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Effect of Top Pruning, Branch Thinning and Gibberellin $A_{4/7}$ Treatment on the Production and Distribution of Conebuds in Douglas-fir

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(Received 15th March 1988)

Abstract

Three levels each of top pruning and branch thinning (in February), with and without stem injections of $GA_{4/7}$ (during June and July), where replicated in two blocks of a 7-year-old Douglas-fir (*Pseudotsuga menziesii*) seedling seed orchard. Flowering was assessed the following year and height extension over two years when the study was accidently terminated by management activities. In one orchard block, topping trees from six whorls of branches to five or three whorls depressed female and male flowering disproportionately relative to contributions of the removed crown regions in untopped trees. Trees in the other block were less vigorous and fecund. Here the light top pruning also depressed female and male flowering but only in proportion to its severity. Heavy pruning increased the tree production of seed cones relative to untopped trees and had no effect on male flowering. Thinning of interwhorl and (or) smaller whorl branches depressed female flowering in approximate proportion to the branches' contribution in unthinned trees, but had a disproportionate effect on pollen-cone production. Results are discussed in relation to the hypothesis that flowering response to top pruning and branch thinning is a function of the vegetative vigor response of shoots following release from apical control. Treatment with $GA_{4/7}$ increased the production of seed- and pollen-cone buds by 161 % and 91%, respectively, although seed-cone abortion was also 35% higher in $GA_{4/7}$-treated trees. A modified stem- injection method for the operational $GA_{4/7}$ treatment of Douglas-fir seed orchards is discussed.

Key words: flowering, Gibberellins, Height control, Pruning, *Pseudotsuga menziesii*, Seed orchards.

Introduction

Conifer seed orchards have changed little over the years. The strategy remains to concentrate seed production on a few, large trees per hectare. This poses obvious problems in harvesting, protection and induction of cones, and for pollen management in general (SWEET and KRUGMAN, 1978; ROSS and PHARIS, 1982). Contrast this with the trend in fruit tree orchards, where " . . . large, spreading apple trees have given way to ordered hedgerows in which the trees are little more than half of the height of their predecessors, a tenth of their spread, and are planted at up to ten times their density" (JACKSON, 1985). Crown training begins at an early age, and serves both to control tree size and to increase the proportion of bearing shoots. As a result, fruit yield per hectare has more than doubled and the unit production cost has been substantially reduced (JACKSON, 1985).

In conifer seed orchards the conventional approach has been to delay any top pruning until the trees become too large to manage efficiently. Removal then of the upper third to half of live crown has either not affected or enhanced cone production in subsequent years (MATHESON and WILLCOCKS, 1976; NIENSTAEDT, 1981; MASTERS, 1982; PHILIPSON, 1985). On the other hand, flowering is frequently depressed following a light pruning which consists of removal only of the stem leader and tips of vigorous branches (VARNELL, 1969; COPES, 1973; LONG *et al.*, 1974). Another disadvantage of this approach is that it offers but temporary height control.

SWEET and KRUGMAN (1978) proposed a new type conifer seed orchard. Patterned after fruit tree orchards, production is diffused over many small, easily managed trees per hectare. The small size of trees facilitates intensive management, including the application of cultural and growth regulator treatments [e.g., gibberellins $A_{4/7}$ ($GA_{4/7}$)] to promote flowering (ROSS and PHARIS, 1986; BONNET-MASIMBERT, 1987), and use of artificial pollination to maximize genetic gains. Such "hedged" orchards have been successfully employed with *Pinus radiata* D. DON to expedite seed production (SWEET and KRUGMAN, 1978) and to accelerate breeding programs (HAND and GRIFFIN, 1979). Analgous "miniaturized" seed orchards are also being tried for some of the Cupressaceae family conifers which respond well to early crown pruning and GA treatment (LONGMAN and DICK, 1981; KATSUTA and ITOO, 1986). *Tsuga heterophylla* (RAF.) SARG. appears to be similarly responsive to such management (ROSS and EASTHAM, 1986).

We report here on the initial flowering and height-growth responses in a young Douglas-fir (*Pseudotsuga menziesii* (MIRB.) FRANCO) seed orchard to different levels of top pruning on the main stem and branch thinning in the residual crown, with and without $GA_{4/7}$ treatment for cone induction. Although scheduled to continue for at least

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five years, the study was terminated after only two years when the lower two to three branch whorls were inadvertantly removed in a bottom pruning of the orchard. Although too short to assess the operational potential for early crown training, our study provides useful insight into the within-crown control of flowering in Douglas-fir.

Materials and Methods

The B. C. Ministry of Forests Saanich seed orchard on southern Vancouver Island was established in 1975 with 3- and 4-year-old progeny of approximately 100 open-pollinated Douglas-fir families (high elevation coast-interior transition zone). Planted at a spacing of 3.8 m × 7.6 m, seedlings averaged 3.7 m ± 0.6 m in height and were open growing at the start of the 1982 treatment year.

