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HIGH-QUALITY COLLECTION AND PRODUCTION OF CONIFER SEED

PROCEEDINGS OF A WORKSHOP HELD NOVEMBER 14, 1979, IN EDMONTON, ALBERTA

Compiled by

R.F. HUBER

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ABSTRACT

A workshop was held to pass seed and cone information to field foresters, technicians, and nursery personnel involved with reforestation in Canada's western and northern region. Papers were presented on genetic quality of seed source: variation, improvement and certification; cone collection and processing—effects on seed quality and yield; lodgepole pine seed extraction; effects of insects on seed and cone production; conifer seed pathology; quick methods for determining seed quality in tree seeds; measuring quality of tree seed; and impact of seed quality in reforestation.

RESUME

Un atelier s'est tenu en vue du transfert d'informations sur les graines et les cônes aux forestiers sur le terrain, techniciens et pépiniéristes impliqués dans la restauration forestière dans l'ouest et le nord du Canada. Des documents ont été présentés sur la qualité génétique de l'origine des graines: variation, amélioration et certification; effets du ramassage et du traitement des cônes sur la qualité et la quantité des graines; l'extraction des graines de pin tordu latifolié; l'impact des insects sur la production de graines et de cônes; la pathologie des graines de conifères; des méthodes rapides pour déterminer la qualité des graines d'arbres; la mesure de la qualité des graines d'arbres et l'impact de celle-ci sur la restauration forestière.

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NOTE

The exclusion of certain manufactured products does not imply rejection nor does the mention of other products imply endorsement by the Canadian Forestry Service.

WELCOMING ADDRESS

It gives me great pleasure on behalf of the Canadian Forestry Service and the Northern Forest Research Centre to welcome you today.

The idea of a workshop on seed came from the Regional Reforestation Technical Committee, which is a committee of foresters from Manitoba, Saskatchewan, Alberta, and the CFS that reviews the reforestation programs in the region and recommends priorities to the Senior Advisory Committee for the lab here. One of its recommendations was to have more workshops--this is the second such workshop held this year.

I am pleasantly surprised and pleased at the size of the turnout. Although this started as a regional workshop, representation is much broader. A special welcome goes to the delegates from the Ontario Ministry of Forestry and those from British Columbia. I hope the benefits from the workshop will make the trip worth while.

If the workshop is a success, it will be encouragement for us to continue with other workshops. You people will, of course, judge the success yourselves.

G.T. Silver
Regional Director
of Forestry

INTRODUCTORY REMARKS

Forest regeneration is currently an important issue in forestry throughout Canada. In the Western and Northern Region, the growing annual harvest and continuing backlog buildup (approximately 16 000 ha in the region in 1978) has prompted large increases in regeneration budgets and plans. For example, nursery capacity increased from 7 to 14 million seedlings (container and bare root) during 1972-76 and doubled again from 1976 to 1980. There are currently eight government and four industrial nurseries producing forestry planting stock.

Seed demands are growing proportionately. For example, from 1978 to 1981 the seed demand in Alberta alone is expected to grow from 800 to 1150 kg for lodgepole pine and from 2400 to 3600 kg for white spruce to support both planting and seeding programs.

There is an acute awareness of the importance of an adequate supply of quality seed to support the expanding reforestation effort. This workshop is designed to address some of the important aspects of seed source, collection, handling, processing, and use as a practical support for reforestation operations.

L.G. Brace

ACKNOWLEDGMENTS

Thanks and appreciation to the authors who took the time to prepare and present their excellent papers. Also thanks to the staff of Pine Ridge Forest Nursery for taking time to prepare for the tour and hosting the luncheon.

R.F. Huber

GENETIC QUALITY OF SEED SOURCE:
Variation, Improvement and Certification

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ABSTRACT

Seed is the vehicle by which genetic quality is transmitted to future forests. An hypothetical example of the distribution of variation in genetic quality through an entire species population is given. Tree improvement strategies differ in the way sources of variation are exploited. Local seed is usually a safe source, but provenance trials may reveal fast growing and more broadly adaptable sources. The main function of provenance trials has been to provide data for the delineation of seed zones. This role is being questioned where tree improvement has progressed to the development of tested seed orchards. The array of wild and orchard seed sources currently utilized makes proper seed source identity essential. Where seed transactions occur between agencies, identity may require certification. A certification service for Canadian forest tree seed exports is provided by the Canadian Forestry Service to meet standards set by the Organization for Economic Cooperation and Development. Certification records indicate a significant movement of forest genetic resources, with exports exceeding domestic demand in some species.

INTRODUCTION

Genetic improvement of seed source is probably the cheapest way to increase growth and yield from our future forests. By the same token, improper regard to the genetic quality of seed provides a sure route to substantial losses in production. Seed is the starting point of the new forest; it is also the vehicle in which efforts behind a tree improvement program are carried into the forest. A genetic entity is sown with a seed, and no amount of subsequent silviculture can alter that fact.

The purpose of this paper is to provide nursery staff and forest managers with a moderately technical background to three aspects of the genetic quality of seed source:

1) origins of genetic variation that make its selection important and its improvement possible
2) procedures for its improvement
3) certification.

ORIGINS OF GENETIC VARIATION

Survival and growth of a tree are controlled by many characters that are themselves controlled by large numbers of genes. The timing of bud formation provides a useful example of these characters. Bud formation is well known as an indicator that "hardening-off" may proceed. In the young seedling, the timing of bud formation will not only determine frost hardiness, but will also affect height growth markedly. The variation found in this important character (Pollard and Ying, 1979) suggests it is controlled by many genes.

In the following example, the dates chosen are hypothetical and are intended to illustrate how different sources contribute to the variation in growth cessation expressed by seedlings of white spruce (*Picea glauca* (Moench) Voss). A single seedling, for example, may cease growth preparatory to bud formation on August 14 in a certain nursery. If this seedling were in some way cloned, little deviation from this date would be observed among the ramets. However, its siblings would vary, their individual dates of growth cessation perhaps ranging from August 10-20. If other families of seedlings from the same parental stand were examined, we might find this range expanded further, from August 10-26. Of course, stands themselves vary, although not by much within an elevational subzone of a single seed zone. However, in Alberta and British Columbia, seedlings from stands at higher and lower elevation bands or subzones account for pronounced variation within one seed zone (Roche, 1969). Add to this the variation expressed among all seed zones designated in a province and the date of growth cessation might range from July 31 to September 9, a span of 40 days. The contributing sources of variation, as discussed above, are illustrated diagramatically in Figure 1.

Additional variation exists beyond a provincial seed zone system. Furthermore, the hypothetical ranges mentioned above are as they might be expressed at one test site. Other test sites would invoke interaction between the new environments and the genetic composition of seedlings.

A tree improvement program may exploit any variation, from the clone to seed zone levels. The appropriate source of variation, *i.e.*, clones, families, stands, *etc.*, for selection depends very much on the strategy of the program.

TREE IMPROVEMENT PROCEDURES

A basic plan for tree improvement comprises five elements (Segaran, in press):

1) Provenance trials for the definition of seed zones and the identification of superior seed sources

2) Establishment of seed production areas as an interim measure
3) Selection of phenotypically superior trees (plus-trees) over a broad genetic base
4) Establishment of clonal and seedling seed orchards
5) Progeny and hybridization tests of selected trees

Although a widely used identifier of seed source, the term "provenance" did not appear in the foregoing account of sources of genetic variation. The reason for the apparent oversight is that provenance is an arbitrary term that refers to the locality of a population of trees or origin of seeds or trees (Callaham, 1964). Usually a provenance collection is a stand collection, but the number of trees represented often will be variable or unknown. Consequently, the geographic limits of a provenance may be difficult or impossible to define; this presents problems for future forest managers who may require large quantities of seed from a certain provenance.

The establishment and conduct of provenance trials is time-consuming, and the appropriate moment for enunciation of seed transfer rules or recommended provenances is often a contentious issue. Provenance trials will produce completely reliable forecasts of performance only after the trees have attained rotation age. Since this agé is typically in the range of 60-120 years, tree improvement programs must resort to interim measures to guide seed source selection and production.

The basic recommendation for seed supply is to use sources in the vicinity of the area to be planted; i.e., local seed. There is plenty of evidence to support such a simple guideline. Yeatman (1976), for example, reported that in nine out of ten test sites planted in Ontario and Quebec, local provenances of jack pine (Pinus banksiana Lamb.) or those from equivalent latitude, ranked among the best of all provenances, measured at age 10 years.

Local sources, however, may not always be the best adapted. On a severe site, the original population may consist of individuals that are the result of very intensive natural selection. If the site is then planted with nursery-grown seedlings derived at random from these parents, much of the selection intensity is lost and high mortality may result (Campbell, 1976). Under these conditions seed from higher altitudes or latitudes may be required; clearly, such recommendations cannot be made without due regard to the nature of sites requiring reforestation.

More widely appreciated and exploited is the fact that trials also reveal provenances whose performances are consistently superior over a wide range of test sites. For example, provenances of white spruce from the Ottawa Valley have grown exceptionally well on a wide variety of sites in eastern Canada and the Lake States (Teich et al., 1975). Provenances may show unexpected qualities, such as resistance to scleroderris canker (Gremeniella abietina (Lagerberg) Morelet), observed in vigorous jack pine provenances from eastern Ontario and Quebec (Teich, 1967). Opportunities thus revealed by provenance trials, coupled with problems in securing sufficient local seed for many sites, make seed transfer from distant sources inevitable. Moreover, the nurseryman can produce and control identity of his stock more easily when a limited number of broadly adapted seed sources are in use.

Because natural stands of trees are climatically adapted through selection to their locality, they are genetically distinct from provenances of climatically different locations. Seed transfer rules are devised and applied to ensure that seed movements do not result in reforestation with genetically unsuitable stock. Providing basic information on which to base these rules is a most important function of provenance trials. In practice, transfer rules are interpreted through the designation of seed zones, within which seed movement can proceed freely without risk of planting climatically ill-adapted stock. In the mountainous provinces of British Columbia and Alberta, elevational sub-zones are necessary within seed-zones to compensate for climatic differences at different altitudes. Some empirical rules of equivalence may be worked out so that, for example, seed can be moved northward into the adjacent zone, provided it is used in a lower sub-zone.

Alberta is developing a system of 60 seed zones and, as an interim safeguard, has prescribed movement of seed to within 80 km distance and 150 m elevation of its origin (Klein 1979). Saskatchewan has 31 seed zones. Seed zones are designated initially without regard to species but, as more information becomes available, their boundaries may be adjusted to suit individual species.

While there can be no doubt that provenance trials reveal superior seed sources, genetic gain is obtained more efficiently and reliably through selection, testing and breeding of individual trees. A common approach is to cruise forests deliberately to find phenotypically superior individuals (e.g., tall, straight boles, small horizontal branches, etc.). These are propagated as clones or seedlings to form, respectively, clonal or seedling seed orchards. The orchards often begin seed production before their contents have been fully tested. Even without testing, some gains are expected from the original selection in wild stands, and from hybridization that takes place between unrelated parents in the seed orchard. Ultimately, however, it is the objective of a tree improvement program to have all seed produced from repeatedly tested and selected parents ("recurrent selection").

The trend toward tested seed orchards may have several repercussions. First, the genetic base for future breeding and selection will be confined to a relatively small number of individual trees. Whether this implies pauperization of available forest genetic resources awaits further investigation. There is evidence that a very large proportion of the total gene complement of a species can be conserved in a few dozen individuals. Nevertheless, conservation of seed sources with adaptive gene combinations would appear to be an important goal for long-term forest management at present, and can be achieved through the establishment of managed areas of local seed sources, as described by Yeatman (1976). Managed areas are not seed production areas in the usual sense. They are harvestable forests that provide: i) reserves for selection, ii) standards for the measure of gain in tree improvement programs, and iii) sources of certifiable and tested seed. When the stand is cut, it is necessary only to regenerate the site with seed from that source.

Another important result of orchard seed production is that provenance trials and seed zones designated from them may become irrelevant. This is a rather startling change, resulting from the recognition that within-provenance variation, particularly at the clonal or family level, is consistently greater than among-provenance variation. There are limits as to how far this concept can be extended, but application of biogeoclimatic zones derived from ecological investigation rather than from laborious and lengthy provenance trials may be adequate for guiding seed transfer on a broad scale. What then becomes important is the adaptability of selected trees and their progenies. It is these that must be tested over a variety of sites and locations; the performance of appropriate provenance collections will not necessarily provide an accurate indication of individual parent suitabilities.

Even while tree improvement programs are under development, with provenance trials and seed orchards being established, the concepts of tree improvement are still evolving. In the face of such evolution and development, the forest manager must still maintain seed supply. A common interim measure is to designate selected stands and seed production areas. The genetic gain from such sources is very small, and cannot be regarded as a significant step in tree improvement. Recent use of such sources in Alberta has supplied only four percent of the province's seed (Klein 1979).

SEED SOURCE CERTIFICATION

Nurserymen will be handling seed from two sources: stands and seed orchards. As might be expected from the foregoing account, there are various classes within each group and it is important that they be recognized and identified. The British Columbia Ministry of Forests recognized six "genetic classes" in each source type (Dobbs _et al._, 1976):

A. Seed Orchard or Special Seed (subject to revision, 1980)

- A1 Breed orchards (containing progeny-tested stock only)
- A2 Full-sib orchards (seedling orchards derived from controlled pollinations between selected trees)

A3 Half-sib orchards (seedling orchards derived from open-pollinated selected trees)
A4 Clonal orchards
A5 Combined clonal, full-sib and/or half-sib orchards
A6 Single tree collections (open pollinated)

B. Stand Seed

B1 Seed production area
B2 Pre-selected stand and/or single trees, collected under supervision
B3 Normal stand (no selection)
B4 Natural stand (no information)
B5 Squirrel caches or cutting
B6 Plantations

Genetic class is coded into a Seed Registration Number, a unique number that summarizes important information about the seed source. The following example of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) Seedlot Registration Number (B.C. Forest Service) was described in Dobbs *et al.* (1976):

F/82G15/B3/2372/1.6

F: Species code (Douglas-fir)
82G15: Geographic origin (Nat. Topographic Grid ref.)
B3: Genetic class
2372: Seedlot number
1.6: Elevation (thousands of metres)

Seed registration systems vary across the country. The Province of Saskatchewan employs a nine-digit number that encodes seed zones, seedlot number, year of collection and species.

Proper records and labelling by seed registration numbers are obviously vital for maintaining genetic integrity of new forests. Where seed is collected by agencies which are responsible for ensuring genetic integrity, their numbers provide the only identification necessary. But there are instances where seed is collected by separate agencies; e.g., commercial cone pickers and seed dealers. The receiving agency may then require some assurance of source identity, especially if seed is required from specific locations.

In Canada, seed source certification has arisen in response to needs of the seed export industry. Export of forest tree seed has assumed significant proportions in the past decade. To date, certification has been limited to seed collected in British Columbia and the Yukon Territory, reflecting the European demand for species of that region. In 1979, Swedish legislation prohibited further importation of uncertified seed of lodgepole pine (*Pinus contorta* Dougl.). This particular market accounts for over half of the certified seed exported from Canada. Canadian seed dealers now have all their seed collections certified as a matter of policy, an action that reflects favorably on the acceptance by dealers of the certification process, and on the quality of seed exported from this country.

The Government of Canada's Designated Authority administering seed certification under rules of the Organization for Economic Cooperation and Development (OECD) is the Canadian Forestry Service (CFS). At present, the CFS has two Certifying Authorities, the Pacific Forest Research Centre in Victoria, B.C. and the Northern Forest Research Centre in Edmonton, Alberta. Under the direction of a Certifying Officer at each centre, certification is performed by several Seed Inspectors, appointed by the federal Minister of Agriculture.

Inspection procedures begin with a submission of collecting plans before collection begins by the company. Collections cannot be certified for source identity retrospectively. Inspections are made at the collection site, at cone storage depots, and at seed extractories and stores. Careful records are made of yields forecast, extracted and packaged. Details of inspection and certification requirements are described in full by Piesch and Stevenson (1976).

In 1979, 1914 kg of seed were inspected and certified in accordance with OECD regulations. An additional 769 kg of uncertifiable lodgepole pine seed were inspected under a special agreement with the Swedish National Board of Forestry designed to minimize impact of new Swedish legislation (see above) on Canadian seed dealers. Prices are generally treated as confidential and are not a matter of concern to the certification process, but it is widely held that lodgepole pine seed is valued at a minimum of $300-400 per kilogram, indicating a total value of about $1,000,000 for seed certified or inspected in 1979 (lodgepole pine accounted for 69 percent of the total weight inspected in 1979). The quantities of seed exported suggest significant movement of domestic forest genetic resources. The 1854 kg of lodgepole pine inspected in 1979 far exceeded the 1977 requirement of 90 kg for this species in British Columbia (Dobbs, 1979) and recent (1977-80) and projected (1981-87) annual requirements (800 kg and 1150 kg, respectively) of Alberta (Klein, 1979).

At present, overseas demand for Canadian forest tree seed is increasing, and may continue to do so if more countries enter the market. The demand may also be spreading into new regions of Canada; for the first time, the Northern Forest Research Centre, Edmonton, was called upon to inspect seed collected in Alberta in 1979.

Demand for wild seed is expected to diminish as European forestry agencies fill their exotic forest needs and develop seed orchards from locally selected trees. At the same time, there may be interest in any future surpluses generated in Canadian seed orchards, especially where seed is produced from tested parents. The Canadian

Forestry Service is exploring market potential for this source; if significant, new Canadian rules for certification will be required to match the OECD categories for improved seed; i.e., "selected reproductive material", "reproductive material from untested seed orchards" and "tested reproductive material".

While seed certification was designed to provide some assurance of seed source authenticity, its real value lies in the high standards of seed source identity and definition implicit for certification. Identity and definition are of paramount importance to those engaged actively in tree improvement, and to forest managers whose responsibilities include the genetic architecture of future forests in Canada and overseas.

