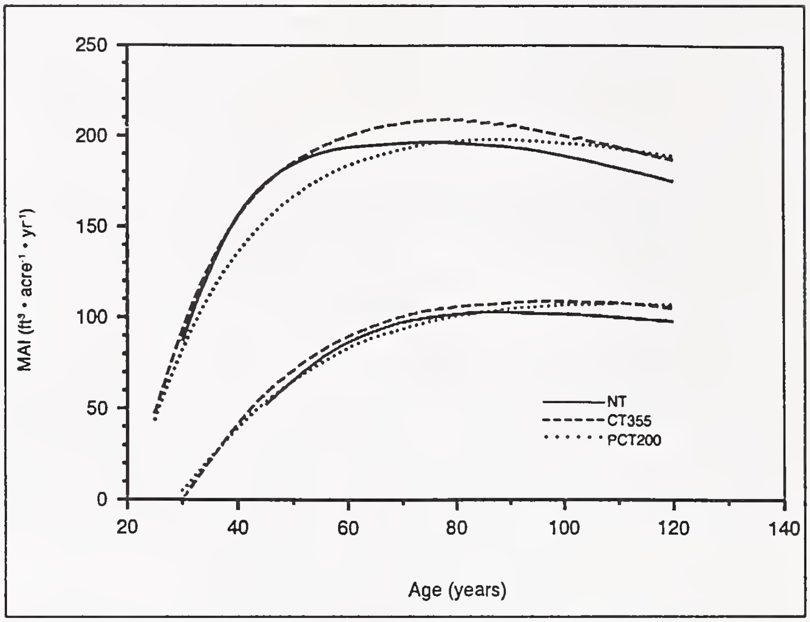

Figure 12—Comparison of DFSIM predictions for sites II and IV for regimes without CT.

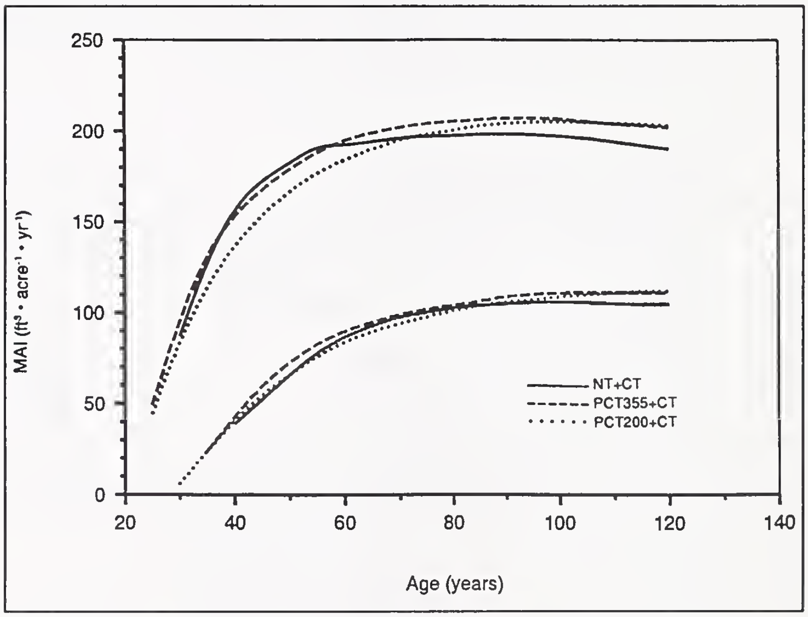

Figure 13—Comparison of DFSIM predictions for sites II and IV for regimes with CT.