A split-plot design was used, with top pruning (3 levels) the main-plot factor, and factorial combinations of branch thinning (3 levels) and $GA_{4/7}$ or no treatment on the split-plot factors. Each top-pruning treatment was applied to 36 trees in two adjacent east-west orchards rows, within which six trees were randomly assigned to each branch-thinning and $GA_{4/7}$ combination. To minimize confounding shading effects, the three topping treatments were arranged consecutively south to north in order of decreasing severity. Rep 2 of this design (in orchard blocks 3 and 4) was situated approximately 150 m north of rep 1 (in blocks 10 and 11).

Trees were either left untopped with six whorls of live branches, or topped above the fifth (W5-topped) or third (W3-topped) whorl counted from the base of the crown (see *Fig. 4*). The cut was made at a slight downward angle (for water runoff) 5—10 cm above the appropriate branch whorl, and the wound sealed with a pruning compound. The three branch-thinning treatments applied to the residual crown consisted of an (1) unthinned control, (2) all interwhorl branches removed, and (3) all but the four largest branches per whorl removed.

Following procedures in Ross *et al.* (1985), $GA_{4/7}$ mixture (ICI Plant Protection Division, England) was injected at 50 mg L^{-1} in 0.05% ethanol-water into the lower stem between the first and second branch whorl. Treatment began once 50% of the trees had flushed (owing to an unseasonably cool, moist spring this was late June, 1982) and continued for six weeks.

Tree height was measured to the nearest decimeter before and after topping in February, 1982, and again after the 1983 growing season. Height after topping was taken as the "reach" of the tallest branch. Trees flowered profusely in 1983, but in 1984 produced too few cones of either sex to warrant assessment. Prior to emergence in spring 1983, all seed- and pollen-cone buds were counted for one south-facing branch per whorl and interwhorl. The same branches were used for September counts of mature seed cones. Branch counts were multiplied by the number of branches per whorl and interwhorl, and the products summed to provide an estimate of total tree production.

The study was analyzed as a split-plot design (*Table 1*). Treatment means differing at $P \leq 0.05$ were compared by DUNCAN's multiple range test.

Results

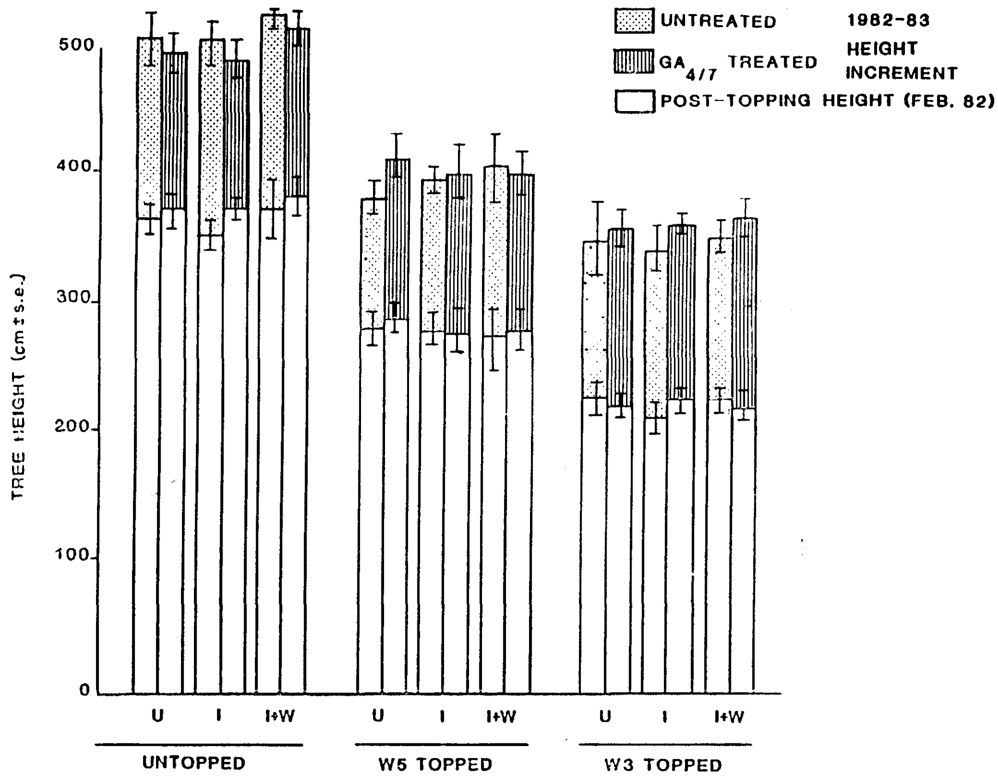
Height extension and crown form

The proportion of total stem length removed in the W5-topping and W3-topping treatments (21% and 47%, respectively) was similar for the two replicates. However, rep 1 trees were initially taller than rep 2 trees (3.8 m vs. 3.6 m, $P = 0.09$), and their 1982 to 1983 extension growth in the W5- and W3-topped treatments was also slightly greater (0.3 m vs. 0.2 m).

Following pruning the untopped, W5-topped and W3-topped trees averaged 3.6 m, 2.7 m and 2.2 m in height, respectively. Height extension during 1982 to 1983 was slightly depressed by branch thinning ($P = 0.08$). However, the effect of top pruning depended on whether $GA_{4/7}$ was also applied (*Fig 1, Tab. 1*). Untopped trees extended more (0.2 m) than W5- or W3-topped trees (0.1 m) without $GA_{4/7}$. $GA_{4/7}$ retarded height extension in untopped trees by 18%, but enhanced it in W5- and W3-topped trees by 10% and 6%, respectively.