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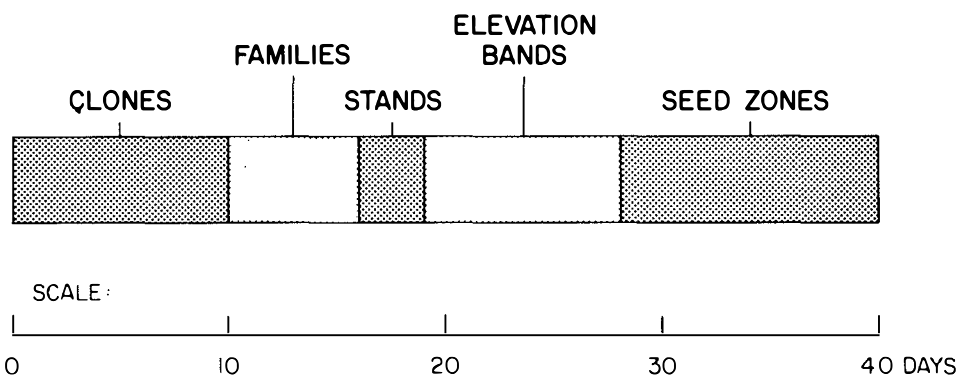

Fig. 1 Sources of variation in the cessation of shoot growth among white spruce seedlings,

CONE COLLECTION AND PROCESSING - Effects on Seed Quality and Yield

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ABSTRACT

The general principles of cone collection and cone and seed processing are reviewed, and the manner in which seed quality and seed yields may be affected are discussed. Emphasis is placed on cone and seed maturity, and the consequences of too early collections. The objectives of each component stage in the processing system, beginning with care and handling before the cones reach the processing plant and terminating with preparing the seeds for sowing, are described and the potential causes of poor seed quality are outlined. The review is illustrated with examples of processing methods and equipment used primarily in British Columbia.

INTRODUCTION

The relatively recent development of container nurseries to meet growing reforestation needs has brought increased attention to the problems of seed supply. Requirements for particular provenances and for genetically improved seeds, as well as rising costs of all levels and types of nursery production, have brought new emphasis to seed quality. The seeds derived from seed processing can be no better than those that were collected, but a good seed processor can upgrade quality at the expense of quantity by removing the empty, weak and damaged seeds.

This paper reviews the general principles of collection and processing of conifer seeds and the manner in which the component operations may influence seed quality and yield. Not highly technical, the review makes no attempt to account for the most up-to-date equipment, and is aimed primarily at reforestation staff, and other workers who may wish to become familiar with the basic steps of cone procurement, handling and seed extraction. All major steps, from consideration of seed maturity to the preparation and pretreatments for sowing, are discussed.

CONE COLLECTION

Seed quality can be impaired at almost every stage in processing from the time the cones are removed from the parent tree. The reasons for damage may be biological (caused by too early collection, the presence of pests, or both), thermal (caused by high temperatures during cone kilning or seed drying), mechanical (caused by abrasion or sharp impact), chemical (such as that caused when pesticides have been applied to the seeds), or a combination of these reasons.

Unlike most of the foregoing reasons, which relate to specific stages of processing, seed maturity influences almost everything that happens to the seeds once the cones have been collected. For practical purposes, maturity can be defined as the stage at which all potentially good seeds are capable of germination and successful storage. Although viable seeds can be obtained from cones collected long before they are ready to open, maturity (ripeness) is usually associated with seed dispersal. Most conifers quickly release the bulk of their seeds once maturity has been achieved; others, such as lodgepole pine (*Pinus contorta*) and jack pine (*P. banksiana*), usually exhibit a serotinous cone habit; *i.e.*, the outer edges of the cone scales are bonded together by resin and require exposure to high temperature for seed release. Thus, cones of these species may remain intact on the tree for a considerable time after maturation, a characteristic of which cone collectors take advantage. A major difficulty in seed collection, whether or not seeds are dispersed at maturity, is that not all cones mature simultaneously. Maturation date varies among cones on the same tree, from tree to tree within the same stand, from stand to stand in the same year and from one year to the next on any particular date.

The general conclusion drawn from the copious literature on seed maturation is that the more mature the seeds are when collected, the greater their vigor and potential for establishment of new seedlings (Pollock and Roos 1972). Among the consequences of too early collection are difficulties in curing (air-drying) the cones; their high moisture levels favor moulds and unless they are well ventilated during storage, the cones may suffer from internal heating, which can cause direct damage to the seeds as well as increasing mould activity. The high moisture content of green (immature) cones requires longer kilning and normal kiln temperatures may be lethal to the immature seeds. Cone scales may fail to reflex properly during kilning, remaining in a semi-closed or closed position, thus preventing the seeds from falling out. Immature seeds are lighter in dry weight, may germinate very slowly or be incapable of germinating, and the seedlings may be of low vigor; *i.e.*, slower growing. Prechilling (stratifying) immature seeds may reduce germination; they are more susceptible to disease and tend to produce a higher proportion of abnormal germinants, which reduce plant yields. In contrast, cones collected close to maturity open readily when kilned and, in good seed years, yield high quantities of seeds. Heavier seed years not only produce the best quality seeds in terms of soundness and viability (Fowells and Schubert 1956; Larson and Schubert 1970), but cone collection costs are lower and cone losses to squirrels and insects are less serious (Rietveld 1978).

A Douglas-fir (Pseudotsuga menziesii) seed orchard study (Olsen and Silen 1975) produced the following observations on seed maturity. Seedlots collected before the third week in August "required several-fold efforts in seed extraction and germination, produced very light seeds, contained nearly all of the lots germinating below 10%, suffered heavily from loss after germination, required inordinate efforts to produce enough seedlings (for a progeny test) and were the major cause of poor seedbed densities." Cones collected within 10 days of natural seed fall developed less mould before the seeds were extracted, required minimal efforts in seed extraction and subsequent seed processing, germinated well in the nursery and produced excellent seedlings. In terms of seedling production alone, it was estimated that 10 times the effort was required with immature seeds than with seeds collected close to seedfall. Although far from exact, such comparisons serve to place a better perspective on the cost of immature seeds (Olsen and Silen 1975).

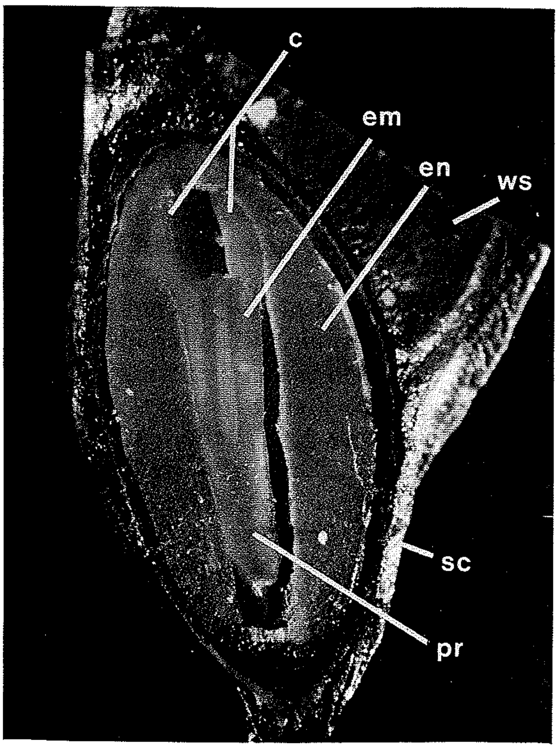

Fig. 1. A mature Douglas-fir seed. The embryo is 90% extended in the cavity in the endosperm which is firm and opaque-white.

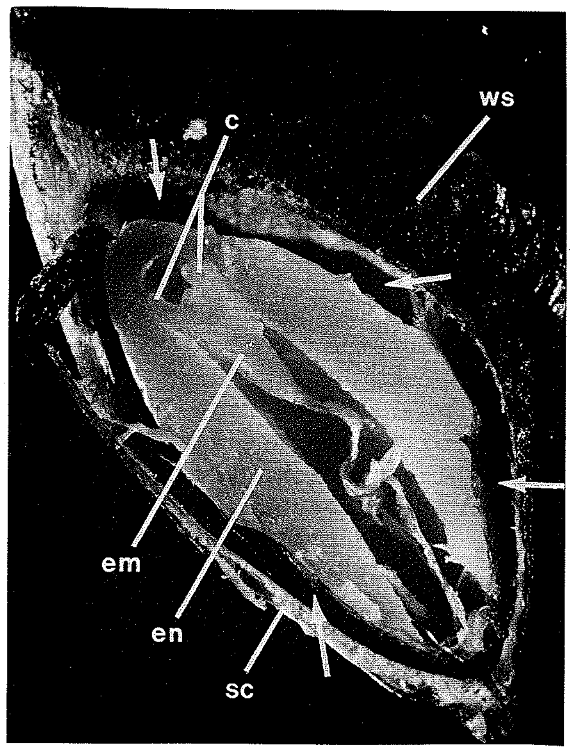

Fig. 2. An immature Douglas-fir seed. The embryo is less than 30% extended and the endosperm, although no longer "milky", has shrunk and separated from the seedcoat (arrows) shortly after sectioning.

em — embryo; en — endosperm; pr — primary root; c — cotyledons; sc — seed coat; ws — stub of seed wing. Scale approx. 12x.

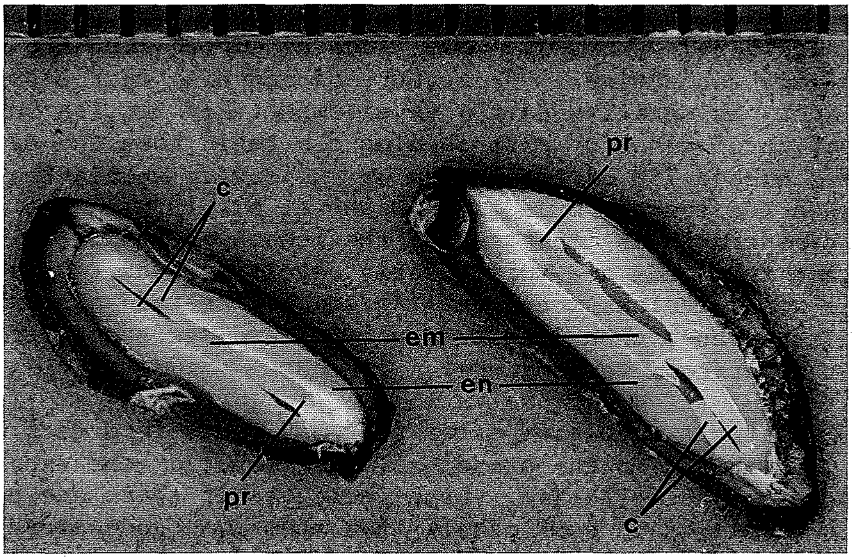

Fig. 3. Mature amabilis fir seeds. Embryos have fully extended, the endosperm is firm, white and shows no sign of shrinkage after sectioning. em — embryo; en — endosperm; pr — primary root; c — cotyledons. Scale is in mm.

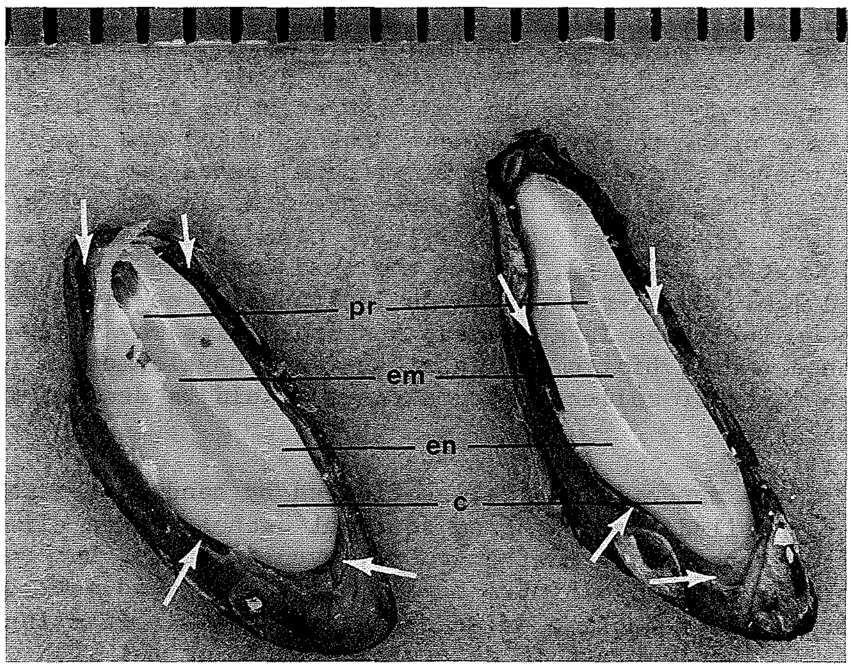

Fig. 4. Endosperm condition is critical in judging *Abies* maturity. Although embryos are fully elongated, the endosperm has pulled away (arrows) from the seedcoat after sectioning, indicating maturation was incomplete.

Methods of assessing seed maturity have been reviewed elsewhere (Edwards 1979a). Some of these, such as cone color, are well known but are highly subjective. One measure of ripening that has gained in popularity is relative embryo development. In British Columbia, collection of cones of most species can begin when the majority of embryos exceed 75% of the length of the cavity within the endosperm, and when the endosperm is firm (Dobbs et al. 1976). The condition of the endosperm is as important as the length of the embryo (Figs. 1 to 4); when the seeds are sufficiently developed, the tissues will show little or no shrinkage and curling and will retain a relatively firm, fresh appearance when longitudinally sliced seeds are left uncovered overnight at room temperature.

Cutting a sample of cones (e.g., 9 cones from each of 6 trees well distributed in the stand) allows a count of the exposed filled seeds in one half-section, which indicates if there are enough seeds to make the collection economical. For spruce, a good average seedcount on the cut surface would be 7-10, and 3-4 for pine; usually there are 3-5 times the number of good seeds per entire cone as are visible on the cut surface. Lodgepole pine cones are difficult to section and it is easier to extract the seeds by dipping the cones in boiling water for 10-15 seconds, then drying them in an oven at 60° - 65°C for 3-4 hours. Filled seeds may be identified by crushing them with the fingernail or with the point of a sharp knife to reveal a firm, white endosperm. A minimum of 20 filled seeds per entire pine cone indicates a collectable crop (Dobbs et al. 1976). As well as seed set, inspections should be made for insect or other damage. Insect presence is often indicated by premature browning of the cones as a whole or in patches, insect entry/exit bore holes, frass, exudations of pitch and disfigured or partially consumed cones (Fig. 5). Slicing the cones, to determine seed set, may reveal the damaging larvae. Insect damage may also impair seed extraction, thereby reducing seed yields. Spruce cones are prone to damage by cone rusts, which are fungi that derive their name from the orange-yellow spore masses produced on the cone scales. Affected cones often open prematurely and seeds frequently are not viable or germinate abnormally. Cone deformities, such as proliferation (Fig. 6), reduce the seed count and may impair seed extraction. Smaller cones on an individual tree have the same genetic characteristics as larger ones, but small size may indicate immaturity, low seed count, biotic damage or abnormal development. The desirability of collecting such cones should be decided in each instance.

Cones are still largely collected by hand from standing or recently felled trees or from squirrel caches. When climbing, cones should not be thrown to the ground, even in sacks, but should be lowered by rope to minimize damage to fragile seedcoats and consequential reduction in seed quality. When collecting from felled trees, it is important to determine whether or not the cones were sufficiently mature when felling occurred. Prompt collection may be necessary to forestall cone opening resulting from high soil temperatures, or losses to birds and mammals. Squirrel-cached cones

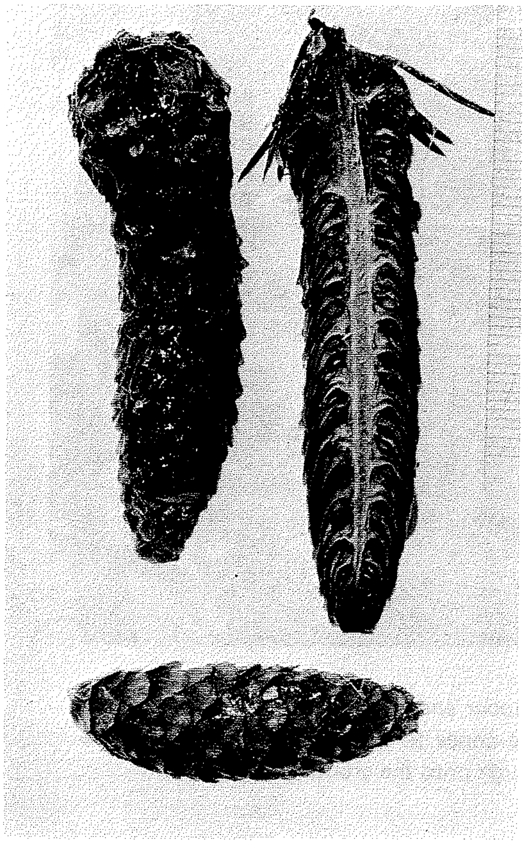

Fig. 5. Insect-damaged (top) and normal (bottom) cones of white spruce. Deformity near cone base and pitch exudation are external evidence of insect attack (left). Sliced longitudinally (right) the damage is more apparent.

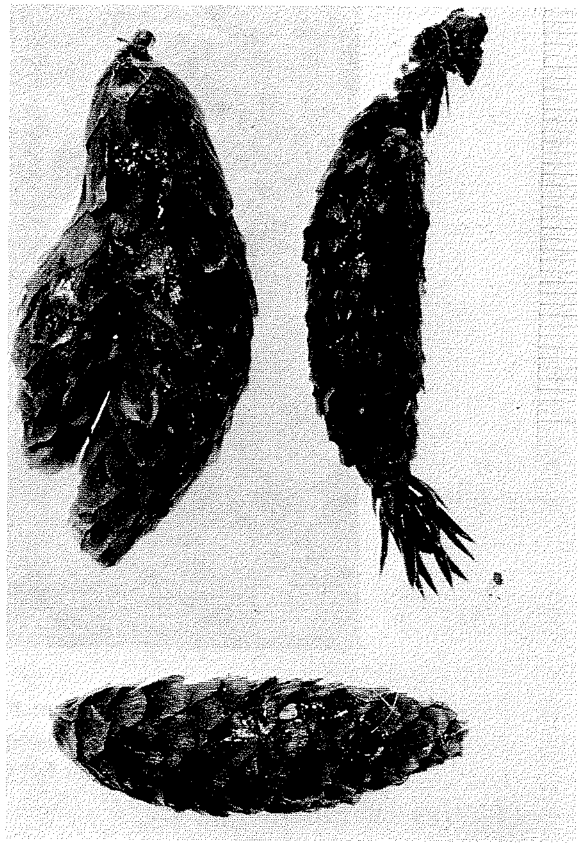

Fig. 6. Abnormal (top) and normal (bottom) cones of white spruce. Proliferated cones, *i.e.,* those in which the apical meristem has resumed vegetative growth (right) after the production of a reproductive structure, or those in which the apical meristem became divided and proceeded along two separate axes (left), although not common, can be observed in most conifers.

must also be checked for maturity as well as for the presence of pests; the crop trees of the stand where the cones are found should be inspected for desirability of form and other physical characteristics.

