617—624 (1981). —— DIXON, R. K., PALLARDY, S. G., GARRETT, H. E., COX, G. S., and SANDER, I. L.: Comparative water relations of container-grown and bare-root ectomycorrhizal and nonmycorrhizal *Quercus velutina* seedlings. Canadian Journal of Botany **61**: 1559—1565 (1983). —— DIXON, R. K., GARRETT, H. E., COX, G. S., MARX, D. H., and SANDER, I. L.: Inoculation of three *Quercus* species with eleven isolates of ectomycorrhizal fungi. I. Inoculation success and seedling growth relationships. Forest Science **30**: 364—372 (1984). —— DUNLAP, J. R. and BARNETT, J. P.: Influence of seed size on germination and early development of loblolly pine (*Pinus taeda* L.) germinants. Canadian Journal of Forest Research **13**: 40—44 (1983). —— EVANS, G. C.: The quantitative analysis of plant growth. University of California Press, Berkeley, CA 734 p. (1972). —— HACSKAYLO, E.: Carbohydrate physiology of ectomycorrhizae. In Ectomycorrhizae — their ecology and physiology (G. C. MARKS and T. T. KOZLOWSKI, eds.), p. 207—230 (1973). —— HARLEY, J. L. and S. E. SMITH: Mycorrhizal symbiosis. Academic Press, NY, NY, 483 p. (1983). —— HOAGLAND, D. R. and ARNON, D. I.: The water-culture method for growing plants without soil. Calif. Agric. Exp. Sta. Cir. 347 (1939). —— LAIHO, O.: *Paxillus involutus* as a mycorrhizal symbiont of forest trees. Acta For. Fenn **106**: 1—73 (1970). —— LEDIG, F. T. and PERRY, T. O.: Net assimilation rate and growth in loblolly pine seedlings. Forest Science **15**: 431—438 (1969). —— LINNEMANN, G.: Rassenunterschiede bei *Pseudotsuga taxifolia* hinsichtlich der Mycorrhiza. Alg Forst Jagdztg **131**: 41—47 (1960). —— LONG, A. J.: Genotype and ectomycorrhizal fungi as factors in feeder root development and patterns of growth in four and one-half-month old loblolly pine (*Pinus taeda* L.) seedlings. Ph.D. diss., N. C. State Univ., Raleigh. 127 p. (Diss. abstr. 74-19009) (1973). —— LUNDEBERG, G.: The formation of mycorrhizae in different provenances of pine (*Pinus sylvestris* L.). Svensk Bot Tidskr **62**: 249—255 (1968). —— MARX, D. H.: The influence of ectotrophic mycorrhizal fungi on the resistance of pine roots to pathogenic infections. I. Antagonism of mycorrhizal fungi to root pathogenic fungi and soil bacteria. Phytopathology **59**: 159—163 (1969). —— MARX, D. H.: Variability in ectomycorrhizal development and growth among isolates of *Pisolithus tintorius* as affected by source, age and reisolation. Canadian Journal of Forest Research **11**: 168—174 (1981). —— MARX, D. H. and BRYAN, W. C.: Formation of ectomycorrhizae on half-sib progenies of slash pine in aseptic culture. Forest Science **17**: 481—492 (1971). —— MARX, D. H. and BRYAN, W. C.: Growth and ectomycorrhizal development of loblolly pine seedlings in fumigated soil infested with the fungal symbiont *Pisolithus tinctorius*. Forest Science **21**: 245—254 (1975). —— MARX, D. H., RUEHLE, J. L., KENNY, D. S., CORDELL, C. E. RIFFLE, J. W., MOLINA, R. J., PAWUK, W. H., NAVRATIL, S., TINUS, R. W., and GOODWIN, O. C.: Commercial vegetative inoculum of *Pisolithus tinctorius* and inoculation techniques for development of ectomycorrhizae on container-grown tree seedlings. Forest Science **28**: 373—400 (1982). —— MEXAL, J. and REID, C. C. P.: The growth of selected mycorrhizal fungi in response to induced water stress. Canadian Journal of Botany **51**: 1579—1588 (1973). —— MOSER, M.: Der Einfluß tiefer Temperaturen auf das Wachstum und die Lebenstätigkeit höherer Pilze mit spezieller Berücksichtigung von Mycorrhizapilzen. Sydowia **12**: 386—399 (1958). —— REID, C, P. P., KIDD, F. A., and EKWEBELAM, S. A.: Nitrogen nutrition, photosynthesis, and carbon allocation in ectomycorrhizal pine. Plant and Soil **71**: 415—432 (1983). —— SCHOPMEYER, C.S.: Seeds of woody plants in the United States. Agricultural Handbook 450. USDA, Washington, D.C. (1974). —— THEODOROU, C. and BOWEN, G. D.: Mycorrhizal response of radiata pine in experiments with different fungi. Australian Forestry **34**: 183—191 (1970). —— WRIGHT, E. and CHING, K. K.: Effect of seed source on mycorrhizal formation on Douglas-fir seedlings. Northwest Science **36**: 1—6 (1962).