Table 1. — Results of split-plot analysis of variance for conebuds per tree, seed-cone survival and 1982-83 height increment.

		Seed-cone buds		Pollen-cone buds		Seed-cone survival		Height increment	
Source of variation	d.f.	Sum of squares	Prob.	Sum of squares	Prob.	Sum of squares	Prob.	Sum of squares	Prob.
Top pruning (T)	2	2 417 309	0.71	342 935 213	0.51	592.66	0.23	132.028	0.21
TxRep (error 1)	2	5 908 149	0.01	352 416 992	0.01	175.22	0.88	35.842	0.15
Rep	1	1 141 739	0.11	67 545 787	0.16	850.85	0.27	1.338	0.70
Branch thinning (B)	2	8 981 110	0.01	1 192 136 484	0.01	1106.75	0.46	47.250	0.08
$GA_{4/7}$ (G)	1	20 316 053	0.01	219 692 806	0.01	8509.79	0.01	3.375	0.55
TxB	4	5 998 362	0.01	249 323 997	0.13	1466.05	0.72	11.306	0.87
TxG	2	2 052 292	0.11	18 403 511	0.77	909.73	0.23	181.028	0.01
BxG	2	897 262	0.38	37 662 842	0.58	1003.30	0.49	14.528	0.56
TxBxG	4	167 664	0.45	41 808 691	0.88	889.16	0.87	40.694	0.36
Bxrep	2	896 725	0.38	52 780 701	0.47	513.35	0.70	1.176	0.94
Gxrep	1	118 535	0.61	4 237 739	0.72	2917.38	0.04	11.116	0.27
TxBxrep	4	1 805 651	0.41	209 264 514	0.20	1992.26	0.59	25.102	0.61
TxGxrep	2	2 995 649	0.04	145 141 331	0.13	447.43	0.73	55.843	0.05
BxGxrep	2	106 449	0.89	47 929 546	0.50	560.12	0.67	7.898	0.65
TxBxGxrep	4	761 560	0.80	72 823 984	0.72	1721.26	0.66	68.269	0.12
Tree (TxBxGxrep) (error 2)	180	81 906 507		6 216 463 584		115786.94		1 665.833	
Total	215	137 980 019		9 270 567 723		140713.28		2 302.625	



U = branches unthinned. I = interwhorl branches removed, I + W = I + weaker whorl branches removed

Figure 1. — Mean tree heights compared for different top-pruning, branch-thinning and gibberellin $A_{4/7}$ treatments following pruning in February 1982 and after two growing seasons (reps pooled, n = 12).

Photographs in *Figure 2* illustrate the crown form of representative trees in each top-pruning regime four months (upper series) and three years (lower series) after topping. Also evident is the severity of the inadvertant bottom pruning in February 1985, which precluded assessment of growth responses by lower-crown branches.

Height extension in topped trees was the result both of a upward turning (hyponasty) of branches below the cut and the elongation of their terminal shoot *(Figs. 2C—H)*. In W5-topped trees, branches subtending the cut rapidly assumed an upright growth habit, forming a dense multistemmed top (*Fig. 2D*). Crown development in W3-topped trees was more variable. Some trees also exhibited a rapid reassertion of apical dominance by one or more of the subtending branches (*Fig. 2F*), whereas for others the vigor response was less and they developed a more open, candelabra-shaped crown (*Fig. 2H)*.

Flowering response to top pruning

Ninety-tree percent of the study trees flowered in 1983, with treatments the previous year primarily affecting numbers of conebuds initiated (*Table 2*). For this trait the between-tree variation was itself quite large (respectively, 59% and 67% of the total variation, *Table 1*), so that relatively large treatment differences were required to establish significance at $P \leq 0.05$ (*Tables 1* to *3*). However, this includes also a tree error of unquantified magnitude associated with the method of estimating total production based on counts of only one branch per whorl and interwhorl.

There was a strong rep by top-pruning interaction (*Table 1*) both for female and male production (*Table 2*). Separate ANOVAs were therefore run on the data for each rep, and results of the DUNCAN's multiple-range tests are provided in *Table 2*. Top pruning depressed the tree production of seed- and pollen-cone buds disproportionately to its severity in rep 1 trees. In rep 2, the top-pruning main effect was not significant, although the more severe W5-topping treatment appeared to increase the tree production of seed-cone buds without affecting male production.

Table 2 also compares rep 1 and rep 2 trees for top-pruning effects on the productivity of different crown zones. (Note that crown zones are defined by their complement of whorl (W) and interwhorl (I) branches numbered from the crown base, see *Fig. 4*). In untopped and unthinned trees of both reps, upper (W7-I6 branches) and middle (W5-I4 branches) crown zones contributed about 13% and 36%, respectively, of the total seed-cone buds. For rep 1 trees, their removal in the W5- and W3-topped treatments depressed total female production by a disproportionate 35 % and 56 %. Thus, the remaining branches became less productive as a result of top pruning.