CONE SHIPMENT AND STORAGE

As mentioned, the effects of seed maturity interrelate with seed processing because immature seeds can be more difficult to extract from

Fig. 7. Cones are placed on the upper end of a cleaning table. The tilted, screen-top vibrates causing the cones to slide to the lower end, while dirt, needles and litter fall through onto the ground.

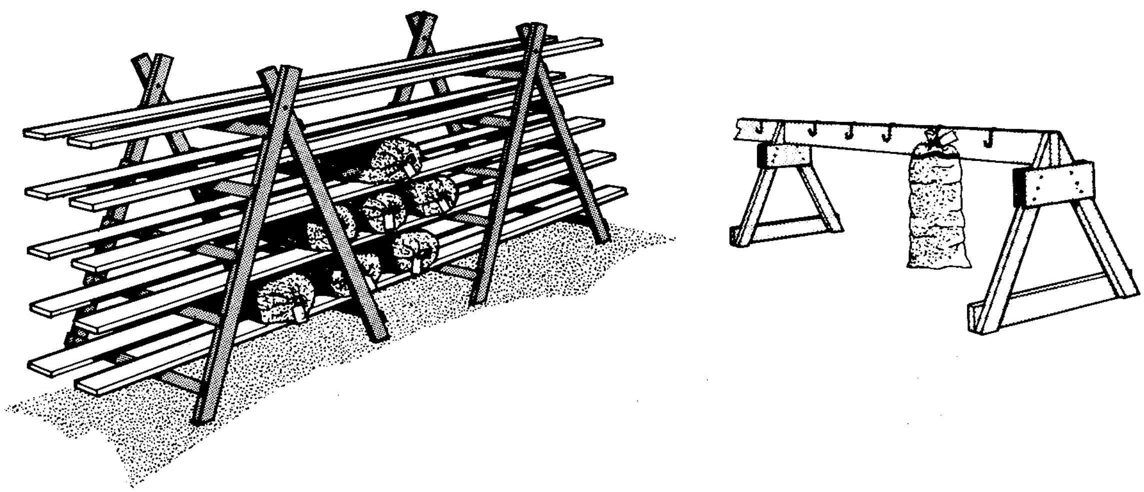

Fig. 8. Two simple cone storage methods for field use. Ladder-like trestles (left) with parallel boards to separate the sacks, and knock-down saw-horse type (right), from the bar of which sacks are hung using hooks, are both built from common materials and are completely portable.

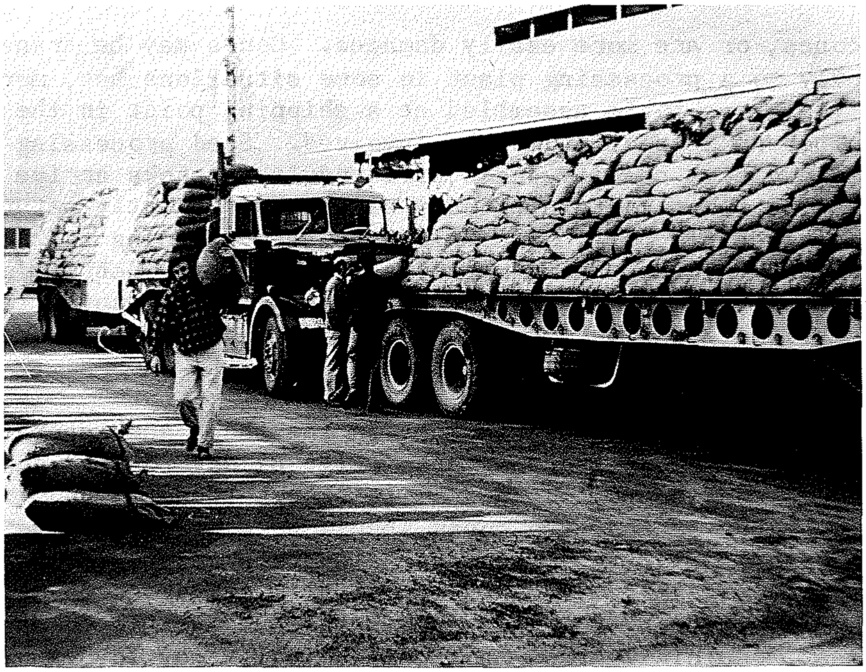

Fig. 9. A large shipment of cones being unloaded at a British Columbia processing plant.

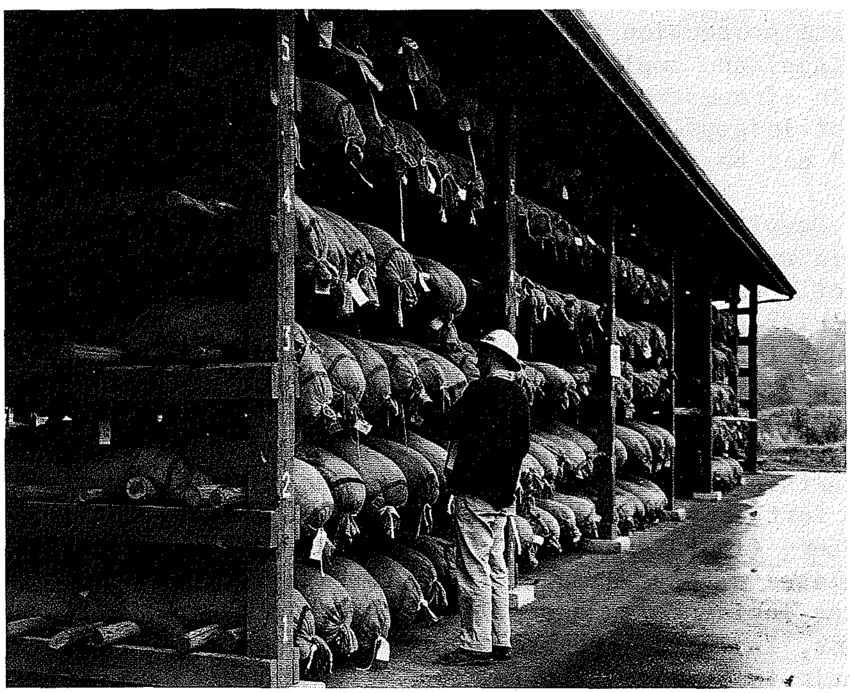

Fig. 10. Traditional cone storage sheds use poles or boards to separate the sacks so that they are well aerated.

the cones, or are more easily damaged. Cones may be transported directly to a processing plant in some situations but, more likely, they will have to be assembled at a shipping point in the field, where cleaning and inspection may be involved. Seed processing will be easier and high quality seeds will result if sacks arrive at the processing plant containing only clean, sufficiently mature cones. Excessive debris not only complicates seed cleaning and increases costs, but may cause damage to the seeds. Where debris in the sacks is unavoidable, it may be practical to use a cone cleaning table (Fig. 7) at the field location. An advantage is that the cones are closed and can be shaken without loss of seeds.

Sacked cones should be kept in the shade and separated for good ventilation; simple storage racks (Fig. 8) may be used in the field. The cones must be protected from being rewetted and from rodents. If very wet when sacked, the cones should be emptied out and air-dried at the storage facility. Once free of surface moisture, they should be placed in dry sacks. Even when partially air-dried at interim (field) storage facilities, the cones are still susceptible to damage during shipment, especially from heat buildup which may favor mould growth. Only open, flat-decked trucks or trailers (Fig. 9) should be used for shipment to the processing plant, and travel times should be kept as short as possible. Truck drivers should be made aware of the perishable nature of their loads; they should park in the shade, whenever possible, during stopovers en route. The need for proper care and prompt delivery should be stressed. Once at the processing plant, the cones may be stored in sheds (Fig. 10) for a further period, to ensure further drying or as a consequence of extraction scheduling. Correctly stored cones continue to lose moisture as their seeds ripen. Adequate protection from external heat sources (direct sun, heated buildings) and ample ventilation, even forced-air circulation in certain circumstances, are required. Green cones of most species (except lodgepole and jack pines) expand as they dry out so the sacks should not be filled with green cones above the fill-line.

Despite the previous emphasis on collecting only mature cones, certain species can be collected quite early in the season and, if correctly handled, will continue to ripen during cone storage. Artificial ripening has been found to enhance seed extractability, although for most species there is a maximum period of safe storage (Table 1); when these periods are exceeded, chances of seed mortality, germination in the cones and complications during extraction increase greatly. Prolonged storage of even mature cones may be disadvantageous for certain species, resulting in reduced viability after extraction and a further loss during seed storage (McLemore 1961). However, Bloomberg (1969) suggested that disease resistance was positively correlated with seed maturity in Douglas-fir; he maintained that disease incidence in a seedlot represents the net effect of several factors, including the proportion of the seeds not mature, the degree of their immaturity, the rate at which maturity occurred and the length of cone storage. The seeds of a number of species, including Douglas-fir, noble fir (<u>Abies procera</u>), Nordmann fir (<u>A. nordmanniana</u>),

Table 1. Safe storage period for some western conifers

Species	Storage period (months)
Douglas-fir; Engelmann, white, and Sitka spruces; western larch; ponderosa, western white and limber pines.	3-5
western hemlock; western red cedar	1
true fir (balsam) species	1 - 2 (in trays)
lodgepole pine	4+

Scots pine (*Pinus sylvestris*), the southern pines (*P. elliottii*, *P. taeda*, *P. echinata*, *P. palustris*), Virginia pine (*P. virginiana*) and white spruce, are known to continue to ripen in the cone if storage conditions are suitable. These conditions are presently ill-defined but, where success has been obtained, air temperature between 5° and 10°C, relative humidities of 65-75% and good ventilation of the cones have all been implicated. Artificial ripening of prematurely collected cones provides three main benefits: cone collection operations can be made more flexible, the collection period can be extended and immature cones from logging operations can be used. Ripening seeds are less sensitive to cone storage conditions the later they are collected (Edwards 1979a).

CONE PROCESSING

Processing includes all those steps from the time the cones arrive at the processing plant until the seeds are prepared for sowing (Fig. 11). Although the cones will have lost considerable moisture since they were picked, further drying in a kiln is usually necessary to reflex the cone scales to their fullest extent so that maximum quantities of seeds can be obtained. Kilns are over-sized ovens and have various forms (Stein *et al.* 1974). Some are the progressive type, employing a tunnel along which the temperature progressively rises; carts laden with cones move slowly from the cooler entrance of the tunnel to its hotter exit. More modern kilns are of the rotary type, containing the tumbler within the heat box and in which the seeds are shaken out of the cones and removed from the heat at the earliest possible time.

The objective of kilning is to get the cones open as quickly as possible without affecting seed viability or causing cone scales to case harden, which occurs when wet cones are heated too rapidly and the scales only partially open. Prolonged slow drying may also prevent

CONES IN STORAGE --- *"PRECURING" (AIR DRYING)*

↓

CONE CLEANING --- *REMOVES NEEDLES, DEBRIS*

↓

KILN DRYING --- *OPENS CONE SCALES*

↓

CONE TUMBLING --- *RELEASES SEEDS*

↓

DEWINGING --- *REMOVES WINGS*

↓

SEED DRYING --- *IF WET DEWINGED*

↓

SEED CLEANING --- *REMOVES LIGHT SEEDS, DEBRIS*

↓

SORTING --- *SEPARATES TOP QUALITY SEEDS*

↓

SEED DRYING --- *ADJUSTS MOISTURE FOR STORAGE*

↓

SEED STORAGE --- *CONSERVES SEED VIABILITY*

Fig. 11. Steps in cone and seed processing. Some techniques may combine two or more steps.

full scale opening. Thus, the heat to which the cones are subjected must be carefully controlled. Ideally, cones should be exposed to an air flow of gradually decreasing moisture content, producing a progressive drying and opening of the cone scales. Air temperatures must not rise above certain limits, otherwise viability will be impaired. Maxima of 50° or 60°C may be reached near the end of the drying period when air humidity and cone moisture are very low; wet seeds exposed to these temperatures likely would be scalded. The biological upper temperature limit for most tree seeds is approximately 66°C. In some processing plants, a ventilated loft above the kiln, employing waste heat, is used as a preliminary drying step after the cones have been removed from storage. This may significantly reduce the kilning time, an effective economy in a large operation.

In some plants, kilning and tumbling are performed simultaneously in a rotating drum kiln. Tumblers are screened drums in which the open cones are shaken to remove the seeds. If tumbling is delayed too long after kilning and the cones are exposed to moist air as they cool, the scales will reclose. Some tumbler drums are enclosed at both ends, and reversing the direction of rotation opens the cylinder to discharge the spent cones and for recharging with fresh ones. Another type is open at both ends, fairly long, with its axis slightly inclined. Cones are fed in at the higher end and, as the cylinder rotates, they roll to the lower end and fall out. This type provides for continuous operation but the rotation speed is usually slow, which may not provide an adequate tumbling action for some species. Whatever type is used, the process should be as gentle and as brief as possible. All tumbler types are contained in an enclosure which traps dust and chaff as well as the extracted seeds, and funnels these materials to a catchment area underneath (Fig. 12). With some species, remoistening the cones after a first tumbling has been used to increase seed yields following subsequent redrying and additional tumbling. The quality of the additional seeds is usually lower than that from the initial tumbling and it is difficult to justify this type of operation, except when the seed crop is poor, when the seeds are exceptionally valuable or for cones that are refractory; i.e., do not open readily. Seeds obtained by this procedure should be used as quickly as possible, since experience has shown that frequently they do not store well.

SEED PROCESSING

During tumbling, a considerable quantity of debris falls through and becomes included with the seeds. Such debris not only complicates later stages in seed cleaning, but may cause, through friction and its sharp edges, actual seed damage. It is often necessary to pre-clean the seeds with a "scalper" (Fig. 13) to remove most if not all of this debris. The scalper, like the cone cleaning table, consists of an inclined vibrating screen; usually several screens of progressively finer mesh from upper to lower are employed. Very coarse material is retained on the uppermost screen and slides down to fall in one bin,

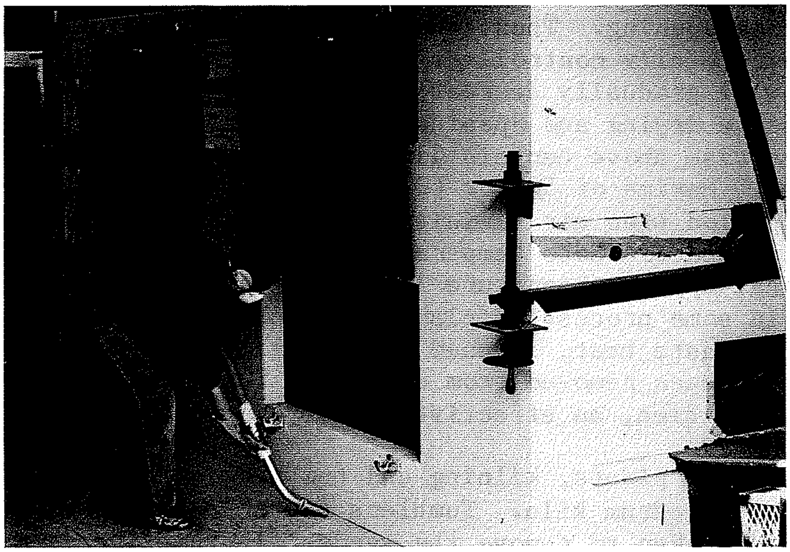

Fig. 12. Enclosure of the inclined-axle tumbler used by the British Columbia Ministry of Forests. The incline of the axle is adjusted using the worm-gear mechanism (centre right). A conveyor belt, near the bottom of the enclosure, moves seeds and other small particles out of the tumbler box. Spent cones exit via the opening at lower right. The operator is meticulously cleaning the equipment between seedlots.

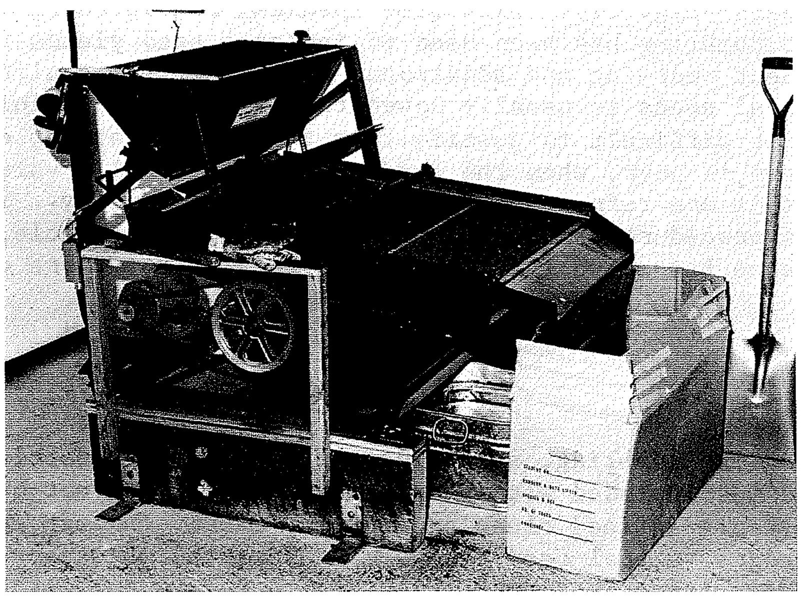

Fig. 13. The scalper resembles a cone cleaning table. A hopper (upper left) provides a continuous flow of material onto the inclined screen. Vibration causes the cone scales and debris to slide to the lower end, to be collected in the cardboard container. Seeds pass through the screen onto a solid metal tray and are collected in a metal bin.

while the very fine material passes through to be deposited in a separate bin. The seeds are usually retained on an intermediate screen. An air supply is often added (the machine is then referred to as a "fanning mill") to help keep the particles moving and reduce lodging in the perforations.