The Effect of Water Spray Cooling Treatment on Reproductive Phenology in a Douglas-Fir Seed Orchard

By A. M. K. FASHLER[1]) and Y. A. EL-KASSABY[2])*)

(Received 11th February 1987)

Abstract

The effectiveness of reproductive bud cooling on the genetic efficiency in a Douglas-fir [*Pseudotsuga menziesii* (MIRB.) FRANCO] seed orchard was tested by comparing the reproductive bud phenology in three cooled and three uncooled years. The cooling system was found to influence two major elements affecting seed orchard genetic efficiency, namely pollen contamination levels and panmictic equilibrium, as well as a number of additional factors, including insect infestation, frost damage, seed yield, and management effectiveness. Based on these results, a solid-set overhead irrigation/cooling system is recommended for Douglas-fir seed orchards.

Key words: Pseudotsuga menziesii, seed orchards, overhead cooling systems, panmictic equilibrium, contamination.

Zusammenfassung

In einer Douglasien-Samenplantage wurde die Auswirkung der Kühlung reproduktiver (Blüten-)Knospen auf die genetische Effizienz geprüft, indem die Phänologie der Blütenknospen in drei Jahren mit Kühlbehandlung mit der in drei Jahren ohne Kühlbehandlung verglichen wurde. Es wurde gefunden, daß die Kühlung zwei Hauptelemente beeinflußt, nämlich das Niveau der Pollenkontamination und das panmiktische Gleichgewicht, außerdem eine Anzahl zusätzlicher Faktoren, wie Insektenbefall, Frostschaden, Samenausbeute und Effizienz der Bewirtschaftung. Auf diesen Ergebnissen basierend, wird ein dauerhaft eingebautes Beregnungssystem für Douglasien-Samenplantagen empfohlen, das über Gipfelhöhe der Pflanzen sprüht.

[1]) Forest Consultant, 2188 West 46th Avenue, Vancouver, B.C., Canada V6M 2L1 (formerley with Pacific Forest Products Ltd., Victoria, B.C.).

[2]) Tree Improvement Supervisor, CIP Inc., Tahsis Pacific Region, Saanich Forestry Centre, 8067 East Saanich Road, RR # 1, Saanichton, B.C., Canada V0S 1M0 and Adjunct Professor, Department of Forest Sciences, Faculty of Forestry, University of British Columbia, Vancouver, B. C., Canada V6T 1W5.

*) To whom reprint requests should be addressed.

Introduction

The advantages of seed orchards for production of consistent and abundant yields of genetically-improved seed for reforestation programs are recognized (cf. FAULKNER 1975). The resulting seed crop is expected to reflect both the genetic superiority and broad genetic base present among the orchard trees. The degree to which a seed orchard achieves this expectation is called the "genetic efficiency" (ADAMS and JOLY 1980). Several conditions are required to achieve maximum genetic efficiency in wind-pollinated seed orchards. These include: a) parental reproductive balance, b) isolation from background pollen, c) minimal rates of selfing, d) random mating with equal compatibility, and e) reproductive synchronization (WOESSNER and FRANKLIN 1973). In short, if a seed orchard crop is to reflect its expected theoretical genetic gain, the orchard itself must represent a nearly perfect, closed, panmictic population.