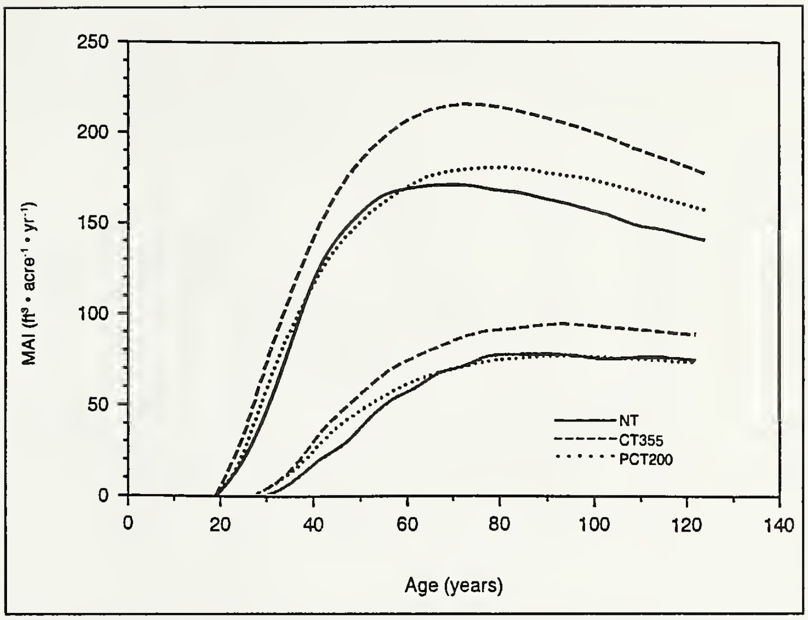

Figure 14—Comparison of SPS predictions for sites II and IV for regimes without CT.

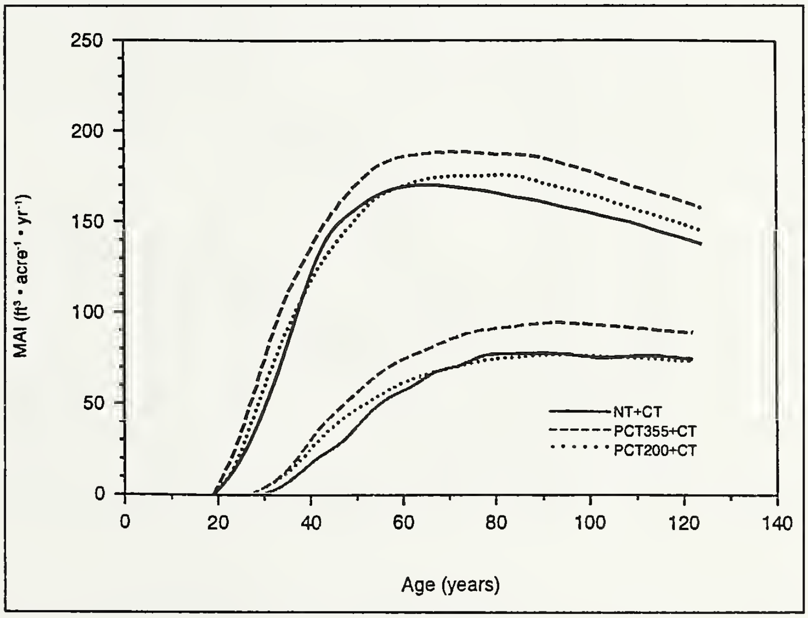

Figure 15—Comparison of SPS predictions for sites II and IV for regimes with CT.