Once excess debris has been removed, the next step is seed dewinging, which improves the field sowing characteristics of the seedlot, facilitates sorting the seeds to the required quality standards, and reduces the volume of material to be stored. Unfortunately, dewinging is the processing step most likely to cause seed damage, the quality of some lots suffering significantly. Repeated dewinging adds to any damage inflicted by earlier dewinging. In the true firs (Abies), losses in quality are almost inevitable; three brush-dewingings of A. lasiocarpa seeds destroyed 50% of the originally viable seeds (Edwards, in press). Excessive dewinging in Douglas-fir produces dull, dusty seedcoats; the seeds are rarely high in germination and seem to be more easily contaminated by mould and the resulting seedlings are weak.

Dewinging methods fall into two general categories. Dry dewinging involves rubbing the wings off mechanically without cracking or damaging the seedcoat. The simplest, and safest, means is to hand rub the seeds in a sack, but this is practical for small quantities only. A simple mechanical device is a wire screen or perforated plate, the holes of which permit the seeds, but not the wings, to pass through. A brush works the seeds against the screen while an air current helps to remove wing fragments (Fig. 14). Brush pressure must be carefully adjusted to prevent cracking the seeds or causing undue heating through friction. In other machines, the seeds are made to pass through narrow outlets between rubber knobs or paddles, again requiring careful adjustment. Another type employs an auger which lifts the seeds and rubs them against one another to break off the wings, inside a cylinder (Fig. 15). Some operators add a small amount of coarse debris to this type of dewinger to increase the rubbing action. In British Columbia, this type of dewinging is very effective on seeds of Douglas-fir and western larch; batches of 1.5-2.0 hectolitres can be effectively dewinged in 2 minutes. Longer treatment can cause damage.

The wings of pine and spruce are attached to the seeds by means of a two-pronged depression that grips the seed (pine) or by means of a spoon-shaped hollow (spruce) (Fig. 16). Since the wings are much more hygroscopic than the seeds, they expand when wet and loosen their grip on the seeds, usually separating with minimal agitation. This is the basis of wet dewinging, a method that used to be frowned upon because it was believed to weaken the seeds, particularly with regard to their storability. The amount of moisture required is very slight, and the moisture content of the seeds need not increase markedly since the method is relatively rapid. The Kason Vibrator, which comprises a vibrating cylinder that can handle up to 0.5 hl batches of seeds, is used in British Columbia for both wet and dry dewinging (Fig. 17). The

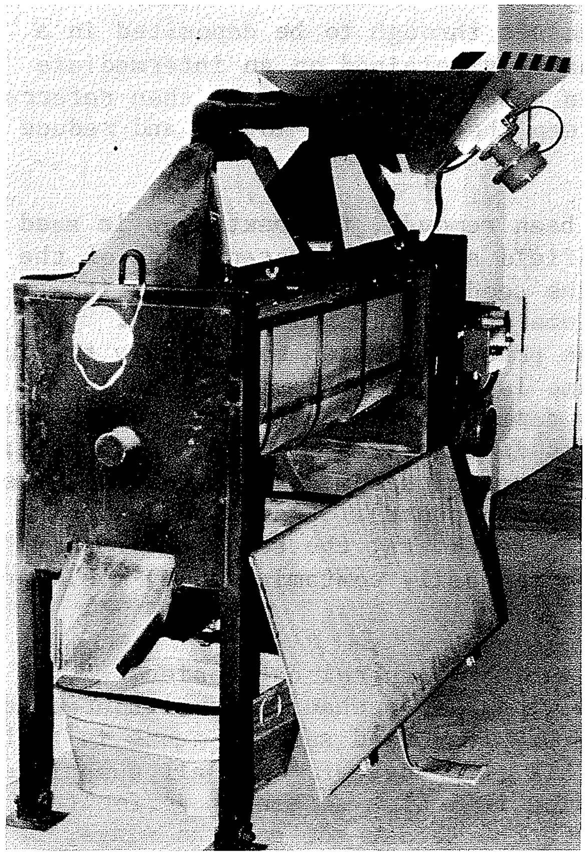

Fig. 14. The front cover of this brush dewinger has been opened to show the curved screen inside which are the rotary brushes. Wings pass through the screen and, together with the dust, are drawn off by a vacuum. Seeds exit by the spout at the near end.

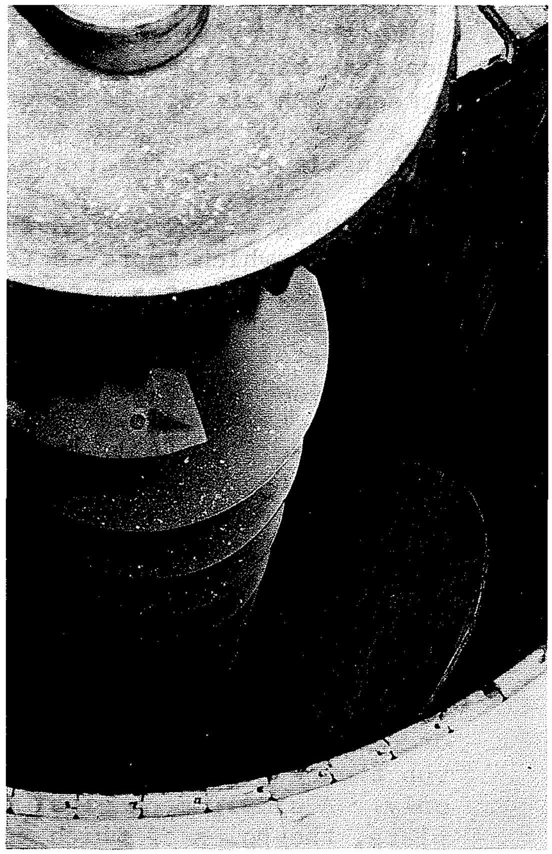

Fig. 15. Looking down inside an auger dewinger.

seeds are caused to circulate in two directions - and rub against one another - by means of eccentric weights placed beneath the drum; hand mixing of the circulating seeds has been found to assist the dewinging process. Spraying a small amount of water onto the circulating seeds permits dewinging of white, Engelmann and Sitka spruce and ponderosa and lodgepole pine with little or no damage. Prolonged wetting of the seeds should be avoided but, in any case, the seeds require redrying before further sorting. For this, the seeds are spread out, usually on fine-screen trays through which warm (not exceeding 30°C), dry air is blown; the detached wings are removed easily in this air current once

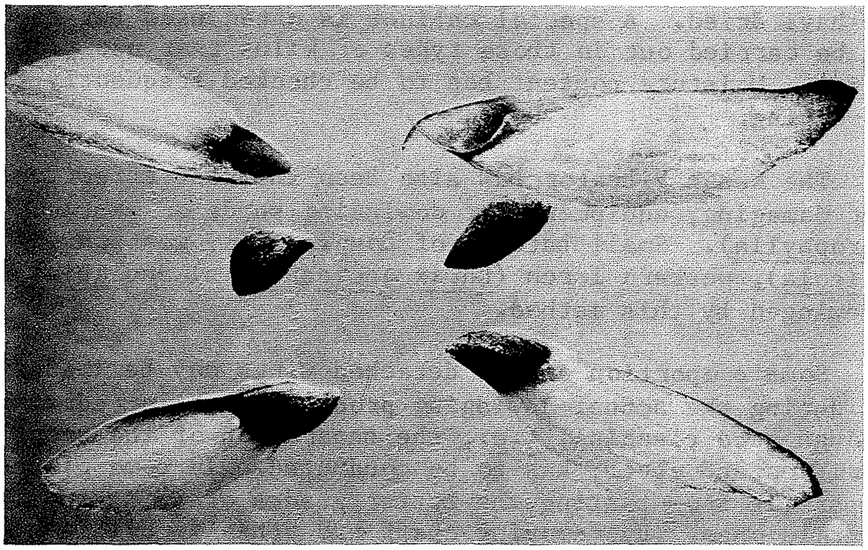

Fig. 16. White spruce (left) and lodgepole pine (right). Top row: seed wings with seeds removed. Middle row: seeds. Bottom row: seeds complete with wings.

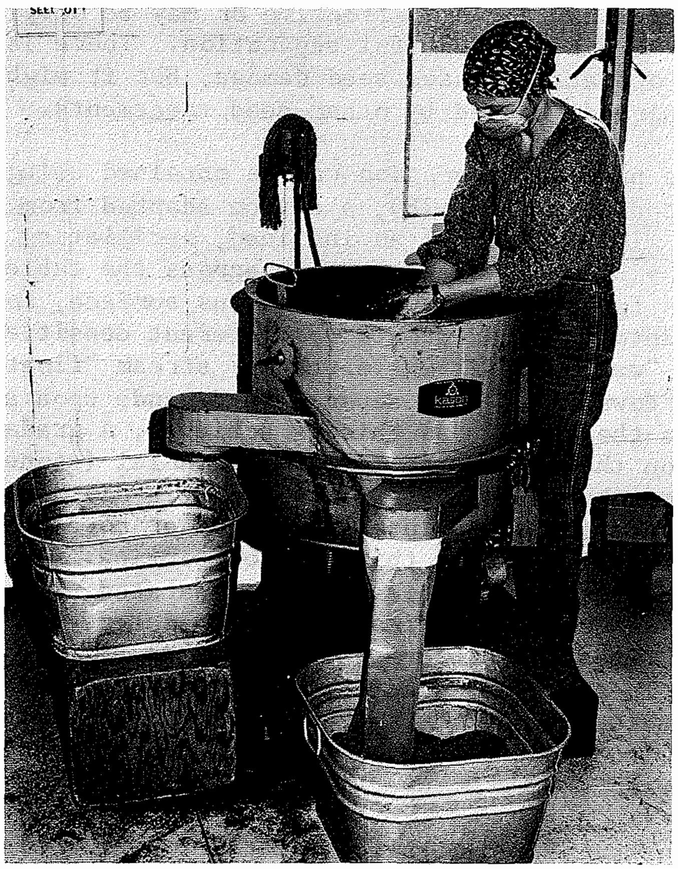

Fig. 17. The Kason Vibrator dewinger. Dewinged seeds exit by the upper "arm" (centre left) while wing fragments fall into the lower bin.

they have dried. A special cabinet is often used but the procedure can also be carried out in those types of kilns that use trays stacked on dollies. Moisture content has to be checked frequently to avoid over-drying.

The Kason Vibrator has also been the most effective, and the least damaging, equipment for dewinging seeds of western hemlock (Tsuga heterophylla). Small batches of Douglas-fir, western white pine (Pinus monticola), western larch (Larix occidentalis) and Abies seeds can also be dewinged by this method.

Some proportion of the detached wings may be lost from the seed bulk during the actual dewinging process or while redrying, but a more thorough seed cleaning, i.e., the separation of the seeds from impurities and chaff, has to be conducted. In some plants, cleaning is inseparable from sorting the better grades of seeds from the poorer and infertile ones. By removing chaff and other impurities, the seed bulk is greatly reduced for storage, and the precision with which the seeds ultimately can be sown in the nursery can be increased. One of the simplest methods of cleaning/sorting is based on differences in particle size, which is the principle of the scalper and fanning mill mentioned earlier. Screen (perforation) size, angle of slope of the screens, rate and distance of oscillation, as well as the speed of any air current are all usually adjustable. Depending upon the species, such cleaning may be very effective or may be only a preliminary operation before more careful separation. There is little evidence that this operation causes seed damage, but it might exacerbate injuries already caused by other seed treatments.

More precise separation can be obtained using the specific gravity separator (Fig. 18), a device adapted from the mineral industry. It consists of an inclined, oscillating, porous table. The slant and vibration move the seeds across the table while an air current is forced up through the porous surface, forcing the seeds to separate into bands or strata of different densities. Heavier particles "walk" uphill while the air stream "floats" the lighter particles downhill. Good separation depends upon a uniform flow of seeds onto the table. As this is achieved, a gradation of light material on the lower side to heavy material (stones, etc.) on the upper side takes place (Fig. 19). Movable dividers on the discharge edge separate the seeds into two, three or more density fractions. Three basic rules govern this type of sorting: i) seeds of the same size but different densities can be separated, ii) seeds of different sizes but the same densities can be separated, but iii) seeds of different sizes and different densities in mixture cannot be separated readily. In any given seedlot, reduction of the variation in seed size by prior screening of the material, then sorting the various size fractions independently, will increase the efficacy of the specific gravity system.

Another method of precise sorting uses a rising air column in which separation depends on the relative rate of fall of seeds with the

Fig. 18. Dividers on the discharge edge of a specific gravity table separate the material into three components: heavy particles (mostly pure seeds) at far right, light debris at far left and a mixture of debris and some seeds in the centre. Material collected in the centre bin usually has to be resorted.

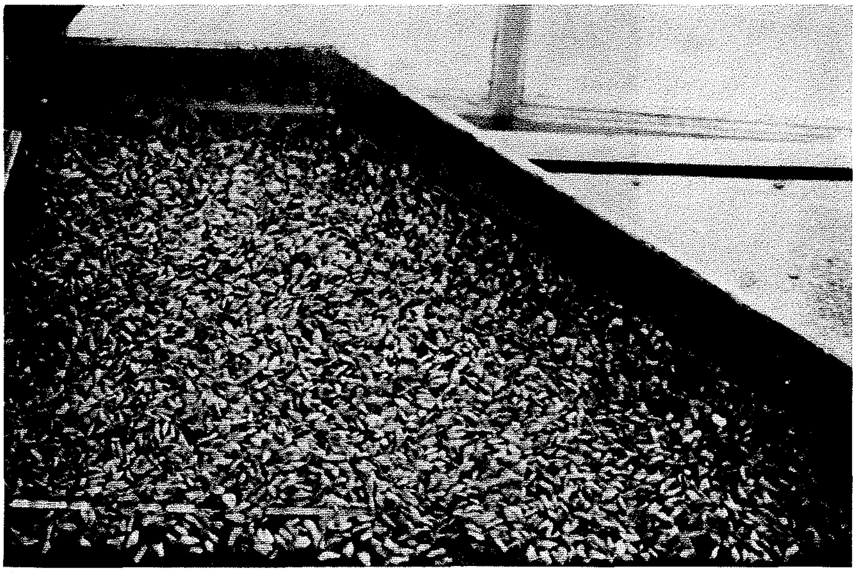

Fig. 19. The darker band at the right edge consists of gravel and small stones. These were picked up on the sticky surfaces of the *Abies amabilis* cones which struck the ground when the trees were felled.

same surface area but differing in weight, or with uniform weight but differing in surface area. Filled seeds with wings or wing fragments still attached will tend to be carried off, while lighter seeds fully dewinged will sink in the same air current. It is important, therefore, to ensure complete dewinging and, as with gravity separation, to minimize variation in seed size. A number of pneumatic devices have been developed for seed sorting. The single tube South Dakota blower (Anon. 1952; Erickson 1944) (Fig. 20) is the simplest, used principally in laboratory testing or for sorting very small lots, such as those from seed orchards; it operates on a batch (non-continuous) process. A more continuously-operating model has been developed for laboratory use (Edwards 1979b), using the same rising-air-column principle (Fig. 21); a larger version has been built by the Britsh Columbia Ministry of Forests.

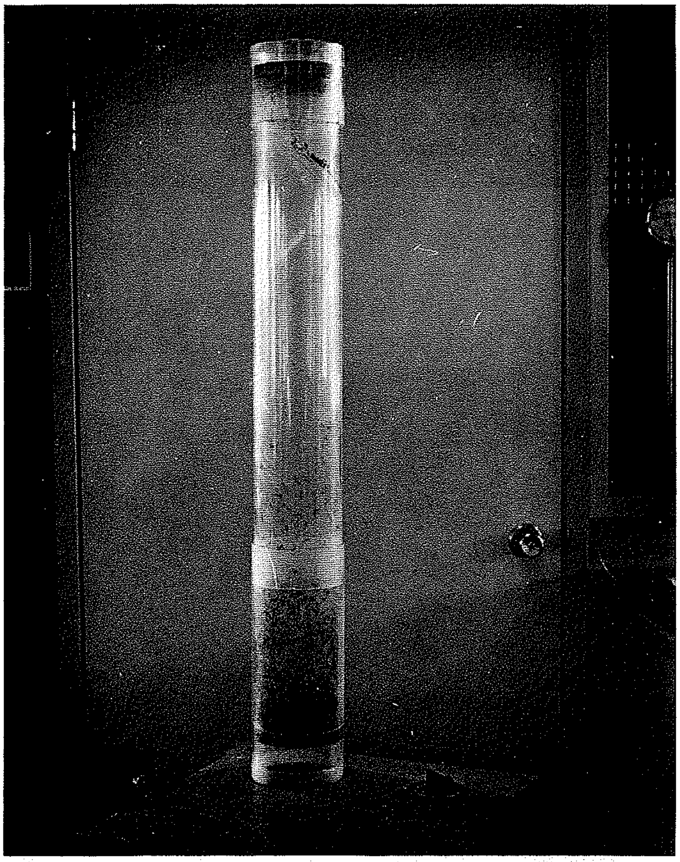

Fig. 20. The South Dakota blower consists of a single, vertical tube closed at the top by a fine screen. A blower beneath provides an air stream that lifts light particles and deposits them on angled shelves near the top of the tube. Air speed is controlled by a diaphragm-opening controlled by the lever at lower left.