Several management practices have been implemented in seed orchards to increase the genetic efficiency. These include location and design choice (GIERTYCH 1975; WERNER 1975) and crop-management options such as supplemental mass pollination (VAN DER SIJDE 1971). Water-spray colling of seed orchard trees has been proposed to reduce pollen contamination by delaying reproductive bud phenology (SILEN and KEANE 1969; FASHLER and DEVITT 1980). This procedure provides temporal isolation for the seed orchard trees and has been proven effective in the reduction of pollen contamination (EL-KASSABY and RITLAND 1986a) and in decreasing cone and seed insect damage (MILLER 1983).

It has been demonstrated for several coniferous species that heat sums have a significant role on flowering time (KRAMER and KOZLOWSKI 1979). As differences in origin among plus trees increase, differences in reproductive bud burst timing among their propagules are expected in a common environment (i.e., seed orchard). Indeed, significant differences in reproductive bud burst timing among clones and open-pollinated families in a Douglas-fir [*Pseudotsuga menziesii* (MIRB.) FRANCO] seed orchard have been reported and elevational differences accounted for the reported variation (EL-KASSABY *et al.* 1984).

The purpose of this paper is to determine the extent of reproductive bud delay by water cooling on the genetic efficiency in a Douglas-fir [*Pseudotsuga menziesii* (MIRB.) FRANCO] seed orchard by comparing the reproductive bud phenology during three years of cooling treatment with that from three uncooled years.

Materials and Methods

The 3.4 ha CIP Inc. (formerly Pacific Forest Products Ltd.) high-elevation Douglas-fir seed orchard at Saanichton, B.C., Canada, provided the material for this study. The orchard consists of a combined clonal/seedling breeding population with 63 clones and 37 open-pollinated families selected from elevations between 450 and 1,000 m on southern Vancouver Island and the south coastal mainland of British Columbia. The orchard is planted in a randomized incomplete block design replicated 16 times (16 blocks). For the purpose of pollen and seed management, the seed orchard population is differentiated according to elevation zones (450—599 m, 600—749 m, and greater than 750 m), and nature of material (open-pollinated vs. grafted trees).

The overhead, solid-set irrigation system provided the cooling treatment during reproductive bud development in 1976, 1978 and 1983. A complete description of the system is reported elsewhere by FASHLER and DEVITT (1980).

Reproductive bud phenology information for the entire seed orchard population (every sexually-active tree) was collected in all six study years. Each tree was monitored every second day throughout the pollination period. The phenological classification followed those of HO (1980) and OWENS *et al.* (1981). To achieve uniformity over the six years, data collected from earlier years which followed the classification of FASHLER and DEVITT (1980) were slightly modified to follow the previously mentioned monitoring system. In all years, the critical stage of female ("flower") receptivity was reached when the seed cone had just emerged fully from the bud scales. The dates of pollen shedding were the critical stage for the male reproductive stage. Reproductive phenology classes reflecting early, intermediate and late reproductive bud development were subjectively created (EL-KASSABY *et al.* 1984).

With the exception of 1977, background pollen levels were monitored through the use of pollen traps (glass slides coated with 27 parts epoxy resin and one part catalyst). Pollen slides were placed inside and around the perimeter of the orchard and mounted on posts 175 cm above ground level. A total of five and six stations were used inside and outside the orchard, respectively. Four slides, one facing each cardinal direction, were placed at a 45 angle. After a seven hour exposure (approximately between 8:00 am and 3:00 pm) the pollen slides were collected and pollen grains were counted. EBELL and SCHMIDT (1964) have indicated that the greatest Douglas-fir daily pollen release occurred between 10:00 am and 4:00 pm. Pollen grains were counted using a light microscope (x100). A total of 30 fields (1.46 mm diameter) were counted for each slide and the average number of pollen grains per day per position was estimated. In addition to the pollen traps, the reproductive phenology of the surrounding stands was also monitored.

The time to female receptivity and pollen shedding for clonal and seedling trees was calculated as the number of days from January 1st of each year. The data were analyzed using one-way ANOVA to test differences among trees belonging to three elevational zones (450—599 m, 600—749 m, and greater than 750 m) under cooling and natural conditions.