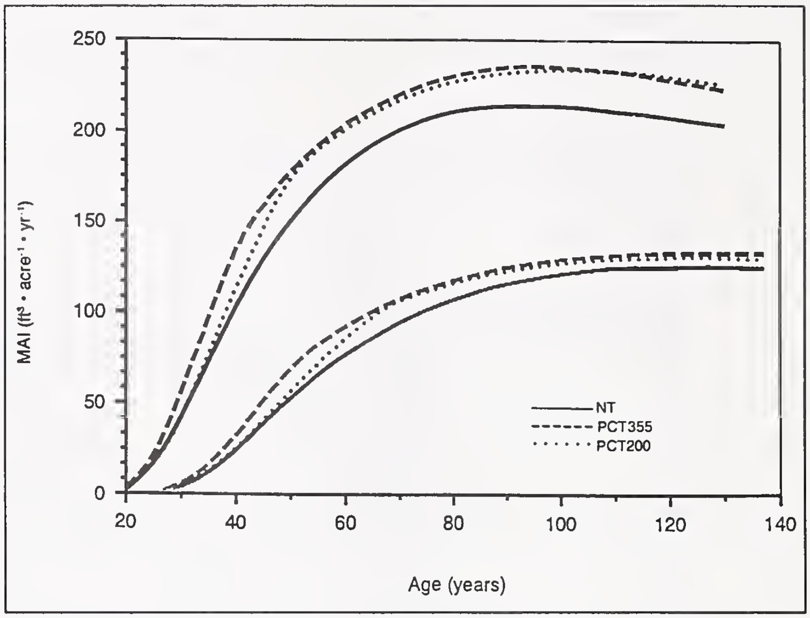

Figure 16—Comparisons of ORGANON predictions for sites II and IV for regimes without CT.

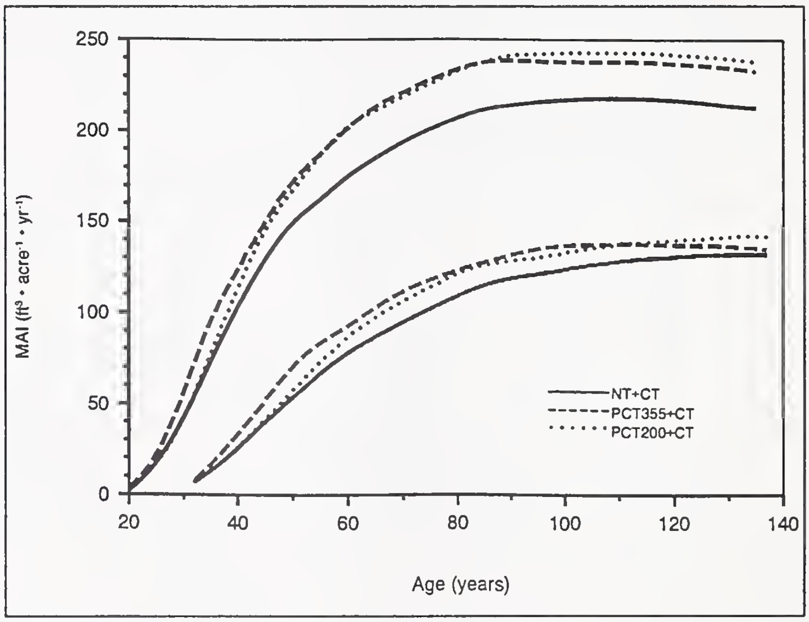

Figure 17—Comparisons of ORGANON predictions for sites II and IV for regimes with CT.

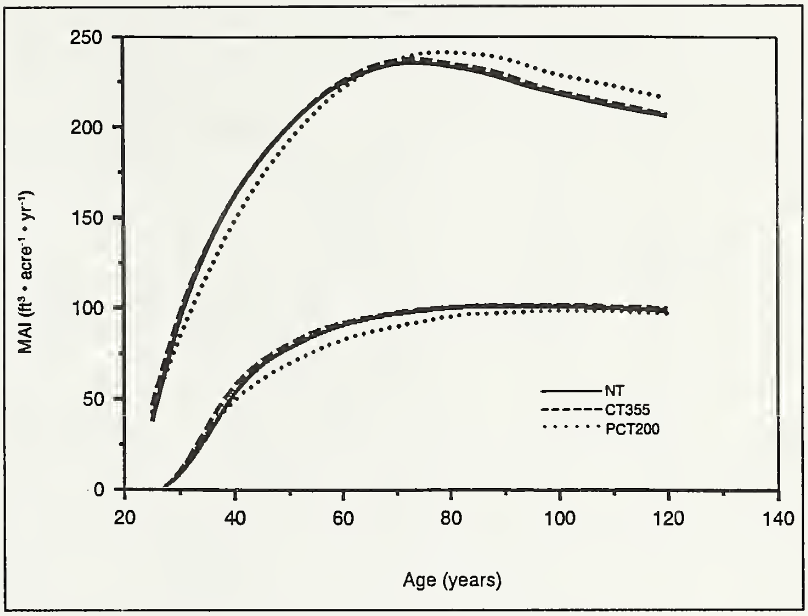

Figure 18—Comparisons of TASS predictions for sites II and IV for regimes without CT.