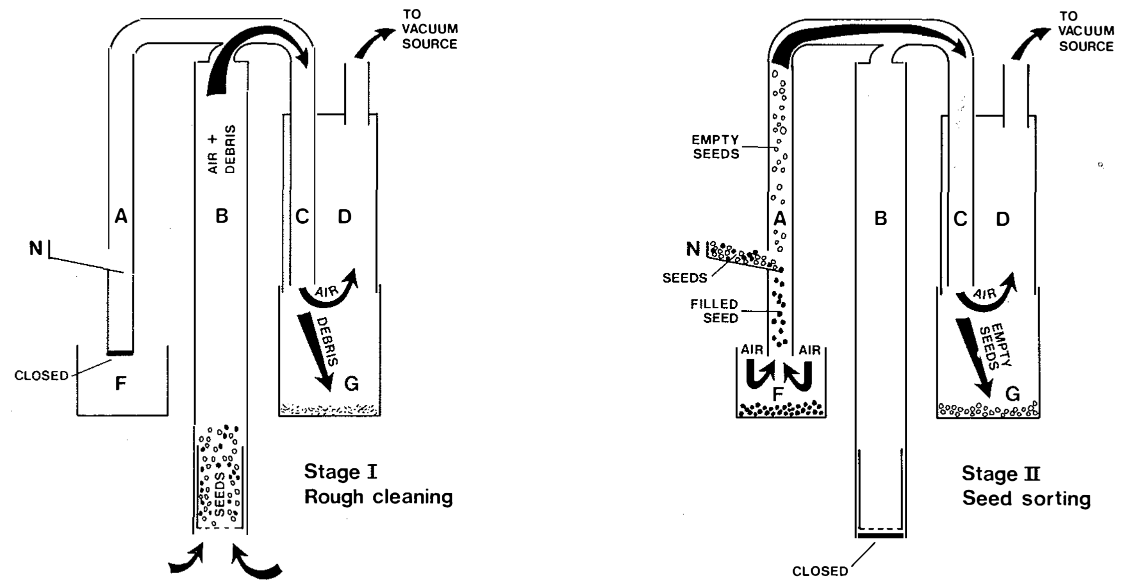

Fig. 21. Schematic working of a two stage air cleaner/sorter. A vacuum cleaner provides the air stream. In stage I, tube A is closed and the seeds plus debris are placed in a container at the lower end of tube B; this container has a wire mesh bottom. When the air stream is turned on dust, chaff, needles, bracts, *etc.,* are drawn into tube C and collect in G. In Stage II, cleaned seeds are placed in N; tube A is opened, tube B is closed. With the air stream on, heavy (filled) seeds fall into F, light (empty) seeds are carried into G.

There is little evidence that gravity separation or pneumatic sorting cause seed damage, although either process might increase injuries caused by other treatments. Pneumatic separation has been observed to inflict some loss of quality in Abies seeds (Edwards, in press). Other types of separation methods based on flotation of seeds in liquids of different densities have been experimented with but none have been developed for commercial use, although this method is used for research purposes (Belcher and Karrfalt 1978).

SEED STORAGE

The key objective in storage is to ensure a seed supply when needed, so it is an important feature in any artificial reforestation program. The crops of most conifers occur periodically, i.e., larger amounts of seeds are produced at intervals of several years, with none at all in some years. This is caused by a combination of interacting factors, including weather conditions, damaging agents and mechanisms within the seeds themselves. To ensure that seeds are available during periods of poor or no crops, large quantities must be collected in heavy seed-crop years and stored. Seed storage has been intensively researched and the technology is well established for conserving most species for at least the period between good crop years (Wang 1974).

The seeds of many conifers retain their viability in the soil for 1 or 2 years only after seedfall but, if stored dry and cold, viability can be retained for more than 10 years in most species. Optimum storage conditions vary, but moisture levels between 6-9% (fresh weight basis) and a temperature of -18°C have been widely used to maximize conifer seed longevity. The general relationship between storage temperature and seed moisture level is: at any given moisture content, seed viability deteriorates faster as storage temperature rises (within limits), and the lower the storage temperature, the greater the tolerance to high moisture content. In other words, storage temperature is of greater importance when moisture content is high.

Sealed storage containers provide several advantages. They avoid the need for costly air-conditioning of the storage room; provide for better maintenance of seed moisture content over prolonged storage periods; protect from losses due to insects or pathogenic organisms and minimize the effects of malfunctions of the refrigerating equipment. Fluctuations in moisture level can be very detrimental, especially if temperatures also rise, since the increased respiration will deplete food reserves within the seeds; disease and insect activity may also spread rapidly. Even in sub-freezing storage, viability can be lost rapidly if moisture contents are permitted to increase; thus, constant moisture levels and steady temperatures are most desirable.

Various types of sealed containers are used (Fig. 22). Although breakable, glass bottles are better than tin cans, which corrode. Screw-top plastic bottles, heavy-weight polyethylene bags and fibreboard drums are used extensively as all are light and unbreakable. A combination of a plastic bag in an aluminum foil-lined fibreboard drum, particularly if filled to leave a minimum air space, was recommended some years ago (Wang 1974). Plastic and polyethylene containers are not completely impervious to moisture; they may not be adequate for long-term storage of seeds requiring low moisture content if there is high external humidity. Container size should be limited to no more than 40 kg. This avoids the waste of space in storing larger containers and their repeated opening and resealing after each seed withdrawal and also minimizes the danger of the lowermost seeds in the container being crushed. The containers should be numbered and used for seed withdrawal in a systematic manner to prevent wastage of storage space and frequent opening of the containers. Records of the amounts of seeds on hand and their location in the storage room should be maintained. To prevent fluctuations in seed moisture level, container seals should not be broken until immediately before the seeds are withdrawn. If removed from cold storage, it is particularly important that sealed containers be permitted to reach room temperature before being opened to avoid condensation of water within the container, which would cause an increase in moisture level.

Fig. 22. Storage containers should be small enough to be handled easily and use shelf space efficiently. Very small amounts of seed may be kept in drawers.

Alternatively, seed withdrawal might be accomplished within the cold storage room.

Even when storage conditions have been optimized, different seedlots can be expected to show considerable variation in storage life. Low quality lots can be expected to deteriorate further, even under the best storage conditions. In general, immature seeds do not retain their viability in storage as well as mature seeds, although a complex of other factors, such as initial viability, lack of mechanical damage as well as storage conditions, govern seed longevity. There have been reports of immature seeds apparently ripening during storage but this cannot be relied upon as a general rule. Poor-quality lots, whatever the reason, should be scheduled for use in the nursery at the earliest possible time.

SEED PREPARATION FOR SOWING

Many species depend on some form of seed dormancy to ensure their perpetuation in nature during adverse conditions, but this dormancy must be overcome for effective seedling production. Rapid (and uniform) nursery germination reduces the risk of disease and predation, facilitates the production of uniform nursery stock and assists in minimizing nursery costs. One of the most commonly applied presowing treatments to break dormancy is prechilling (also known as stratification). This consists of soaking the seeds in water, usually for 24-48 hours, then chilling them between 1° and 5°C, for 3-12 weeks, depending on the species. The technique of "naked stratification" entails placing the seeds in a polyethylene bag containing the water, soaking them for the required time at room temperature, then draining the water off; puncturing the bag is used at some nurseries. The top of the bag is usually closed to maintain a high moisture level and to avoid spillage, but some nurseries place a plastic breather tube in the neck to ensure good aeration. The seeds are then refrigerated. Species or seedlots requiring long periods of chilling are said to be more dormant than those that germinate after shorter treatment. Damaged seeds, or those that were of low quality when collected, usually do not withstand long periods of treatment. Some species, *i.e.*, yellow cedar (*Chamaecyparis nootkatensis*), require a warm, moist period before the cold treatment to overcome dormancy.

Preparing large quantities of valuable tree seeds requires organization, careful measurement and attention to the proper technique. Seedling production costs may be decreased by eliminating the expense of pre-sowing treatments through use of untreated, dormant seeds in the fall. Weak or damaged seeds rarely survive the winter, and fall-sown seeds are much more vulnerable to predators and disease. If sown too early, germination may occur before winter and the seedlings will be lost; sown too late, the seeds may be frozen in the soil before the dormancy-breaking changes are sufficiently advanced, resulting in intermittent germination and poor stocking in the spring.

Fungicides and seed colorants may be applied to the seeds immediately prior to sowing. The effects of such "seed dressings" on seedling production should be carefully evaluated in advance. Extensive screening programs have produced only a few fungicides, such as captan, thiram and benomyl, suitable for use on tree seeds. Germinating seeds are very sensitive to chemicals and negative effects have been reported for all types of fungicides. In several studies, few if any fungicidal treatments have increased seedling production, primarily because fungicidal toxicity often counterbalances, and may exceed, any beneficial effects of protection against disease, especially in years of low disease incidence (Lock *et al*. 1975). In other words, the practical influence on the percentage or rate of seedling emergence may be nil but the chemicals reduce seed quality. Fungicidal treatments should be used only in bareroot nurseries when high disease incidence warrants them; their use in container nurseries should be avoided because of phytotoxicity problems (Van Eerden 1974).

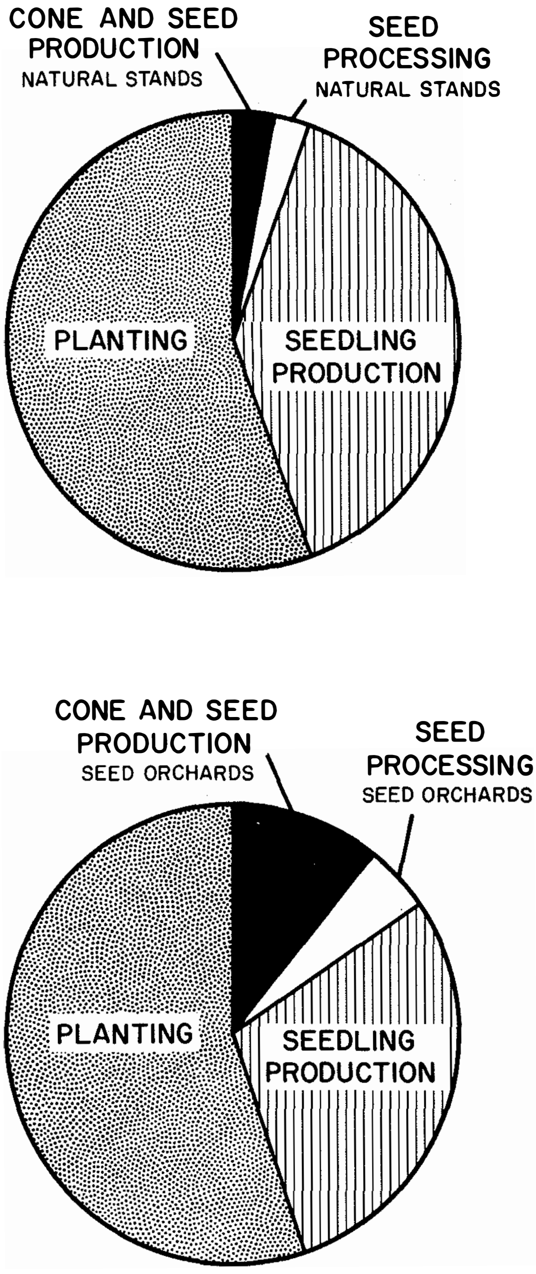

Fig. 23. The cost of seed production and seed processing are relatively small when compared with other major components of the reforestation process. These costs will increase, at least double, for seeds obtained from seed orchards. (Gross comparisons only are shown.)

When seedling requirements have been established, sowing schedules can be formulated. These are based on the viable seeds per gram in the seedlot (determined through seed testing) and on sowing factors developed through experience for the different species. No two bareroot nurseries produce seedlings at identical rates; differences in environmental conditions, disease and predator problems and many other factors make it impossible to predict exactly what the plant yield will be from any given seedlot. In the relatively more controlled environments of container nurseries, sowing factors are less important; calculations here aim at producing a plant in every cavity. Present technology requires that more than one seed has to be sown in each cavity for most species, and extra cavities must also be sown to allow for losses during the growing season. (This is discussed in more detail elsewhere in this Workshop.) Since container production is more highly mechanized, and the vacuum-seeders used cannot discriminate between seeds and similarly-sized non-seed particles, seedlot cleanliness (purity) is more important than in bareroot nurseries. Low quality seedlots are not normally used in containers unless pregermination techniques can be used; i.e., the seeds are germinated in trays or flats and only those seeds that show a protruding radicle are placed in the containers.

Although the relative cost of seed processing is a very small component in the overall reforestation program (Fig. 23), the impact of poor seed quality can be highly significant.

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LODGEPOLE PINE SEED EXTRACTION[1]

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PREAMBLE

Cones of lodgepole pine (*Pinus contorta* Dougl. var *latifolia* Engelm.) are collected year around in Alberta. These cones are shipped to the nursery and may contain anywhere from about 12% to about 30% moisture upon entry into the extraction process. Cones collected in winter normally contain 20% or more moisture. Cones stored under shelter at Pine Ridge Forestry Nursery, during summer, may contain as little as 12% moisture. Cones stored in a heated building may contain as little as 6-7% moisture, even after brief periods of a few weeks or even days.

INTRODUCTION

Seed extraction from lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) cones has kept man puzzling for nearly 70 years, ever since Clements' questioning report of 1910.

Temperature was identified then as the factor needed to open the cones. It has been assumed ever since that the seeds would be released automatically once the resin melted or vaporized or somehow disappeared from the cone scales. This assumption has, in my mind, led to the array of confusing publications on the subject of so called "cone serotiny" in lodgepole and jack pines. (Cameron 1953, Clements 1910, Critchfield 1957, Crossley 1956a, b, Edwards 1954, 1955, Hellum 1978, Krugman and Jenkinson 1974. Lotan 1964, 1967, 1975, 1976, MacAuley 1975, Rietz 1939, Rudolph et al. 1959, Teich 1970, Thompson 1969, Wang 1973, 1978, Wright 1931).

There are two processes involved in obtaining seeds from lodgepole pine cones and probably from other trees of serotinous or semi-serotinous cone habit as well. Cone opening takes place most efficiently under high heat or scorching, while seed release takes place under the influence of moderate but warm temperatures and some additional moisture (Krugman and Jenkinson 1974, MacAuley 1975).

What we have failed to recognize up to now is that the two processes are discrete and need to be understood as separate problems. Ergo: the term serotiny, meaning dealyed action, is a poor term to use for both.

[1] Study funded by Alberta Forest Development Trust Fund 1977 to 1980 and by N.S.E.R.C. Grant #46934.

The purpose of this paper is to present, in summary form, findings on lodgepole pine cone opening at the University of Alberta (Hellum and Pelchat 1979, Hellum and Barker, in press 1980). I intend to do this in the form of a prescription on how to obtain full seed yield and yet not to damage the seed in the extraction process.

All the answers to this problem are not known, however, and that the genetic aspect is largely untouched and the importance of rates of cone moisture loss are still under study.

PROPOSED METHOD

1. Collect and store cones at a moisture content close to 20%.

   - Unpublished data suggest that collection should be done between November and April when cones are in their moistest condition.

   - Store cones in unheated shelters and inside burlap bags. Do not store cones inside heated buildings unless cones are very wet when received for seed extraction. If stored inside, they should be moved to outside shelters as soon as they dry down to 20% moisture (oven dry base).

   - Figure 1 shows that if cones enter the extraction process with less than 20% moisture then varying amounts of seed are retained in the cones. Up to 25% of the seed from any lot could be lost if cones are dry (6-7% moisture content).

2. Weigh 30 cones from each bulk lot before extraction starts. Dry them at 105°C for 24 hours and reweigh. Weigh all 30 cones together each time and calculate average cone moisture content for each lot.

3. Send bulk lots through scorcher set at 180°C (±) for 2 minutes or less. This will open bonds on all cones, regardless of serotiny, provided cones are at room temperature when entering the scorcher.

   - This procedure will prevent seeds from overheating (Figure 2) assuming that 80°C of heat will damage germinability of the seed.

   - Do not try to handle old, silvery cones differently from young, brown cones. Within reason, they all yield their seed well. Tree to tree variation is large even within stands (Figure 3) but cones cannot be sorted by parent tree in bulk lots.

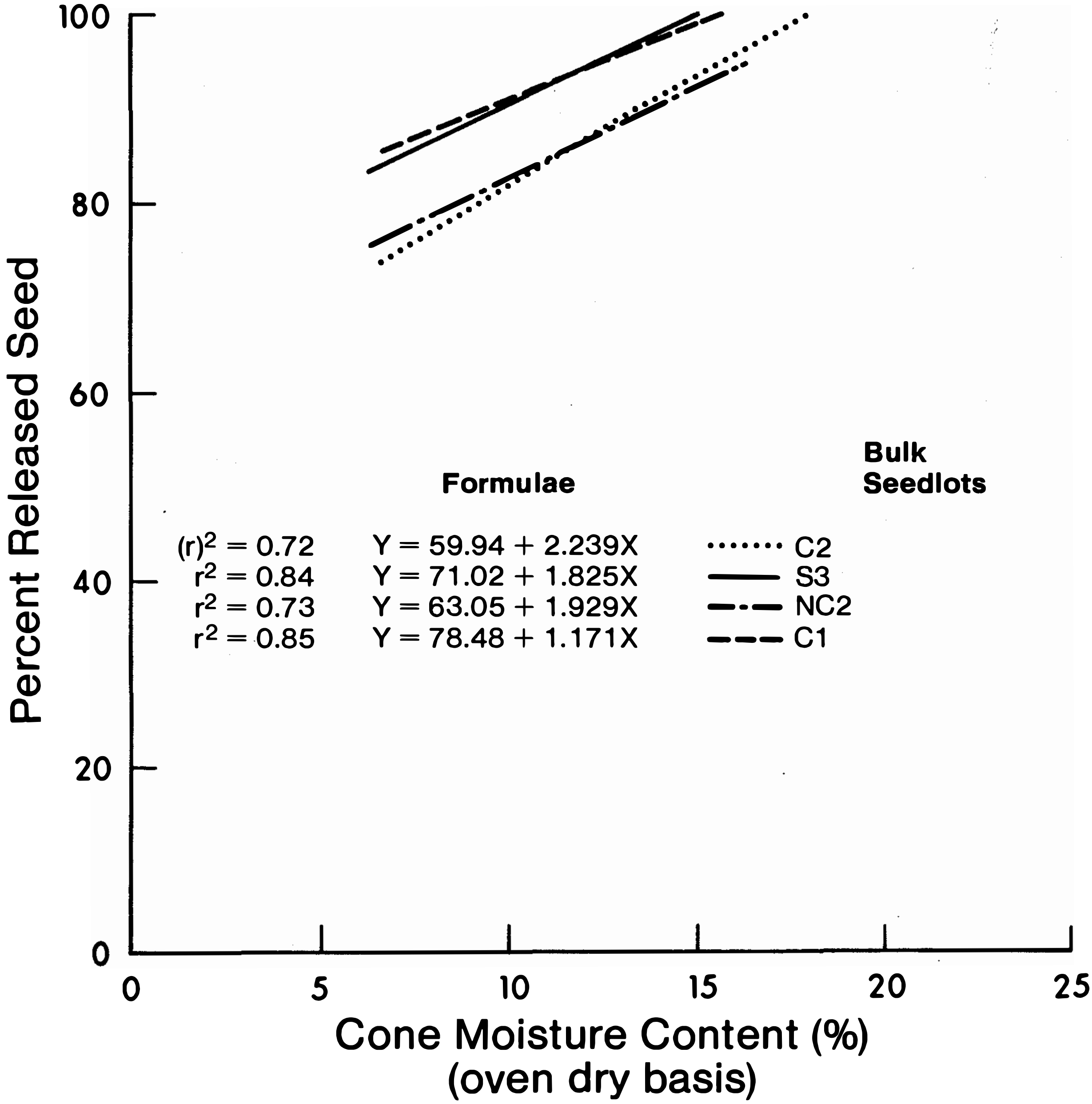

Figure 1. The effect of cone moisture content on total percent seed release in four bulk lots of lodgepole pine (Hellum and Barker, C.J.F.R. 1980).