This was not the case for rep 2 trees. Compared to untopped trees, the lower crown (W3-W1) branches of W3-topped trees produced over twice as many seed-cone buds. This was more than sufficient to offset the lost female production of the removed upper and middle crown. The 14 % reduction in total seed-cone buds for W5-topped trees of this rep matched the upper-crown's contribution in untopped trees.

The upper crown contributed (both reps) only 3% to 5% of the total pollen-cone buds, whereas its removal repressed total male production by 36% and 20% in rep 1 and

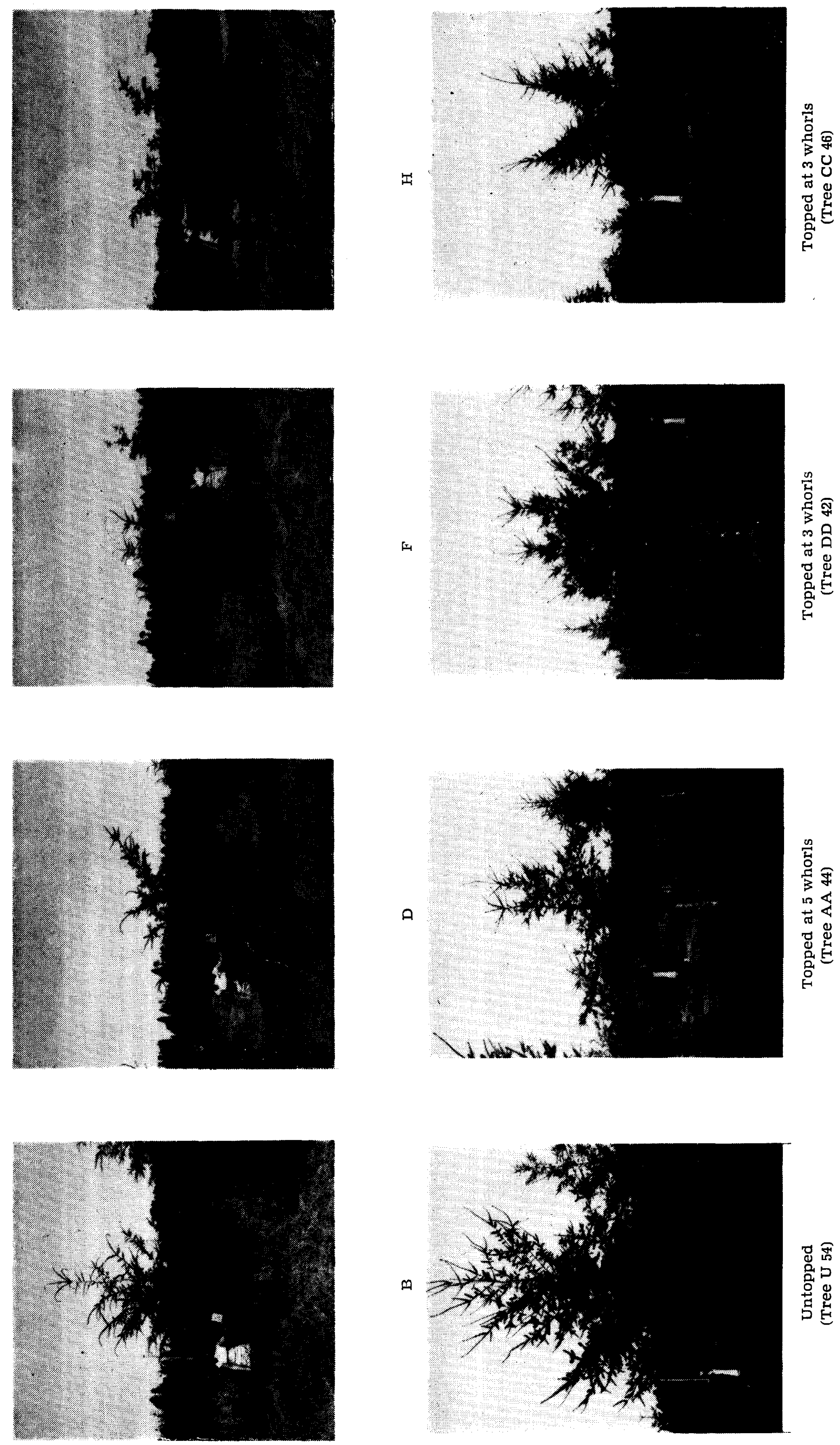


Figure 2. — Representative trees in each top-pruning regimen showing crown for 5 months (upper photographs) and 36 months (lower photographs) after treatment in February, 1982. *Figs. 2E* to *F* and *Fig. 2G* to *H* compare the vegetative response to severe top pruning by a lesser and more vigorous tree representative of reps 2 and 1, respectively. Note that the bottom 2 to 3 whorls of branches were accidently pruned from study trees shortly before the lower series of photographs were taken in February, 1984.

rep 2 trees, respectively (*Table 2*). The upper and middle crown combined produced 40% to 42% of the total pollen-cone buds in untopped trees (both reps). Their removal depressed total male production by a disproportionate 65% in rep 1 trees, but had little effect on rep 2 trees, whose lower-crown branches responded with increased production to offset the loss.

Table 2. — Top-pruning effects on conebud production by crown zone and tree compared for the two orchard reps (branch-thinning and $GA_{4/7}$ treatments pooled, n = 36).