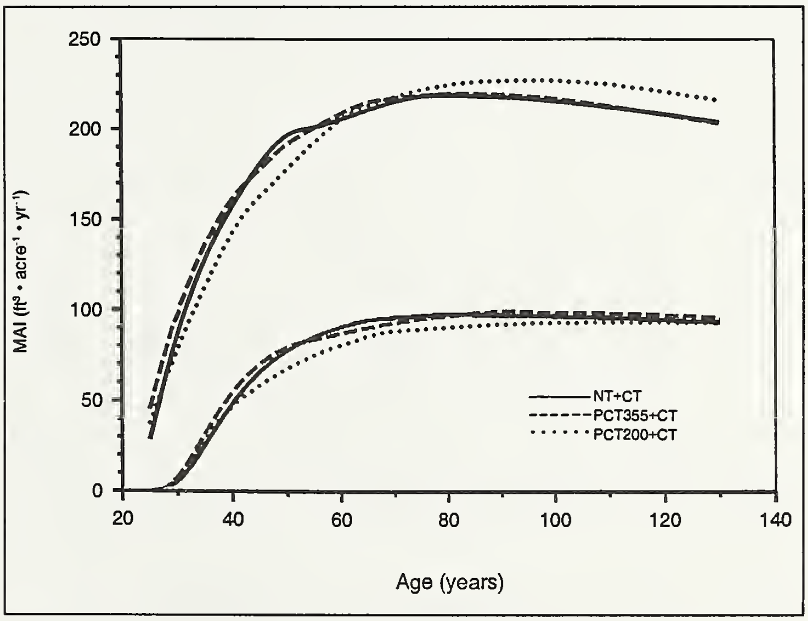

Figure 19—Comparisons of TASS predictions for sites II and IV for regimes with CT.

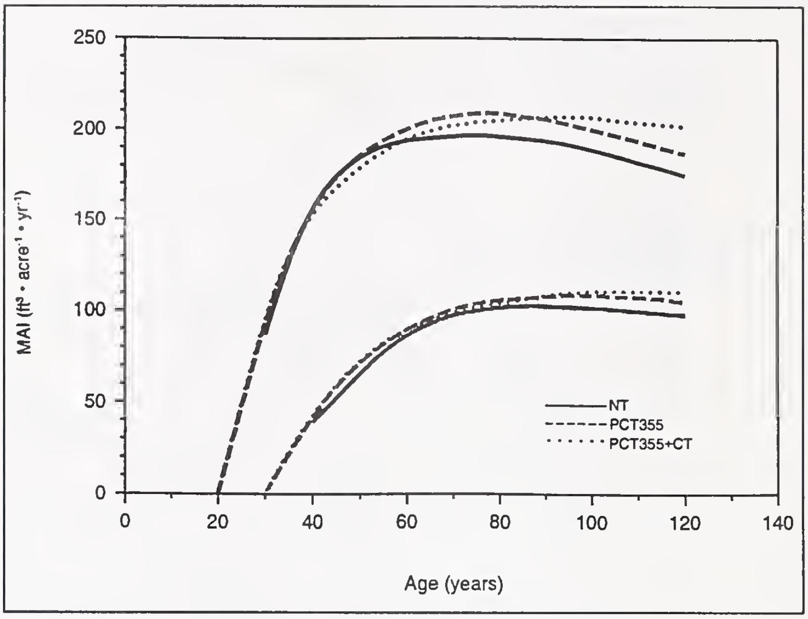

Figure 20—DFSIM: predicted effect of density control for sites II and IV. Regimes NT, PCT355, and PCT355+CT were compared.