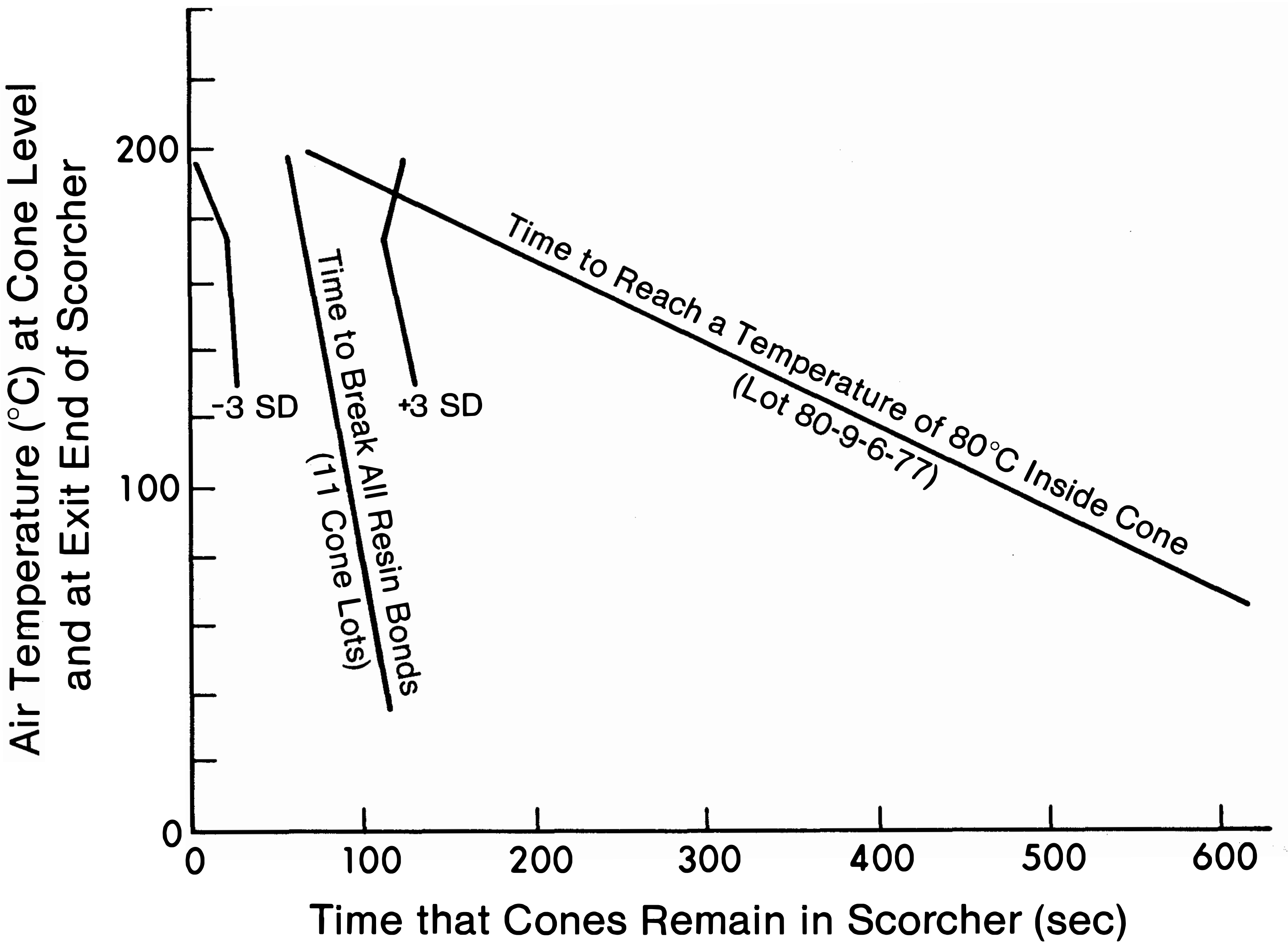

Figure 2. The relationship between times to reach 80°C inside cones and times to break resin bonds for 11 cones lots. Variability among cone lots in the time needed to break cone bonds is noted by the ± 3 standard deviation spread in the data.

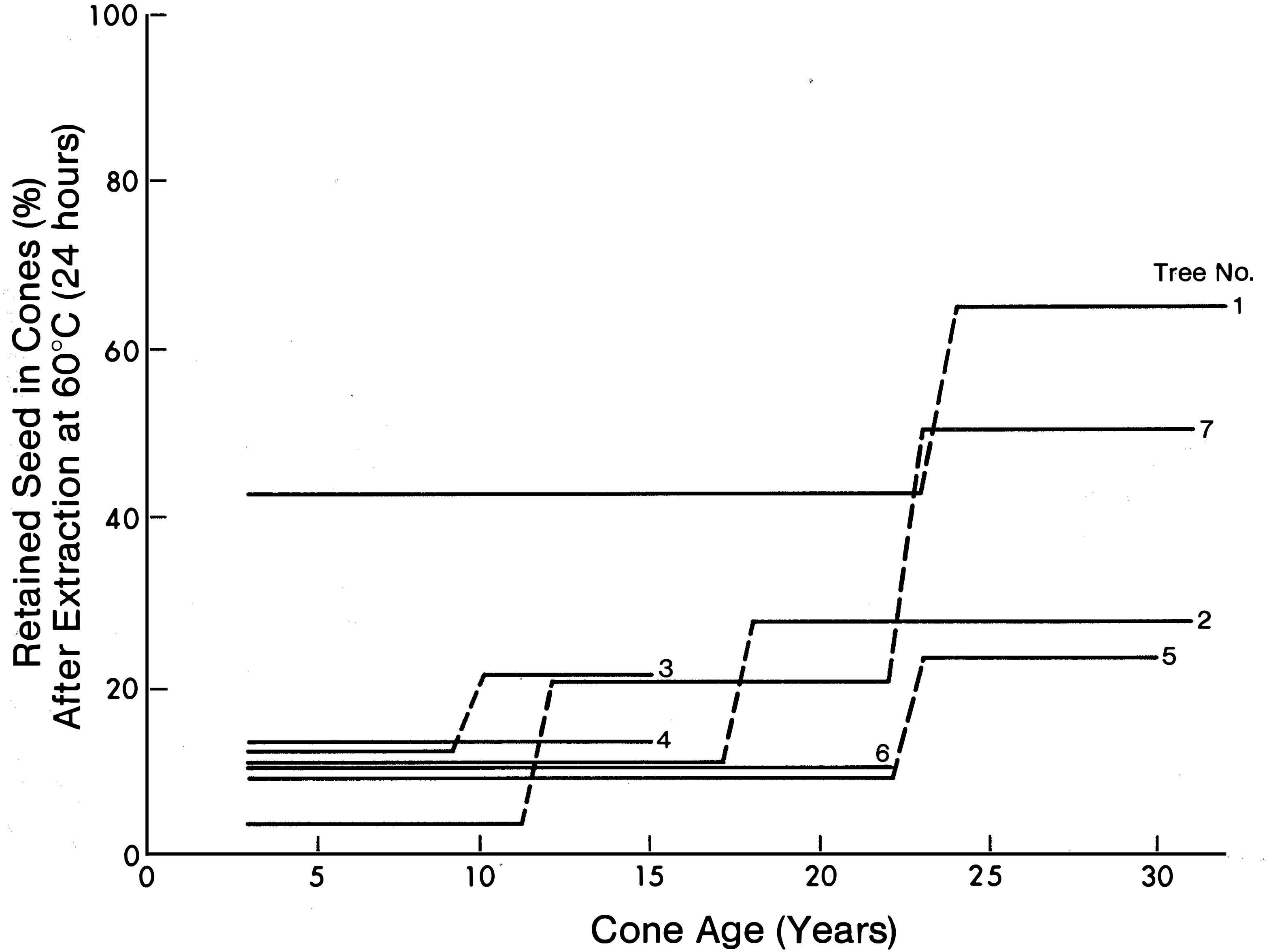

Figure 3. Percent seed retention in cones of variable age from seven mature trees of lodgepole pine (Hellum and Barker, For. Sci. 1980).

- Over 80% of all the cones on 7 test trees were less than 17 years old and up to this point cone age did not affect seed release adversely - on the average (Figure 4).

- The wetter the cone is the longer it will take to break resin bonds (Figure 5).

4. Calculate, on the base of cones weighed under 2 above, average cone weight at a 20% moisture content.

5. Spray or mist the cones as they come hot off the scorcher. Figure 6 shows that if cones are soaked for about 30 seconds they absorb about 14% moisture providing resin bonds have been broken.

   - Sample cones should be pulled off the misting area and weighed to determine when cones do contain 20% moisture.

   - Avoid wetting cones to contain much more than 20% m.c. This only leads to overlay in seed extraction and does not help seed release.

6. Convey misted cones into hoppers and store cones there only for as long as it takes to fill a kiln with 30 bushels. Warm, moist cone storage can only lead to moisture loss under normal Alberta conditions.

7. If cones contain about 20% moisture they will open and release their seeds more rapidly than at any other cone moisture content (Figure 7), provided the moisture is vented quickly from the kilns.

   - This implies that extraction can be completed in well less than 12 hours. It is estimated that all seed will be released in 6 hours or less.

   - Data in Figure 8 show how spread out seed release is if cones enter the extraction process with variable and low moisture contents.

8. Seed extraction at 60°C does not affect germination even after 14 hours (Figure 9) suggesting that this is a perfectly safe temperature to use.

9. Empty seed content increases gradually from the second to the 10th hour of extraction. With time, it can amount to over 40% of sample. It may therefore be practical to terminate extraction procedures before the last small amounts of seeds are released if extraction costs equal or exceed the value of the sound seed component of the lot (Figure 10).

10. Send seed for dewinging, cleaning and cold storage at 0°C and with 3-5% moisture content.

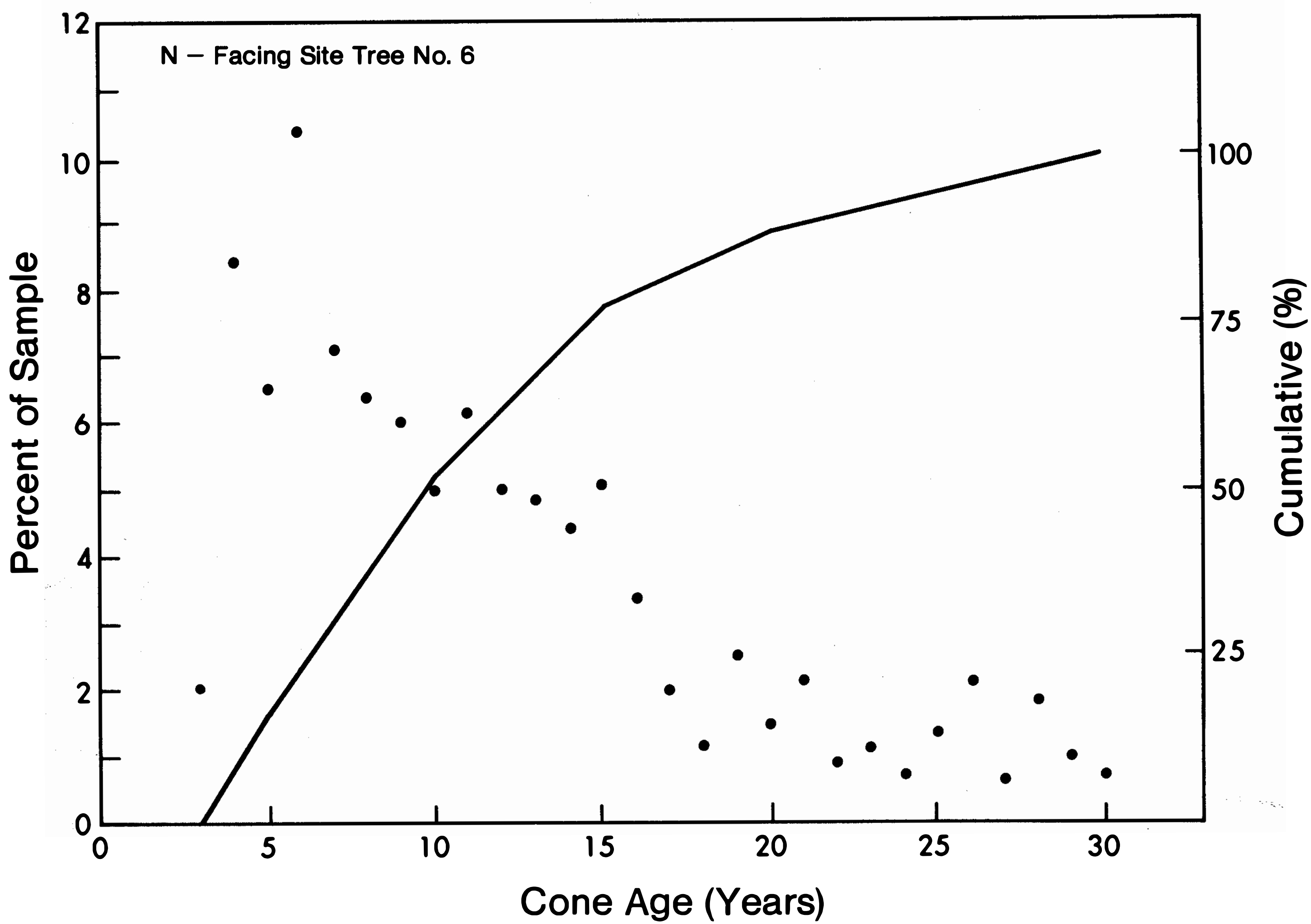

Figure 4. The distribution of cones by age on one lodgepole pine tree near Hinton, Alberta. The tree was codominant in a closed stand 110 years old (stump age). This pattern is typical for all eight sample trees.

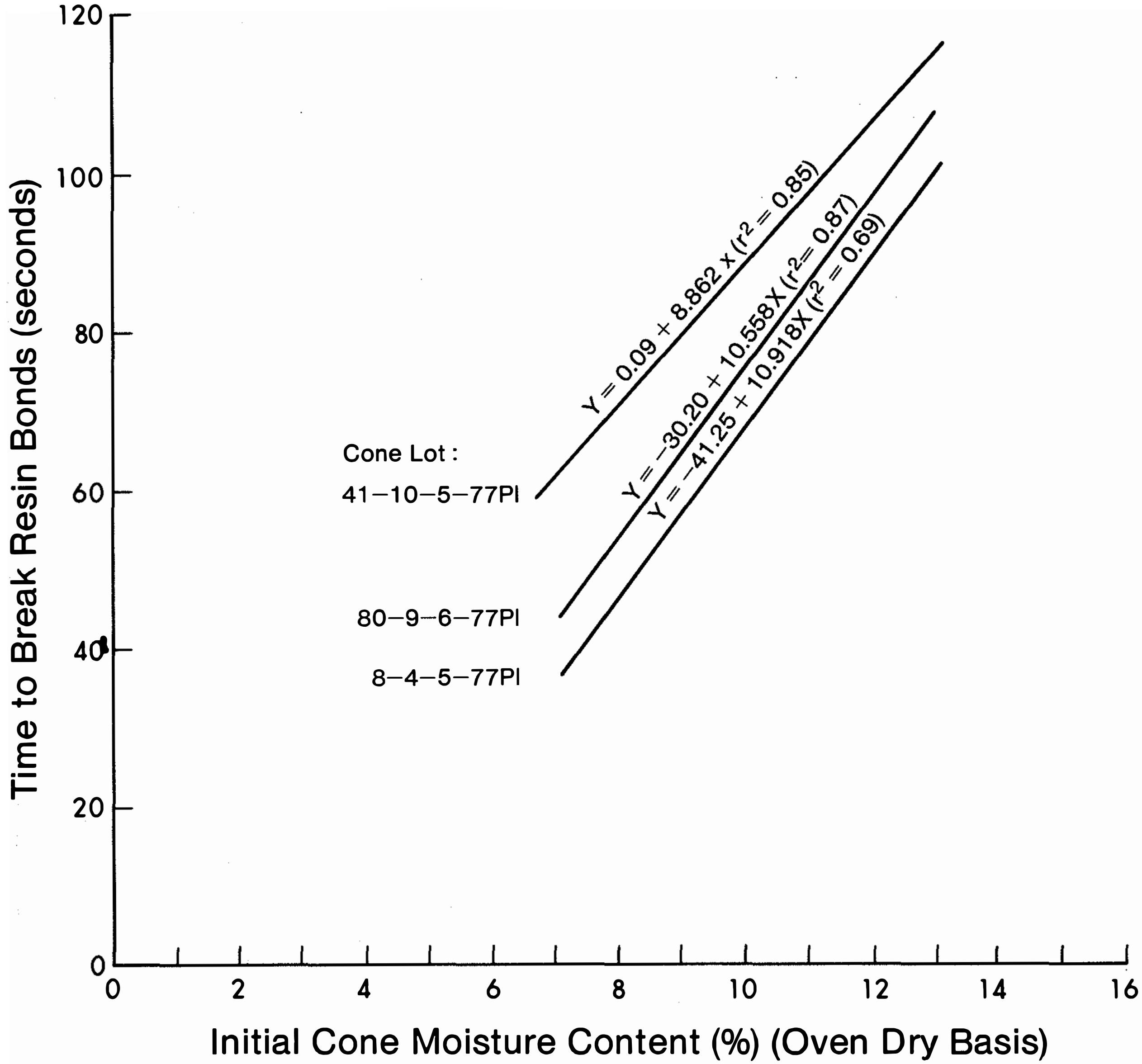

Figure 5. Cone moisture content influences the time of complete bond breaking in bulk lots of lodgepole pine cones (Hellum and Barker, For. Sci. 1980).