Results

Differences in both the length of pollination period and the number of genotypes reproductively active at a given time, occur between cooled and uncooled years (*Fig. 1*). In the uncooled years, the extent of female receptivity and pollen release averaged 24.3 and 24.7 days, respectively. Not only is pollination occuring over a long period, but also the maximum number of receptive females and pollen shedding trees occurs over a relatively longer period as well. In general, the seed orchard peak pollination period averages 15 days in the uncooled years.

The situation in cooled years indicates a much-reduced pollination period (17.3 days for females and 18.3 for males), averaging seven days shorter. In addition, the maximal number of available flowering females and males occurs later than the local pollen flight and over a relatively short time averaging 11 days. The unusually cold spring temperatures in 1982 (an uncooled year) caused an imitation of the cooling treatment, producing somewhat sharper peaks in female receptivity and pollen density than would be expected with no cooling (*Fig. 1*). The overall length of the pollination period, however, remained longer than the average in cooled years.

The local pollen (background) flight (*Fig. 1*) suggests no delay between the period of maximum female receptivity and local pollen flight in uncooled years. The comparison in cooled years indicated a delay from eight days (1976) to 14 days (1983) for an average 11-day delay from the local pollen flight to the height of seed orchard flower receptivity.

Differences in the numbers of available receptive females and available pollen-shedding males were apparent at various stages (i.e., early, intermediate and late) in the pollination period in both cooled and uncooled years. Cooling appears to have greatly reduced the magnitude of these differences in 1976, although little effect is noted by cooling in 1978 and 1983. The disproportion in females and males suggest potential differences in the viable seed produced in each phenological class due to lack of pollen.

Table 1 presents the variation in reproductive bud-burst timing among and within elevational zones for clones and open-pollinated families for the six-year period. The total