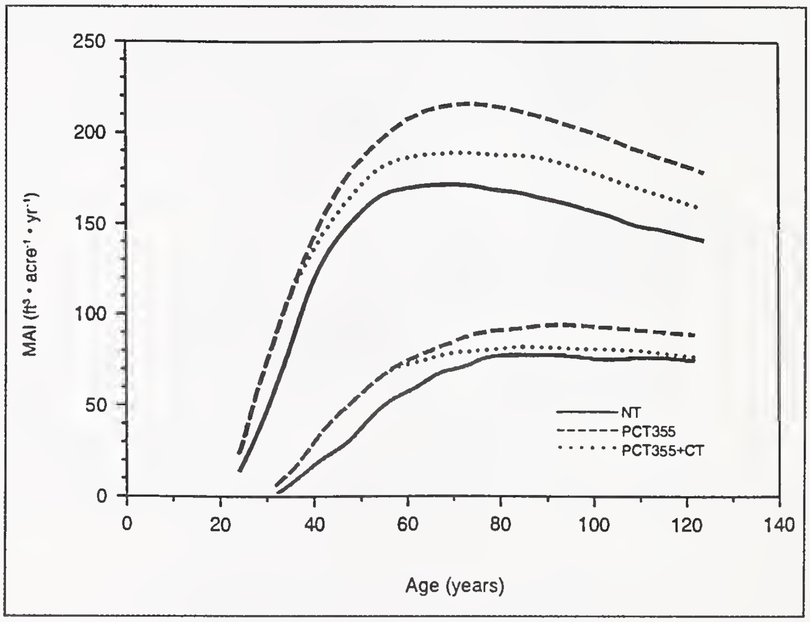

Figure 21—SPS: predicted effect of density control for sites II and IV. Regimes NT, PCT355, and PCT355+CT were compared.

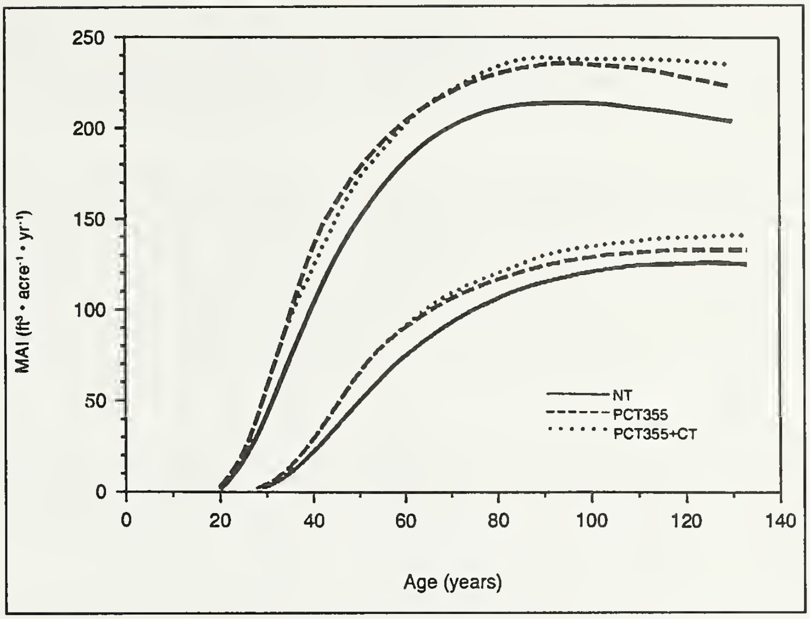

Figure 22—ORGANON: predicted effect of density control for sites II and IV. Regimes NT, PCT355, and PCT355+CT were compared.