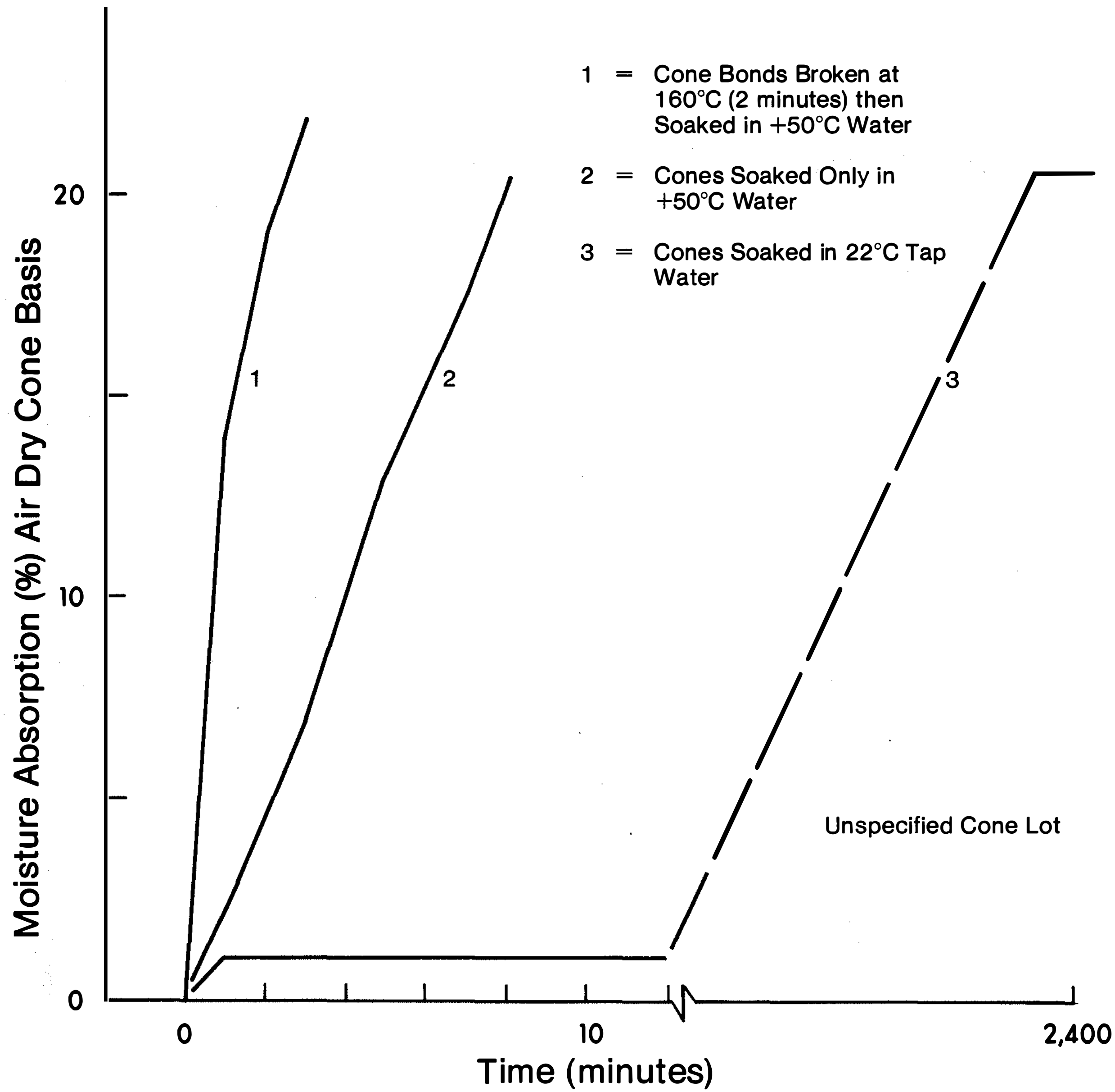

Figure 6. Three methods for moistening lodgepole pine cones and their effects on water uptake (Hellum and Barker, C.J.F.R. 1980).

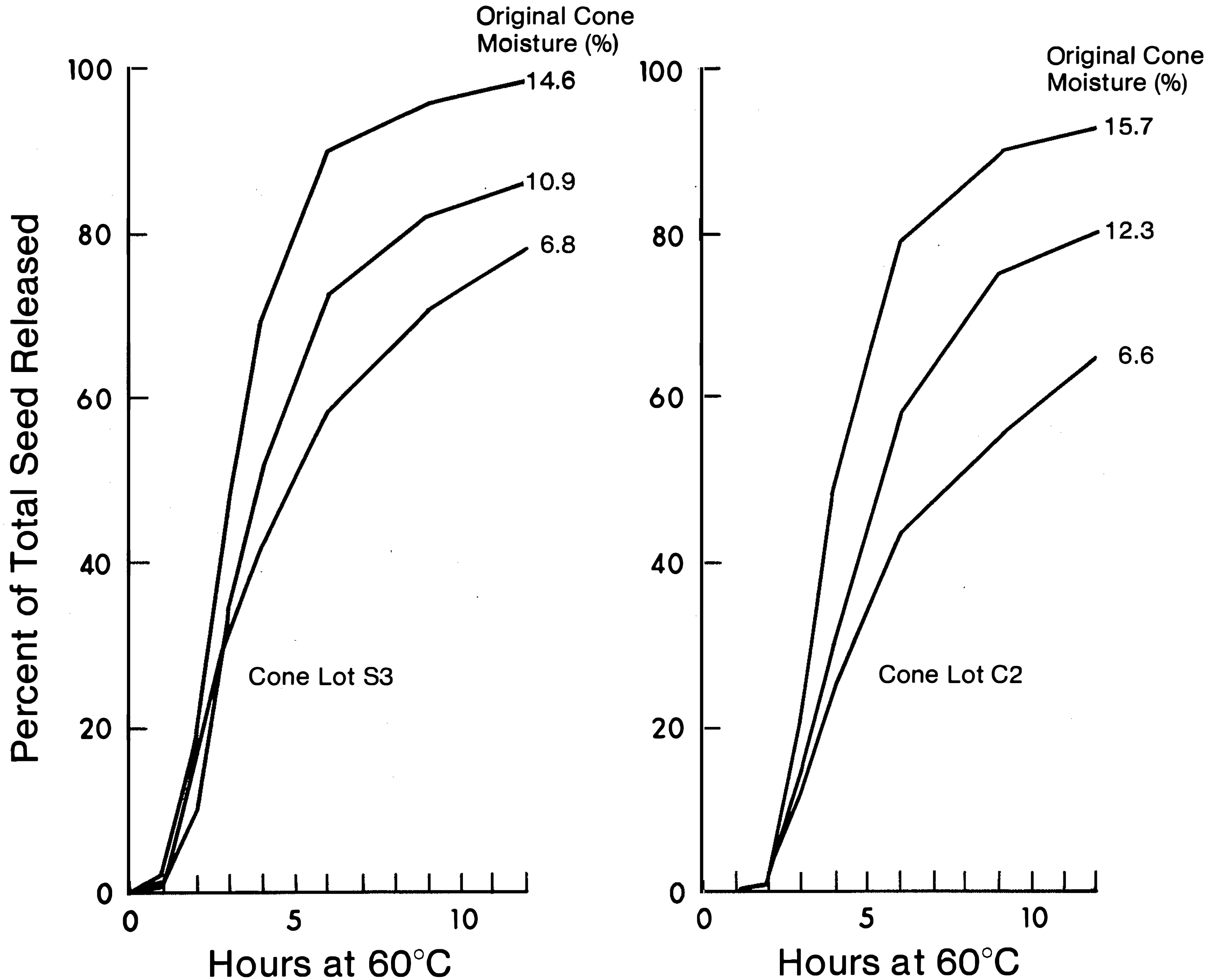

Figure 7. The effect of cone moisture content at start of seed extraction on rates of seed release from two bulk lots of lodgepole pine (Hellum and Barker, C.J.F.R. 1980).

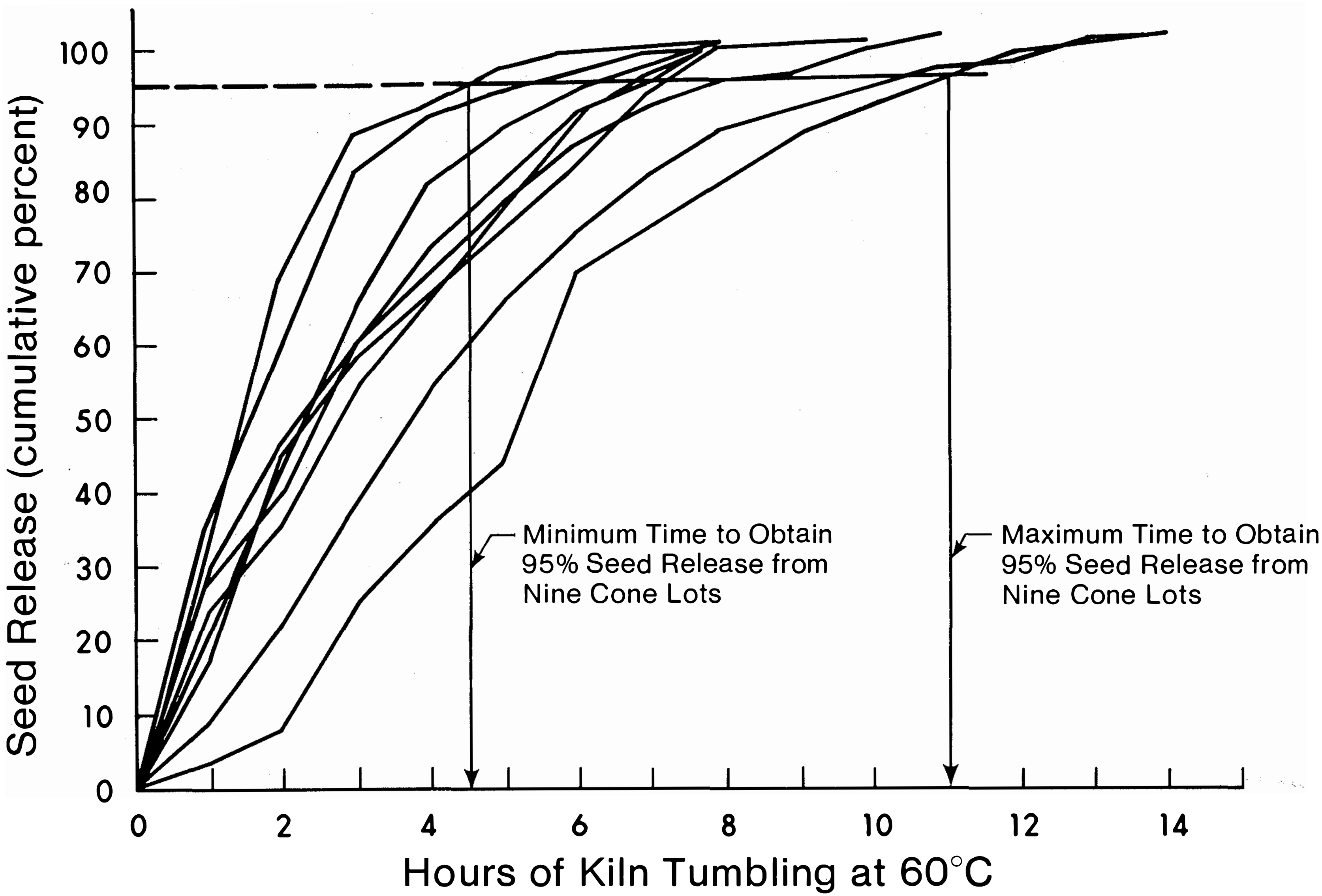

Figure 8. Rates of seed release from nine cone lots tumbled continuously at 8 rpm in a 60°C kiln. Minimum and maximum times to obtain 95% seed release are noted (Hellum and Barker, C.J.F.R. 1980).

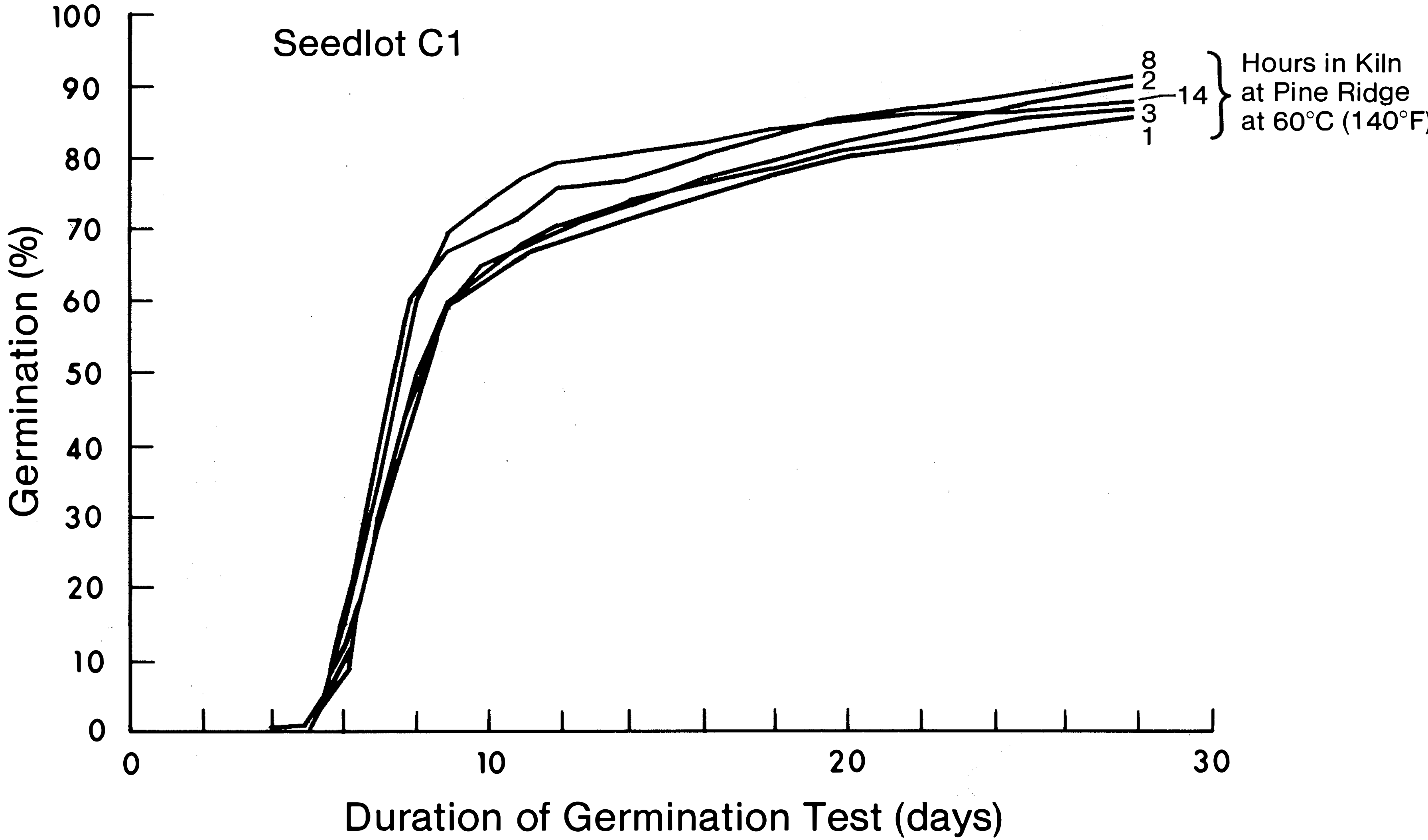

Figure 9. The effect of kiln time at 60°C on seed germination for one representative bulk seed lot of lodgepole pine (Hellum and Barker, C.J.F.R. 1980).