Orchard rep	Top-pruning treatment	No. conebuds by crown position⁺ (Pct. of total conebuds) Upper	Middle	Lower	No. conebuds per tree
		Seed cone			
1	Untopped	153(14)	380(35)	558(52)	1091a*
	W5-topped		284(40)	420(60)	704b
	W3-topped			476(100)	476b
2	Untopped	69(12)	194(34)	313(54)	576a
	W5-topped		217(44)	278(56)	495a
	W3-topped			764(100)	764a
		Pollen cone			
1	Untopped	380(5)	3126(37)	4897(58)	8403a
	W5-topped		2181(41)	3193(59)	5374b
	W3-topped			2911(100)	2911b
2	Untopped	92(3)	1344(37)	2187(60)	3633a
	W5-topped		1336(46)	1575(54)	2911a
	W3-topped			3558(100)	3558a

⁺) Upper, middle and lower crown consists, respectively, of W7 to I6, W5 to I4 and W3 to W1 whorl (W) and interwhorl (I) branches numbered from crown base- see *Figure 4*.
*) Values with reps followed by the same letters do not differ significantly at $P \leq 0.05$ using error 2 of *Table 1*.

Flowering response to branch thinning

Branch thinning strongly depressed the production of seed- and pollen-cone buds for trees in both reps (*Fig. 3, Table 1*). Internodal branches of untopped, W5- and W3-topped trees (reps and $GA_{4/7}$ treatments pooled) contributed, respectively, 16%, 2% and 2% of the total seed-cone buds, and 23%, 7% and 6% of the total pollen-cone buds (*Fig. 4*). However, their removal resulted in a 26% and 44% reduction in the tree production of seed- and pollen-cone buds, respectively (*Table 3*). This disproportionate reduction in tree production is in part due to the fact that some branches that would have been classed as "whorl" branches when conebud counts were made (spring 1983) were included with the "interwhorl" branches removed in spring 1982 (*Table 3*). Although removal of "interwhorl branches only" had a generally similar effect on the productivity of trees in all top-pruning regimes, removal also of the weaker whorl branches caused a further reduction in seed-cone buds only for untopped trees (note significant T*B effect in *Table 1*). The interaction was not significant for pollen cone buds.

Unlike the response to top pruning, the remaining whorl branches produced fewer pollen-cone buds following branch thinning; the more severe the thinning generally the greater the reduction (*Table 3*). Branch thinning had no consistent effect on production of seed-cone buds by each remaining whorl branch.

Table 3. — Effect of removing interwhorl branches (I) and interwhorl plus smaller whorl branches on branch and total production of conebuds for trees in different top-pruning regimes.

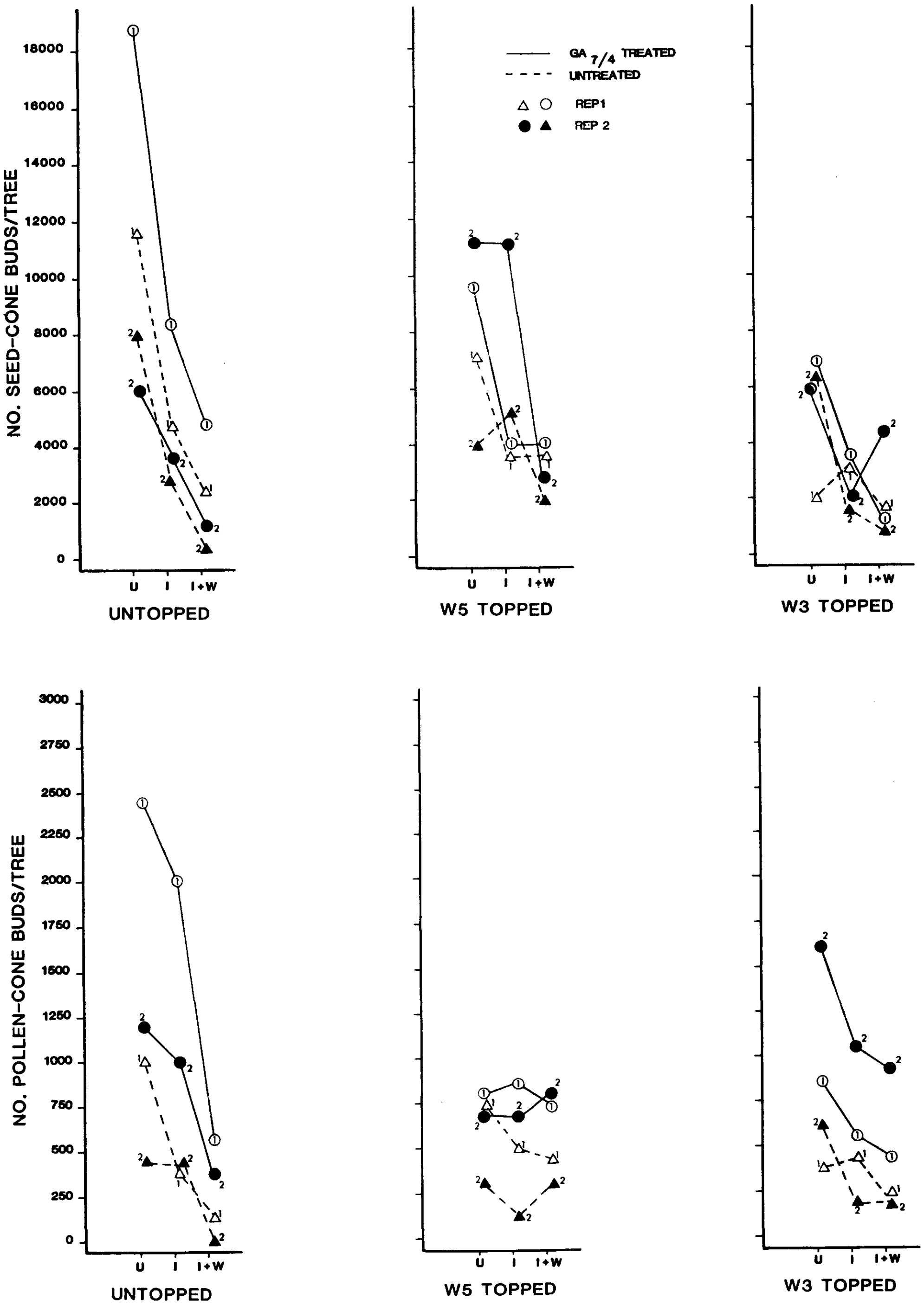
Top-pruning regime	Branches thinned	Branches per whorl (No.)	No. Seed-cone buds Per whorl branch	Tree Total	No. Pollen-cone buds Per whorl branch	Tree Total
Untopped	Unthinned	5.7	27	1277ᵃ	201	11097ᵃ
	Interwhorl	5.0	25	952ᵇ	119	4898ᵇ
	I+whorl	3.6	20	269ᶜ	80	2119ᶜ
W5-topped	Unthinned	5.9	21	660ᵃ	239	8009ᵃ
	Interwhorl	5.2	20	562ᵃ	203	6041ᵃᵇ
	I+whorl	3.6	31	575ᵃ	174	3176ᵇ
W3-topped	Unthinned	6.4	37	875ᵃ	238	5222ᵃ
	Interwhorl	5.5	29	549ᵇ	128	2492ᵇ
	I+whorl	3.8	37	452ᵇ	167	1990ᵇ