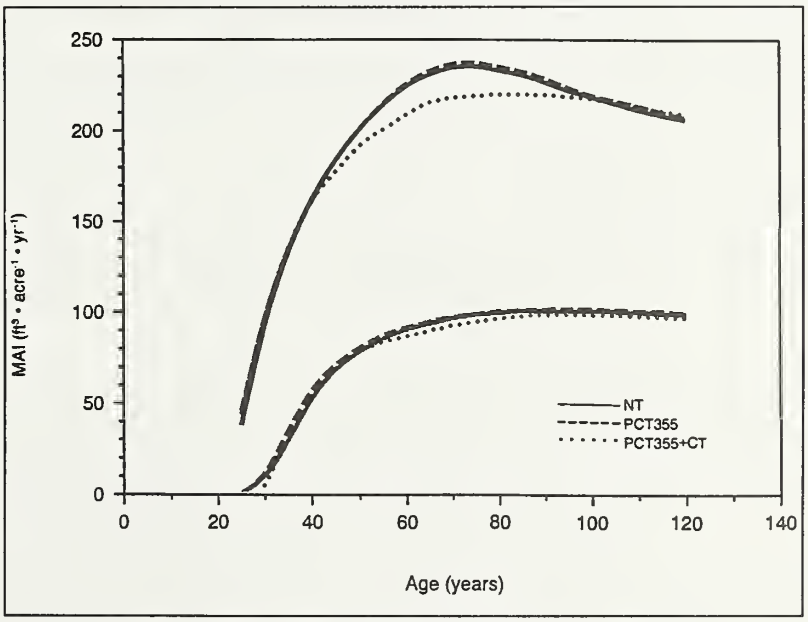

Figure 23—TASS: predicted effect of density control for sites II and IV. Regimes NT, PCT355, and PCT355+CT were compared.

3. Commercial thinning delays predicted age of culmination in DFSIM, ORGANON, and TASS; the trend in SPS was unclear. The effect on low sites is uncertain because precommercially thinned stands often do not attain thinnable diameters and densities within the age range considered.

   Estimated culmination ages more or less correspond to the point at which each simulator runs out of data. Consequently, none of these estimates of culmination age can be regarded as solid values, but they do show that culmination is later than many people think. They are consistent with the general observation that we have not yet clearly observed culmination in any existing thinning studies where stand densities have been held at levels that avoid competition-related mortality and no untoward stand damage has occurred.

Mean annual increment at culmination—ORGANON and TASS have the highest values and SPS generally the lowest (tables 1-4, figs. 2-7). Differences are often large. A considerable part of these differences arise, however, from the later culmination of the ORGANON growth curves at higher levels; differences are much less in the age range 20-60 years.

Thinning effects on volume production—All programs predict major diameter increases from precommercial thinning, compared to no thinning. DFSIM, SPS, and ORGANON all predict substantial volume production gains from precommercial thinning (figs. 12-17). TASS is more equivocal (figs. 18, 19), possibly because of the very high densities predicted for the NT regime.

On the better sites, commercial thinning produces substantial further gains in diameter, but predictions of volume gains, if any, differ considerably among simulators. The patterns suggest that such gains may be realized only on fairly long rotations and may be accompanied (DFSIM, ORGANON) by delay in culmination.

Commercial thinning of site IV stands not previously receiving precommercial thinning shows little apparent effect. This is primarily because, with the high initial stocking considered (1,068 stems per acre), low-site stands do not attain commercially thinnable diameters until quite advanced ages.

Predicted differences in volume production with and without commercial thinning are relatively small; SPS is less optimistic than the others. The absence of large gains is consistent with the expectation, based on existing thinning studies (which do not extend beyond about 70 years of age even for late initial entries), that the principal gains from commercial thinning are not in cubic volume production, but rather are in increased piece size and quality, enhanced stand health and stability, and changes in stand structure and vegetation that may enhance wildlife and amenity values.

Attained diameters—Tables 1-4 show estimated quadratic mean diameters at ages 45 and 80 for the various regimes, as estimated by the four simulators. By and large, these are not drastically different for DFSIM, ORGANON, and SPS. The TASS estimates agree reasonably well with the others for site IV and for stands with density control on sites II-IV, but are much higher for unthinned stands on site II.

Effect of early harvest—The estimated ratios of MAI at age 45 to MAI at culmination (tables 1-4) express the fraction of potential production attained for various regimes and sites at age 45. Thus, they express the loss in potential volume production associated with very short rotations.