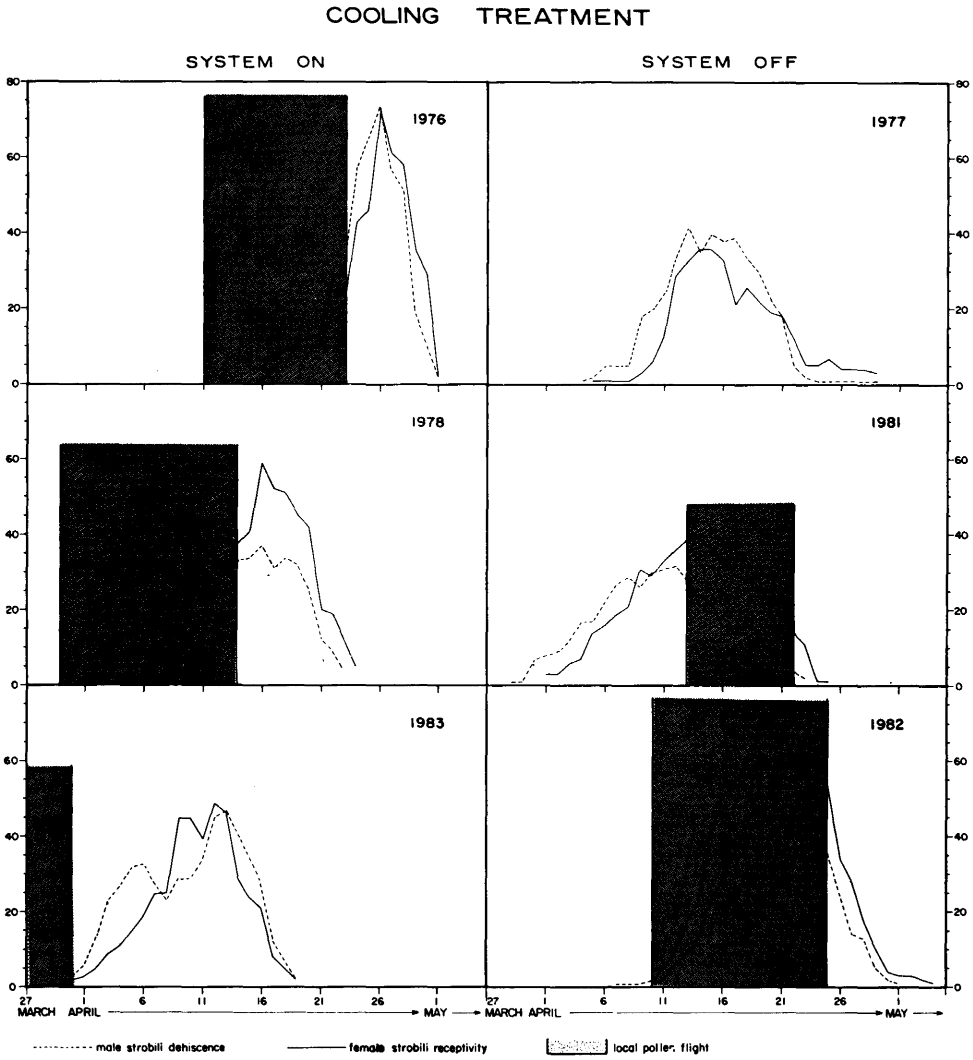

Fig. 1. — Comparison of pollination periods and local pollen flight between cooled (1976, 1978 and 1983) and uncooled (1977, 1981 and 1982) years.

number of significant difference cases among the three elevational zones for the uncooled and cooled years are six and three, respectively (*Table 1*). Significant differences for males or females in the uncooled years are twice as many as those observed in the cooled years. Thus, cooling treatment has an effect in reducing the observed differences in phenology among the three elevational zones; an important feature of the general reduction in flowering time from the cooling treatment.

Discussion

The primary effect of the cooling treatment is the delay of reproductive development due to evaporative cooling. The comparison in this study of three years of orchard cooling with three intervening years without cooling verify a delay averaging seven days. Reproductive bud delay significantly improves genetic efficiency by reducing contamination from surrounding local trees (Silen and Keane 1969; Fashler and Devitt 1980). Results of contamination estimates for 1983 (cooled year, El-Kassaby and Ritland 1986a) and 1984 (uncooled year, El-Kassaby and Ritland 1986b) showed that the average contamination levels were close to 0.2% ± 5.7% and 12.2% ± 9.2%, respectively. The extent of potential contamination for the "early" class for a cooled and uncooled year (1983 and 1984) was even more dramatic. For trees flowering early in 1983 (cooled) the rate of contamination was 9% (El-Kassaby 1985) while 24% was estimated for the same class in 1984 (El-Kassaby and Ritland 1986b). Thus, the cooling treatment improved the genetic quality of the seed orchard crop by reducing or eliminating contamination from outside pollen sources as well as by promoting crosses only among seed orchard trees.

Further improvement to the genetic quality could be attributed to better panmictic equalibrium within the seed-orchard population. The duration of receptivity of a seed strobilus ranges from four to six days (Owens *et al.* 1981) and the optimal duration of pollen shedding varies between three to five days (Barner and Christiansen 1962). The longer pollination periods observed in the uncooled years could produce a continuum of various breeding population components throughout the pollination period, since females opening early would be unavailable for fertilization by pollen from later-flowering trees and *vice versa.* In cooled years, however, the orchard's overall pollination period is shorter (*Fig. 1*) thus improving panmixis.

The shorter pollination period produced by the cooling treatment may be explained by heat shock (Boyer 1973). In studies of heat effects upon plant development, heat is usually expressed in degree-hours or degree-days above a

Table 1. — Variation in reproductive bud burst timing among elevational zones.