⁺) Values within top-pruning regimes followed by the same or no letters do not differ at $P \leq 0.05$ (reps and $GA_{4/7}$ treatments pooled, n = 24).

Flowering response to $GA_{4/7}$

Averaged over both reps and all treatments, stem injections of $GA_{4/7}$ increased the production of seed- and pollen-cone buds by 161 and 91%, respectively. Analysis of variance (*Table 1*) disclosed only one interaction effect ($P = 0.04$), that between $GA_{4/7}$, top pruning and replicates (*Fig. 3*). In rep 1, $GA_{4/7}$ treatment increased the production of seed-cone buds by 220% to 250% for trees in al 1 top-pruning regimes. In rep 2, the growth regulator was similarly effective on untopped trees (220%), but less effective on W5-topped (48%) and W3-topped (83%) trees.

Interwhorl branches were more responsive than whorl branches to $GA_{4/7}$ treatment (*Fig. 4*), the respective increases being 225% and 119% for seed-cone buds and 196% and 57% for pollen-cone buds. Branches in the lower crown also tended to be more responsive than those in the upper or middle crown (increases of 196 vs 138% for females and 57 vs. 33% for males).



U=BRANCHES UNTHINNED I= INTERWHORL BRANCHES REMOVED
I+W=I+WEAKER WHORL BRANCHES REMOVED

Figure 3. — Flowering response to top pruning, branch thinning and gibberellin $A_{4/7}$ treatments compared for rep 1 and 2.