This loss is substantial for all regimes. It increases with reduction in initial stocking and is much greater on poor sites than on good sites. Losses estimated by ORGANON are much greater than those estimated by the other simulators, primarily because of the high level of MAI at the later culmination in ORGANON.

Characteristics of the MAI curve near culmination—Both ORGANON and DFSIM, and to a lesser extent SPS and TASS, predict that the MAI curve will be relatively flat for a considerable span of years near and beyond the maximum.

The predictions made with ORGANON by using actual data from southwest Oregon plots as initial conditions (figs. 24-25) show considerable differences in curve shapes among plots, arising from the combination of wide differences in initial stand structure and density, and differences in site. They show the same general characteristics, however, as the comparisons based on the Sayward diameter distribution: namely, (1) relatively late culmination, (2) later culmination with density control than in unmanaged stands, and (3) curves that are quite flat near and beyond the predicted culmination age.

This consensus indicates that there is a considerable range of harvest ages that will produce about the same long-term annual volume production. The upper limits of this range are not known, but it extends to ages greater than rotation ages common in the recent past. This is a very important point for public land managers who are attempting to reconcile aesthetic, wildlife, and landscape values with timber production.

Management Implications

Two trends in management of Douglas-fir in recent decades have been (1) a shift to lower initial densities designed to reduce establishment costs and accelerate individual tree development and (2) a progressive reduction in average harvest ages (rotations). Forty- to fifty-year rotations are now common on private and industrial ownerships.

The estimates presented here indicate that very short rotations—particularly for stands of low initial density—mean reductions in production per acre per year that vary (according to site, initial stocking, and simulator used) from substantial (c. 20 percent) to large (50 percent or more). Whether or not these estimates are correct in detail, the general picture is clear. Continued reductions in harvest ages will simply intensify the long-term regional timber supply problem.

It is also clear that substantial lengthening of rotations to reduce conflicts with amenity and wildlife values could mean a long-term increase in timber volume production and probably would increase value production (larger diameters, less juvenile wood). Within limits, these goals are not necessarily incompatible. For public land managers who are now considering very long rotations (c. 120 to 150 years or more), the apparent flat-topped nature of the MAI overage curve for low sites suggests that long rotations (combined with commercial thinning) do not necessarily imply long-term reductions in yield on the poorer sites.

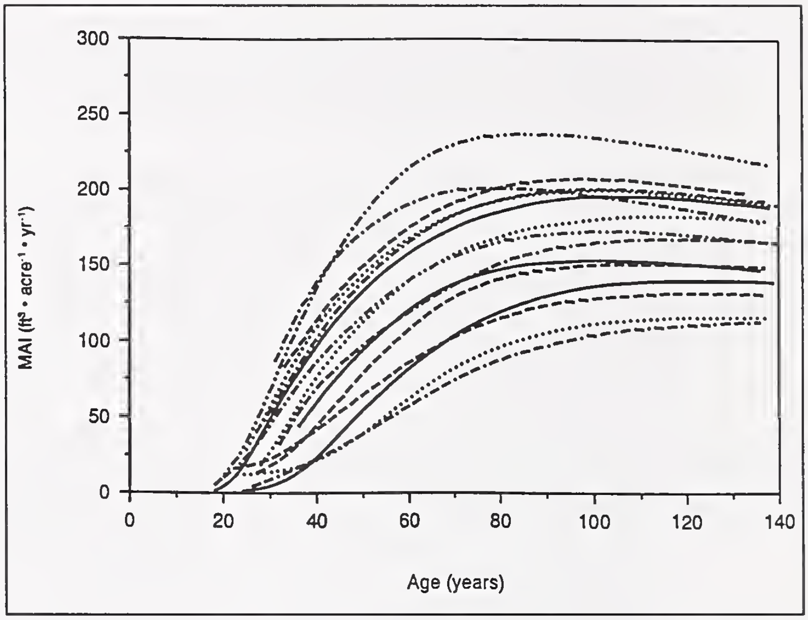

Figure 24—ORGANON MAI curves generated by projection of actual southwest Oregon plot data of varying initial stocking and site index. Regime NT (unthinned).