Cooling	Year	S.O.V.	Clonal Trees				Open-pollinated Trees			
			Females		Males		Females		Males	
			df	MS	df	MS	df	MS	df	MS
ON	1976	Among Elev.	2	25.12^{ns}	2	5.78^{ns}	2	0.89^{ns}	2	0.45^{ns}
		Residual	50	15.31	50	8.37	35	2.58	35	2.23
	1978	Among Elev.	2	36.31*	2	42.03^{ns}	2	10.08^{ns}	2	45.51**
		Residual	57	10.46	58	21.68	35	8.21	35	8.30
	1983	Among Elev.	2	29.69^{ns}	2	73.86*	2	10.45^{ns}	2	16.36^{ns}
		Residual	49	18.23	60	18.34	33	7.57	34	15.80
OFF	1977	Among Elev.	2	20.22^{ns}	2	5.69^{ns}	2	19.71*	2	20.64**
		Residual	29	32.85	44	17.85	35	7.01	35	4.96
	1981	Among Elev.	2	41.59^{ns}	2	261.95*	2	324.35*	2	1065.90*
		Residual	24	40.40	44	82.35	34	175.78	34	255.92
	1982	Among Elev.	2	19.43^{ns}	2	51.96^{ns}	2	106.49^{ns}	2	267.56*
		Residual	29	513.12	56	48.15	34	51.01	34	69.42

* Significant at $P < 0.05$; **, Significant at $P < 0.01$; ns, Not Significant

biologically-established threshold temperature. Heat sums associated with a phenological event for a given species often vary among locations and over years in the same location. Any change in source altitude or latitude of a species is always associated with changes in the average required heat units to attain a specific phenological stage. EBELL and SCHMIDT (1964) have demonstrated that Douglas-fir at a high elevation (2,500—3,500 ft.) required half of the degree-hours for pollen dispersal needed by populations at low elevation (1,000 ft) and the same latitude. BOYER (1973) has indicated that longleaf pine (*Pinus palustris* MILL.) required an average of 9,862 degree-hours above 50° F between January 1 and peak pollen shedding in North Carolina in 1967 and 1968, while values for the same two years in southwestern Alabama averaged 11,341 degree-hours. MAGOON and CULPEPPER's (1932) study on sweet corn supports this hypothesis with the added information that a smaller heat sum was needed for a single genetic strain of corn to reach maturity in Maine (cooler) than in Virginia (warmer).

In our study, variation in bud burst timing was reduced in the years when the trees were exposed to the cooling treatment. The ANOVA results on both the clonal and open-pollinated trees support MAGOON and CULPEPPER's work and indicate that flowering actually progressed at a faster pace after the cessation of the cooling treatment. The heat units delivered to the trees in the latter part of the season (i.e., after cooling) is higher per day than received in the earlier part (i.e., no cooling). In other words, a larger heat-sum may be needed for the same effect in early than in late flowering years (i.e., cool vs. warm springs). Differences between the cumulative degree days above 5° C between 1981 and 1982 for a four-month period (January to April) have shown to drastically affect the timing and magnitude of the reproductive bud phenology in that orchard (EL-KASSABY *et al.* 1984, *Table 3* and *Fig. 1*). In our study, the reduced variation among sources from low, medium and high elevations may also have reflected this phenomenon.

An extended pollination period may also increase the chance of selfing, particularly in periods characterized by a decreased number of flowering trees. However, the colling treatment caused a compaction of the pollination period, improving the likelihood of panmixis and increasing the frequency of outcrossing. Assessment of the exact effect on outcrossing rate is a difficult parameter to identify in the current study due to the confounding effect of possible pollen contamination, hence the considerable data gathered on filled and empty seed yields is not presented. This relationship and the effect of contamination on the net outcrossing within this orchard seed crop are discussed in detail elsewhere (EL-KASSABY *et al.* 1986a, EL-KASSABY and RITLAND 1986a and b, RITLAND and EL-KASSABY1985).

Other effects of cooling have been shown advantageous in earlier reports. A substantial reduction in frost damage to both receptive females and developing conelets has been observed in cooled years. The shift and delay in the reproductive phenology have reduced the chance of damage caused by the late spring frosts common to the Saanichton area (CHILTON 1980). The cooling system is being used also as a frost-protection system similar to systems routinely used in agricultural and horticultural crops (LOMBARD *et al.* 1966, GILBERT *et al.* 1970, GAY *et al.* 1971, ANDERSON *et al.* 1975). It must also be emphasized that the cooling of the orchard trees and the subsequent delay of the reproductive phenology could set up the majority of the crop to very late severe frosts (N. WHEELER, personal communication). Fortunately, such events were not experienced in the Saanichton area during this study.