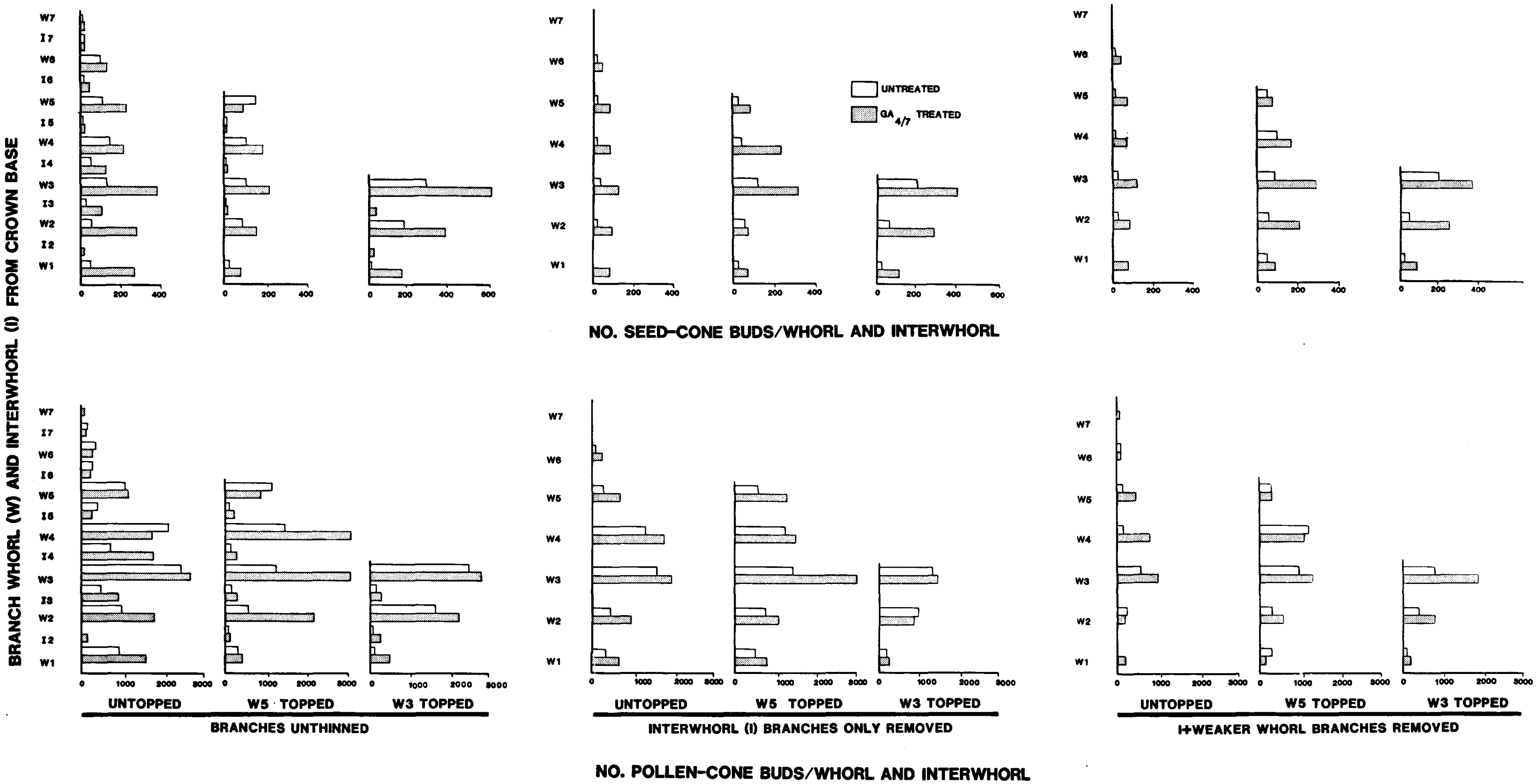


Figure 4. — Treatment effects on the within crown distribution of cone buds (W = whorl and I = interwhorl branches counted from the base of the live crown, reps pooled, n =12).

Seed-cone survival

Due to damaging spring frosts during the susceptible post-emergent 'flower' stage, overall only 58% of the seed cones initiated survived to maturity. Cone survival was independent of top-pruning and branch-thinning regimes but was adversely affected by $GA_{4/7}$ treatment the previous year (*Table 1*). Although $GA_{4/7}$-treated trees had a 37% higher abortion rate, they still produced on average 130% more seed cones each than nontreated trees ($P < 0.01$).

Discussion

Trees in the two orchard blocks responded differently to top pruning (*Table 2*). Top pruning of rep 1 trees depressed female and male flowering disproportionately to its severity, based on contributions by the removed upper and middle crown in untopped trees. In orchard rep 2, the light top pruning also depressed flowering, but only in proportion to the lost productivity of the removed upper crown. With the more severe pruning, the tree production of seed-cone buds actually increased, and pollen production remained the same.

Unlike branch-thinning and $GA_{4/7}$ treatments, which were randomized within top-pruning regimes and showed no interaction with reps, topping treatments were systematically blocked within reps (see Methods). Yet, there is no evidence from past flowering records to suggest that the top pruning × rep interaction was an artifact of site variation. Other than in the severe topping treatment, rep 1 trees flowered more profusely than rep 2 trees. Rep 1 trees also were initially larger and more vigorous, and that may account for their different responses to top pruning.

The developmental fate of a bud appears to be closely associated (through hormonal and(or) nutritional status) with the vigor of the shoot on which it is borne (see reviews by Ross and Pharis, 1985, 1987). Individual species vary somewhat, but the general relationship between shoot vigor (decreasing) and probable bud development is: strong vegetative > seed cone > intermediate vegetative > pollen cone > weak vegetative (Wareing, 1958; Tompsett, 1978; Bonnet-Masimbert *et al.*, 1982). The suggestion has been made (Hand and Griffin, 1979; Ross and Pharis, 1982, 1987) that top pruning may promote, inhibit or have a neutral effect on flowering depending on how the vigor status of the remaining shoots is affected.

The middle- and lower-crown branches of rep 1 trees were still moderately vigorous at time of treatment (*Fig. 2A*), and upon release from apical control they responded with greatly enhanced vegetative growth (*Fig. 2D*). Many shoots that otherwise would have had a potential for producing seed or pollen cones were possibly elevated to a vigor class less conducive to reproductive differentiation. A similar depression of flowering disproportionate to the productive capacity of the crown removed (*Table 2*) is typical of the response to a light top pruning (Long *et al.*, 1974; Varnell, 1969; Copes, 1973; Hand and Griffin, 1979). Rep 2 trees responded less vigorously to light top pruning, and their flowering was correspondingly less affected by this treatment.