Lengthening of rotations would involve problems with short-term timber flow, which to some unknown extent might be offset by increased production from thinnings and reduced pressures to remove land from the timber base. Long rotations would not be a feasible option for some owners with little or no land in older age classes. Substantial lengthening of rotations is probably most feasible for public ownerships, which still have substantial amounts of old timber and are subject to greater social and political pressures to minimize use conflicts.

Research Needs

The shortcomings and inconsistencies of current simulators indicate need to:

1. Better define behavior of stands of low initial density and stands on low sites.

2. Better define the MAI curve near and beyond culmination and extend reliable estimates to considerably greater ages.

3. Quantify effects of thinning regimes on composition, structure, and development of lower vegetation as these relate to wildlife, biodiversity, and amenity values.

4. Evaluate heavy thinning regimes that may have potential for filling the timber supply gap during any shift to longer rotations.

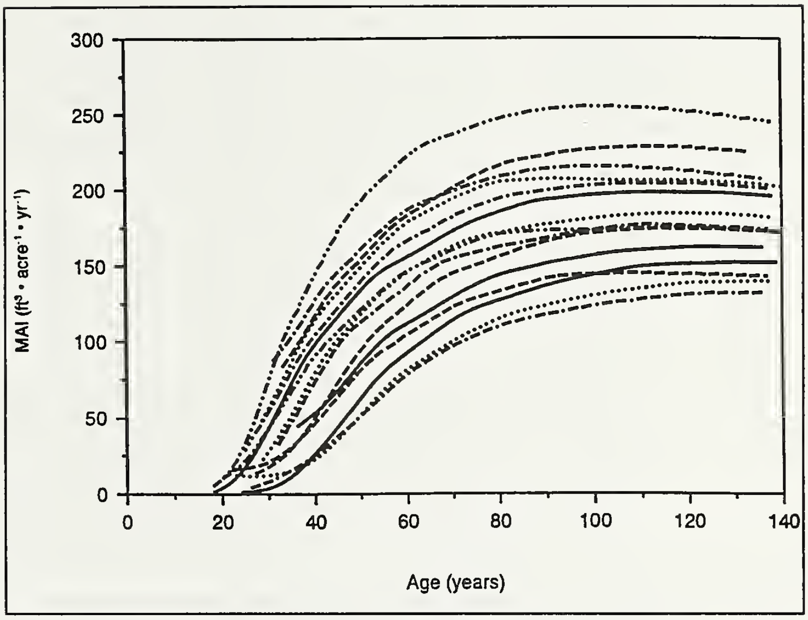

Figure 25—ORGANON MAI curves generated by projection of actual southwest Oregon plot data of varying initial stocking and site index. Regime PCT355+CT.

Acknowledgments

I thank Kenneth Polsson and Kenneth Mitchell of British Columbia Ministry of Forests for providing TASS runs used in these comparisons and for review; David Hann of Oregon State University for review and use of southwest Oregon data; Greg Johnson of International Paper Co. and Charles Chambers of Washington Department of Natural Resources for helpful review suggestions.

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Patterns of development of mean annual increment in relation to age predicted by the widely used DFSIM, SPS, TASS, and ORGANON simulators were examined. Although predictions differ considerably among simulators for portions of the range of sites, ages, and treatments, comparisons indicated that (1) culmination is relatively late, (2) the curve is relatively flat in the vicinity of culmination, and (3) systematic thinning tends to delay culmination. Harvest ages of 40 to 50 years reduce volume production relative to potential by amounts ranging from moderate to large according to site, treatment regime, and simulator. Within unknown upper limits, moderate extension of rotations to minimize conflicts among timber production and environmental, aesthetic, and wildlife values would not materially reduce long-term volume production and might increase value production.

Keywords: Growth and yield, mean annual increment, rotation, growth models, Douglas-fir, *Pseudotsuga menziesii*, new perspectives, alternative silviculture, ecosystem management.

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