The cooling treatment has been effective also in reducing the amount of insect damage (MILLER 1983). By retarding the phenological development of seed orchard strobili, trees are forced out of synchronization with the insect population which, having responded to the local weather conditions, subsequently lay their eggs outside the seed orchard. This physical prevention of insect infestation may be the only safe alternative for seed orchards located in populated suburban areas sensitive to the application of pesticide sprays. Annual surveys for the Douglas-fir cone gall midge (*Contarinia oregonensis* FOOTE) have indicated that a pesticide spray is needed in uncooled years. Dimethoate is the insecticide used operationally in Douglas-fir orchards for control of cone and seed insects and the application is effective only when applied before the conelets are in their pendant position (JOHNSON and HEDLIN 1967). Within a non-cooled orchard, variation in the time when conelets reach this stage is at its maximum, therefore, an effective control method requires several application times.

In addition to affecting the dynamics of orchard flower phenology and seed predation, the effect of cooling is apparent also on seed-orchard management procedures. A shorter, more-compact pollination period has improved management effectiveness by reducing costs. Less labour has been needed in the cooled years, with fewer visits per tree for supplemental mass pollination and less need to pollinate intermediate flowering trees, after cooling and open pollination, their seeds exhibit high embryo heterozygosity (El-Kassaby *et al.* 1986b) and high seed yield (El-Kassaby *et al.*1984). This treatment may then be focussed on the early and late phenological classes where it can effectively increase the pollen cloud gene pool and produce a greater proportion of seeds of high genetic quality. Other seed orchard management practices will also be undertaken over a shorter period due to the shorter pollination period, thereby reducing the labour cost of additional seasonal employees, however, larger crews are needed for that period.

In conclusion, reproductive bud cooling has been shown to be effective in a variety of biological and managerial seed orchard factors. The data indicate that a solid-set irrigation/cooling system is highly recommended for Douglas-fir seed orchards. The restriction on tree height and the availability of a reliable water source are two limiting factors for this technique. Top pruning is an effective method for keeping the orchard trees to a manageable size. The cost and scarcity of water source are usually the major limiting factors for the overhead irrigation/cooling system.

Acknowledgements

We thank R. Bower, R. Davidson, C. Heaman, V. Korelus, M. Meagher, R. Silen, J. Webber and N. Wheeler for reviewing the manuscript, D. Andrews and C. Cook for technical assistance, M. Robertson for typing and A. Philip for drafting. The authors appreciate the moral support of all Pacific Forest Products Ltd. staff. The use of the computing facility of the Faculty of Forestry, University of British Columbia is highly appreciated.