Contrast this to the enhanced flowering observed in especially older trees following removal of the vigorous upper and middle crown (Matheson and Willcocks, 1976; Hand and Griffin, 1979; Nienstaedt, 1981; Masters, 1982; Philipson, 1985). Prior to top pruning the lower crown of such trees consists of numerous shoots of intermediate-to-low vegetative vigor and potential for differentiating seed cones (Wareing, 1958; Tompsett, 1978). Upon release from apical control these more aged shoots respond with but a modest increase in vegetative vigor (Matheson and Willcocks, 1976; Hand and Griffin, 1979). Shoots of previously intermediate vigor may be elevated to a moderate-vigor class where their potential for differentiating seed cones is greater; similarly for suppressed shoots with regard to male flowering. The lower crown of rep 2 trees approximated older trees in its flowering and growth response to severe top pruning. Contrast it (*Figs. 2G* to *H*) with the more vigorous growth response and associated depression of flowering characteristic of rep 1 trees (*Figs. 2D* to *E*).

A similar vigor hypothesis was advanced by Tompsett and Fletcher (1979) to explain the action of $GA_{4/7}$. Recent evidence (Ross, 1983; Pharis and Ross, 1986) suggests that the growth regulator has a direct morphogenic effect on flowering in conifers independent of its ability to enhance shoot or bud vigor. However, it is noteworthy that $GA_{4/7}$ was more effective in promoting female flowering for interwhorl than whorl branches; for lower- than upper-crown branches (*Fig. 4*); for rep 2 than rep 1 trees; and in rep 1 for untopped than topped trees (*Fig. 3*). In all instances it was the less vigorous and less fecund branches or trees that responded best.

Branch thinning was tested in conjunction with top pruning on the assumption that opening the dense crown of these seedlings (*Fig. 2*) would create more favorable light and temperature conditions for flowering. This clearly was not the case (*Figs. 3* and *4*, *Tab. 3*). Removal of interwhorl and smaller whorl branches had no consistent effect on female productivity of remaining branches, and it significantly depressed their production of pollen-cone buds.

These results are not inconsistent with the vigor hypothesis if one assumes that there is an important difference in the growth response to branch thinning and top pruning. When a branch is released from apical control, as in top pruning, it is typically the more vigorous distal shoots on which seed cones are normally borne that respond with the greatest increase in growth. In open-grown seed orchard trees, these are exposed shoots whose growth is not normally limited by low light, so that neither their vigor nor potential for differentiating seed cones should be greatly affected by branch thinning. This is not true for the more proximal, less vigorous shoots that produce the majority of pollen cones. Exposed to higher light intensities following branch thinning, their vegetative vigor may be elevated to a degree that is inhibitory to male differentiation, and may or may not be conducive to female differentiation.

For reasons already discussed, we were only able to assess the first-year flowering response to top pruning and branch thinning, which may or may not reflect longer term effects. That will depend on how the residual crown readjusts over time to initial treatment. Theory predicts, and studies on various conifers are beginning to confirm, that crown training beginning at an early age can be a valuable tool, not only for maintaining orchard trees at a manageable size but also for maximizing the production of potential bearing shoots (Sweet and Krugman, 1978; Griffin and Hand, 1979; Longman and Dick, 1981; Katsuta and Itoo, 1986; Ross and Eastham, 1986). Our results, however, illustrate the desirability of basing crown training regimes on an understanding of those physiological, morphological and positional attributes (all interrelated) of shoots that govern the potential for differentiating seed and pollen cones.

Finally, the operational use of $GA_{4/7}$ to enhance Douglas-fir seed orchard yields bears special mention. Heretofore, practical difficulties of applying the growth regulator to especially larger trees have restricted the use of this highly effective treatment (Ross and Pharis, 1982; Bonnet-Masimbert, 1987). The preferred method of application for Douglas-fir — continuous stem injection by the "hanging bottle" technique used here — is very labor intensive. A much simplified method was recently described by Philipson (1985) for treating pole-size *Picea sitchensis* (Bong.) Carr. grafts. A concentrated ehanolic solution of $GA_{4/7}$ is injected into shallow holes drilled on opposite sides of the main stem, followed by retreatment two weeks later. Ross and Bower (1989) have since shown that a single injection of $GA_{4/7}$ at the proper dose and time can be a highly cost-effective treatment for promoting flowering in Douglas-fir seed orchards, especially when applied in conjunction with stem girdles.

Acknowledgements

This study was conducted with help from the Saanich seed orchard staff. We also acknowledge the able assistance of Research Technicians C. Hollesreund and R. Painter, with appreciation to W. Bergerud and D. Errico of the Biometrics Group for input on experimental design and statistical analysis.

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Outcrossing Rates and Seed Characteristics in Damaged Natural Populations of Abies alba Mill.

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(Received 25th March 1988)

Abstract

Open pollinated seeds were collected of 251 single trees originating from 9 natural *Abies alba* populations located in the southwest of Western Germany. On an average the weight per 1000 seeds was 47 g and the amount of empty seeds 29%. Results of isozyme analyses are reported for the enzyme systems IDH and 6-PGD. Heterozygote frequencies of the progeny in general were found to cor-