References

Adams, W. T. and R. J. Joly: Allozyme studies in loblolly pine seed orchards: clonal variation and frequency of progeny due to self-fertilization. Silvae Genet. **29**: 1—4 (1980). —— Anderson, J. L., G. L. Ashcroft, E. A. Richardson, J. F. Alfaro, R. E. Griffin, G. R. Hanson and J. Keller: Effects of evaporative cooling on temperature and development of apple buds. Amer. Soc. Hort. Sci. **100**: 229—231 (1975). —— Barner, H. and H. Christiansen: The formation of pollen, the pollination mechanism and the determination of the most favourable time for controlled pollination in *Pseudotsuga menziesii*. Silvae Genet.**11**: 89—102 (1962). —— Boyer, W. D.: Air temperature, heat sums, and pollen shedding phenology of longleaf pine. Ecology **54**: 420—426 (1973). —— Chilton, R. R. H.: Saancich Peninsula spring-time freeze risk. Province of British Columbia, Ministry of Environment, Assessment and Planning Divisin, APD Bulletin **1**, 25 pp. (1980). —— Ebell, L. F. and R. L. Schmidt: Meteorological factors affecting conifer pollen dispersal on Vancouver Island. Can. Dep. For. Publ. 1036. 28 pp. (1964). —— El-Kassaby, Y. A.: Reproductive phenology, outcrossing rate, contamination, and supplemental mass pollination in a Douglas-fir seed orchard. Unpublished Research Grant Contract Report Prepared for the British Columbia Ministry of Forests (Research Branch). 29 pp. (1985). —— El-Kassaby, Y. A., A. M. K. Fashler and O. Sziklai: Reproductive phenology and its impact on genetically improved seed production in a Douglas-fir seed orchard. Silvae Genet. **33**: 120—125 (1984). —— El-Kassaby, Y. A., J. Parkinson and W. J. B. Devitt: The effect of crown segment on the mating system in a Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] seed orchard. Silvae Genet. **35**: 149—155 (1986). —— El-Kassaby, Y. A. and K. Ritland: Low Levels of Pollen Contamination in a Douglas-Fir Seed Orchard as Detected by Allozyme Markers. Silvae Genet. **35**, 224—229 (1986a). —— El-Kassaby, Y. A. and K. Ritland: The relation of outcrossing and contamination to reproductive phenology and supplemental mass pollination in a Douglas-fir seed orchard. Silvae Genet. **35**: 240—244 (1986b). —— El-Kassaby, Y. A., K. Ritland, A. M. K. Fashler and W. J. B. Devitt, 1987. The effect of reproductive phenology timing on the mating structure in a Douglas-fir seed orchard. Silvae Genet. (in press). —— Fashler, A. M. K. and W. J. B. Devitt: A practical solution to Douglas-fir seed orchard pollen contamination. For. Chron. **56**: 237—241 (1980). —— Faulkner, R.: Seed orchards. For. Comm. London, Bull. No. 54 (1975). —— Gay, L. W., R. L. Stebbins and R. M. Black: The effect of spray irrigation on plum temperature. Northwest Sci. **45**: 200—208 (1971). —— Giertych, M.: Seed orchards designs. *In:* Faulkner, R. (ed.) Seed Orchards. For. Comm. London, Bull. **54**: 25—37 (1975). —— Gilbert, D. E., J. L. Myer, J. J. Kessler, P. D. LaVine and C. V. Carlson: Evaporative cooling of vineyards. Calif. Agr. **24**: 12—14 (1970). —— Ho, R. H.: Pollination mechanism and seed production potential in Douglas-fir. For. Sci. **26**: 522—528 (1980). —— Johnson, N. E. and A. F. Hedlin: Douglas-fir cone insects and their control. Can. Dep. Agric. For. Branch Publ. **1169**. 11 pp. (1967). —— Lombard, P. B., P. H. Westigard and D. Carpenter: Overhead sprinkler system for environmental control and pesticide application in pear orchards. Hort Sci. **1**: 95—96 (1966). —— Magoon, C. A. and C. W. Culpepper: Response of sweet corn to varying temperatures from time of planting to canning maturity. U.S. Dep. Agric. Tech. Bull. **312**. 39 pp (1932). —— Miller, G. E.: Evaluation of the effectiveness of cold-water misting of trees in seed orchards for control of Douglas-fir gall midge (Diptera: Cecidomyiidae). J. Econ. Entomol. **76**: 916—919 (1983). —— Owens, J. N., S. J. Simpson and M. Molder: The pollination mechanism and the optimum time of pollination in Douglas-fir (*Pseudotsuga menziesii*). Can. J. For. Res. **11**: 36—50 (1981) —— Ritland, K. and Y. A. El-Kassaby: The nature of inbreeding in a seed orchard of Douglas-fir as shown by an efficient multilocus model. Theor. Appl. Genet. **71**: 375—384 (1985). —— Silen, R. R. and G. Keane: Cooling a Douglas-fir seed orchard to avoid pollen contamination. U.S.D.A. For. Serv. Res. Note PNW-101. 10 pp. (1969). —— van der Sijde, H. A.: Some aspects of hand pollination in seed orchards in South Africa. For. S. Afr. **12**: 67—73 (1971). —— Werner, M.: Location, establishment and management of seed orchards. *In:* Faulkner, R. (ed.) Seed orchards. For. Comm. London, Bull. **54**: 49—57 (1975). —— Woessner. R. A. and E. C. Franklin: Continued reliance on wind-pollinated southern pine seed orchards — Is it reasonable? *In:* Proc. 12th South. For. Tree Improv. Conf. pp. 64—73 (1973).