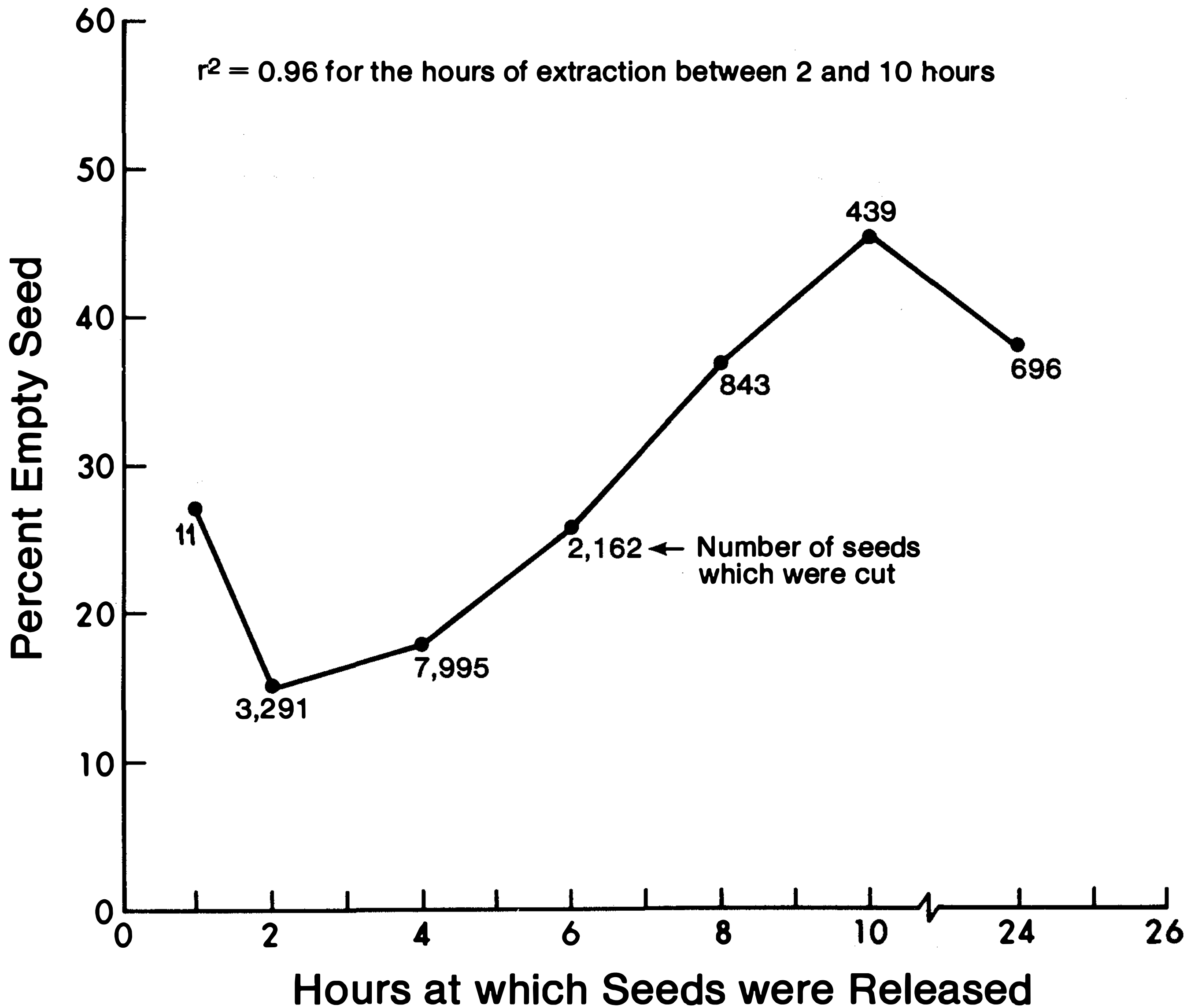

Figure 10. Correlation between percent empty seed and time of seed release in lodgepole pine based on a total of 2,284 cones collected from six trees (Hellum and Barker, For. Sci. 1980).

SUMMARY

It should be clear from the foregoing that full seed yield from cones of lodgepole pine is aided if care and attention is paid to cone collection, cone storage, seed extraction and seed storage. In the past, pine cones were thought to be collectable at any time of the year, that they could be stored nearly anywhere and that the seed could be extracted whenever convenient. It is clear now, however, that a cone moisture content of about 20% is prerequisite to good seed yield regardless of the condition of the cones up to the extraction time. It is also certain that an extraction temperature of 60°C is safe and adequate. In addition, seed yield happens more quickly from moistened cones rather than from dry cones or wet cones.

In Alberta, it is not uncommon that 40,000 bushels of pine cones could be collected in one year for reforestation. If these cones contain less than 7% moisture, as much as 2,500 pounds of seed could be lost at an equivalent value of $250,000. At a cone moisture content of 12% the loss is still 250 pounds of seed at a value of $25,000. The seed loss and the dollar value should both indicate that cone collection, handling and seed storage in lodgepole pine should be managed according to precise and well-controlled procedures.

There is still much to be learnt about this problem to understand why cones behave as they do, but we know how to extract all the seed safely from cones of lodgepole pine in Alberta. The ecological implications of our findings are worth further study, however, as are the genetic aspects, and these are being pursued.

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EFFECTS OF INSECTS ON SEED AND CONE PRODUCTION

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INTRODUCTION

My presentation on the effects of insects on seed and cone production is primarily based on conditions in the three prairie provinces, although I realize that much of the information base comes from adjacent provinces and from other outside sources. Also, because of the shortage of time, I will not deal with problems of seed storage.

Within this region of Canada, three coniferous species provide the major seed supplies for most reforestation programs, namely, white spruce, jack pine, and lodgepole pine. Seed and cone insects on spruce have been given widest attention for several reasons: (a) The insect complex on white spruce is fairly diverse and includes at least two important species that are consistently present throughout a wide geographical range extending from eastern Canada to British Columbia and Alaska. (b) Insect-caused damage to seeds and cones of spruce has been sufficiently high as to render cone collecting unprofitable. This has not usually been the case for lodgepole and jack pines. (c) Cone crops on white spruce tend to be more sporadic than those on pine, and therefore insect-caused losses, when they occur, are often more critical to seed supplies. (d) White spruce seeds are not retained in cones on the tree after the year of production and must be collected during the year they are produced and prior to release. This is not the case with lodgepole and jack pines, which retain several years of seed-bearing cones.

Although most of the information I have relates to white spruce, I will indicate potential insect problems on other important tree hosts, including balsam fir, eastern larch, black spruce, Douglas-fir, and red pine.

CONE AS A HABITAT FOR INSECTS

The female cone structure of conifers is a highly complex organ that has necessitated development of specialized adaptations by many of the insect species in order to survive. Each cone consists of a central axis around which close-fitting scales are arranged in a spiral directed toward the cone apex. Each scale may have a bract attached to its outer surface, and on its inner concave surface next to the central axis lie two seeds. A thin membranous wing is attached to each seed. In most cones the scales may be smaller at the base and apex, and most of the potentially sound seed is produced in the central portion of the cone. Much of the insect damage also tends to occur in the central portion of the cone.

In species such as spruce, fir, and tamarack in which cone development is completed in 1 year, the cone must grow from a small soft budlike structure in the spring to an elongated structure of hardened tissue by August. During this period the insect must also respond to these changes in its development and behavior. For example, moisture content in the spring may vary from 120% to 160% dry weight, but by September it will have dropped to 30-60% dry weight.

The insect species that inhabit cones of the different tree species have become highly specialized in several ways. Many are specific to a single host, while others are specific to certain structures of the cone. Specializations are apparent in both the adult and immature forms that allow, for example, exclusive feeding of larvae within seeds such as by chalcids, within scale tissue as in the case of certain midges, and by spiralling around the central cone axis to damage or destroy several seeds as in the case of the spruce seedworm.

HOST SYNCHRONY AND PHENOLOGY RELATIONSHIPS

An important aspect of insect-cone relationships is the sporadic and variable cone productivity of most tree species. White spruce, for example, may produce a good cone crop on average only every 4 years. In general, populations of insect species attacking seeds and cones tend to fluctuate with abundance of cones, but other factors also influence their numbers. Many of these factors are not well understood. During years of cone scarcity many of the insect species survive the discontinuity of food supply by adaptation to remain dormant. During such periods of food scarcity a portion of the population may remain in dormancy for 1, 2, or more years. There is a tendency for dormancy to coincide with years of low cone yield.

There is also a synchrony of insect development in relation to phenological development of the host. For example, spring emergence of the spiral cone midge on spruce in any given geographical location always coincides with the period of pollination.

KINDS OF INSECTS AND THEIR DEVELOPMENT

The complex of insect species attacking seeds and cones can be divided into two broad groups:

a. Internal feeders - Members of this group feed exclusively within the cone and include midges, certain moth larvae, beetles, and seed chalcids. They appear to be the most highly specialized for their habitat. During feeding they often leave little evidence of attack on the exterior of the cone.

b. External feeders - Members of this group mostly feed externally on the cone or burrow indiscriminantly throughout the cone. Certain species such as seedbugs feed externally by extending tubelike sucking mouthparts into the young cone tissue. Others such as the spruce budworm and spruce coneworm also feed on foliage and utilize more than one host.

LIFE HISTORY

Most seed and cone insects have a 1-year life history, although a variable proportion of the population of many species may remain in dormancy for 1 or more years. For most species, adult emergence occurs in the spring, and eggs are laid about the time female cones are open for pollination. Larval feeding (the damage stage in most species) commences shortly after eggs are laid and is completed during late June to early August, depending upon the species. Specialization of feeding and development allow one or several species to co-exist within the same cone.

INSECT SPECIES COMPLEX AND THEIR DAMAGE

Slides were shown to illustrate several insect species and the damage caused by internal and external feeders.

STAND CHARACTERISTICS, CONE PRODUCTION, AND INSECT ABUNDANCE

Information is relatively rare on fluctuations of seed and cone insect populations from year to year. In one study followed for 6 years in British Columbia, four insect species in Douglas-fir cones were monitored. Their abundance generally followed the same trend as cone abundance. Small differences in species abundance were attributed to the elevation at the plot locations. It has been widely observed that cone and seed damage is often greatest during years when cone productivity is low, probably because the ratio of insects to cones is much higher then than when cone productivity is high. During years of low cone production the percentage of damaged cones of white spruce and Douglas-fir can reach 100%, but it may only reach 25% when cones are abundant. This suggests that additional collecting of cones should be done during years of cone abundance.

Within crowns there appears to be little variation in insect species diversity. On Siberian larch in the USSR, however, three main damaging species are usually present, but their population densities may fluctuate from area to area, tree to tree, and even within crowns of individual trees.

The incidence of damaged cones and seed may also vary greatly from location to location within the same year. In 1967, a year of fairly good cone production in Alberta, white spruce cone collections were made at 17 locations throughout the province. The incidence of damaged cones at these locations varied from 4% to 97%. In 1978 two white spruce cone collections from the Lac la Biche area had estimated seed losses due to insect damage of 31% and 42%, but the average number of potentially viable seeds per cone was relatively low (average 42 and 31 per cone). The fact that the number of potentially viable seeds per cone varies with cone production may help account for the higher insect losses in different locations and years.

In 1979 two locations near Grande Prairie were sampled, and the incidence of damaged cones was 21% and 10%, even though good cone crops were produced at both locations. This amounted to only 5-6% seed loss due to insects alone.

In Ontario a recent study of insects attacking white spruce cones in three different habitats indicated that the abundance of certain insect species varied greatly with stand conditions. This could have implications where stands are thinned and maintained for permanent seed collecting areas. In special areas where higher cone productivity is promoted there is the possibility these areas will sustain higher losses due to insects than will the surrounding forested areas. Hence, some form of control may have to be instituted on an annual basis.

There is evidence that fertilization of stands to promote tree growth may also affect insects in an unfavorable way. For example, in shelterwood stands of Norway spruce in northern Europe, fertilization with nitrogen and phosphorus caused increases in both larval numbers and weights of larvae of *Laspeyresia strobilella*, a cone-feeding insect. This occurred 1 year after application of fertilizer.

INSECT-CAUSED LOSSES PER CONE

Seed losses per cone are dictated by the insect species involved, the incidence of cones damaged, and the number of insects per cone. The following examples of white spruce cones containing one larva of *Laspeyresia youngana* or *Hylemya anthracina* illustrate the potential damage.

L. youngana: (British Columbia estimate) One larva destroys 23-40% of seeds.

H. anthracina: (British Columbia estimate) One larva may destroy 30-90% of seeds per cone.
(Alberta estimate) One larva may destroy an average of 40% of seeds per cone.

CONTROL STUDIES OF SEED AND CONE INSECTS

Several attempts have been made since the 1960s in both Europe and North America to control insects of seeds and cones by use of chemical insecticides, especially those with systemic properties. Dimethoate and metasystox-R applied as a 0.5-1.0% solution in water have generally provided good control on white spruce and Douglas-fir in British Columbia and the northwestern United States. Application to spruce seed orchards in Finland has also given good control. However, timing of application is important and should be made shortly after pollination or about the time when cones have started to turn down. Concentrations of insecticide greater than 1% have produced phytotoxic effects, especially when applied during pollen germination. Application by helicopter has helped ensure good coverage of the upper crown and cone-bearing twigs.

In pine seed orchards of the southern United States, carbofuran has been applied to the soil to effectively control two species of seedbug. Percentages and yields of filled seeds per cone were greatly increased with application of 45 g of 10% carbofuran per cm of tree diameter of loblolly, slash, shortleaf, and Virginia pines.

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CONIFER SEED PATHOLOGY

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To ensure the supply of high-quality conifer seeds for nursery production, it is important to know and be aware of tree diseases that prevent or reduce the production of seeds, disease organisms carried by seeds, and microorganisms that can damage seeds in storage. Very little is known in this area because no research has been done in the prairie provinces. I would like to briefly discuss several aspects.

SPRUCE CONE RUST

This is the only cone disease I can think of that adversely affects production of conifer seeds in the prairie provinces. It is caused by a rust fungus, *Chrysomyra pirolata*, and attacks cones of white and black spruces. Several other rusts on pine and spruce cones are known but are not important in this part of North America. Up to 85% of cones have been reported damaged by spruce cone rust, and infection rates of 20-30% are common. The fungus infects cones systematically, and seeds in infected cones are not viable. Infected cones open much earlier than healthy ones and are easily recognized in the field. Because this disease cannot be carried by seeds, it is safe to use seeds collected from an infested area. The life cycle of this rust is rather complicated, having five different spore stages. Also, this fungus needs another group of plants in addition to spruce to complete its life cycle. Species of wintergreen (*Pyrola* spp.) are alternate hosts of the fungus. Preliminary results by Dr. J.R. Sutherland (Pacific Forest Research Centre, Victoria, B.C.) show that levels of infection are predictably proportional to the population of infected wintergreen plants in the stands. Spruce cone rust is important in situations such as seed orchards and designated seed collecting areas. Control measures have not been established, but in certain situations eradication of wintergreen plants should be effective and may be economically feasible.

SEED-BORNE DISEASES

Many plant diseases are known to be carried and disseminated by seeds. Our knowledge in this area is still very scanty; however, several cases have been documented in recent years. A soil-borne fungus, *Caloscypha fulgens*, that was found in England several years ago originated in spruce seeds sent from western Canada and was found to be damaging to seeds (Salt 1974). This fungus has since been found in Canada (Paden *et al.* 1978, Sutherland and Woods 1977). A pathogen of a seedling disease, *Ascochyta piniperda*, is also known to be carried by seeds of conifers.

SEED STORAGE FUNGI

Under certain seed storage conditions, growth of various fungi are encouraged and often cause mortality of seeds. A study in the U.S.S.R. isolated 78 different species of fungi from pine and spruce seeds (Prisyazhnyuk 1960) and indicated that methods of cone collection, condition of transport, and storage environment were important factors. Dr. Sutherland suggests that if storage conditions are proper, which means low in temperature and moisture, this problem should not cause much concern. To understand and cope with the problem of seed-borne diseases and seed storage fungi, it is important to consider those problems in relation to various tree seed activities such as cone collecting, transportation, storage, seed extraction, and presowing treatments.

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QUICK METHODS FOR DETERMINING SEED QUALITY IN TREE SEEDS

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ABSTRACT

In consideration of the length of time required for the completion of a standard germination test, several quick methods for determining seed quality are discussed. The biochemical and physiological basis and general methodology for the tetrazolium chloride, the hydrogen peroxide, and the X-ray contrast methods are described. The quick tests were performed on seeds of five coniferous species from British Columbia, then the tests were compared for their ability to predict germination percentages obtained in a standard incubator test. Of the three quick tests, the X-ray contrast predictions most often agreed with standard germination test results. The versatility of X-rays for monitoring the collection, processing and damage of seeds is also examined. A number of examples illustrating the use of X-rays is included.

INTRODUCTION

The standard germination test is perhaps the most familiar method for determining seed quality; it is conducted in controlled environment chambers and generally takes 6 to 8 weeks to complete (Association of Official Seed Analysts, 1978; International Seed Testing Association, 1976). Half of the testing period is required for stratification, a moist chilling treatment needed by most conifer seeds for rapid and complete germination. After stratification, seeds are transferred to warm, short days (20-30 C, 8 hrs light) to stimulate germination. The seeds are grown for an additional 3 - 4 weeks, and the test is terminated after final germination counts have been made. The germination test has been considered the standard by which most other seed assessment methods are evaluated because it is an actual measure of growth and with minor modifications, the results can usually be related to the performance of seeds in the field.

However, the germination test has a distinct drawback--almost two months are required for its completion. Because of its length, a number of quick procedures have been proposed for assessing seed quality. Quick tests are generally based upon some special biochemical or physiological feature of the seed and require correlation with the germination percentage obtained in a standard germination test. There are three commonly known and used quick tests: the tetrazolium chloride test, the hydrogen peroxide test, and the X-ray contrast test. The biochemical or physiological basis and the general methodology of each test are discussed in the following section. In addition, the three methods are compared and examined for their ability to predict the germination obtained in a standard test. The last section deals with the use of X-rays for assessing indicators of quality other than germinability.

THE USE OF QUICK TESTS FOR ASSESSING SEED QUALITY

Tetrazolium chloride (TZ)

The tetrazolium chloride test is based upon the chemical reaction

$$\underset{\text{(colorless)}}{\text{Tetrazolium chloride}} + H^{+} \longrightarrow \underset{\text{(red)}}{\text{Formazan}}$$

In healthy, physiologically sound areas of the seed hydrogen ions released during respiration combine with the colorless TZ solution to form a red precipitate, formazan, in the tissue. Weak, dead, or damaged parts of the seed remain as white or lightly colored areas. To allow penetration of the tetrazolium chloride, seeds are soaked in water for 24 hours, then the seed coats are partially cut, and the seeds are incubated in the TZ solution for 4-16 hrs at room temperature. After incubation, the seeds are cut in half and the staining pattern is evaluated. Differential staining of the endosperm and embryo allows the analyst to define live, weak, or dead areas of the seed (Moore, 1973; Simak and Kamra, 1963).

Hydrogen peroxide (H_2O_2)

The hydrogen peroxide test is a growth test in the same sense as the germination test, but results of the H_2O_2 test can be obtained within a week. H_2O_2 stimulates respiration and enhances early germination without the need for stratification. Seeds are prepared for the test by clipping the radicle end of the seed, then placing the seeds in a 1% H_2O_2 solution. After incubation for 3-4 days, germinated seeds (>1 mm radicle protrusion) are counted and removed. Ungerminated seeds are transferred to fresh H_2O_2 for an additional 3-4 days. After all germinated seeds have been counted, the test is terminated at the end of the second incubation period.

X-ray contrast (X-C)

In the X-C technique, contrast agents are used to aid in the interpretation of seed X-rays. Both the X-ray contrast and tetrazolium methods are staining techniques; however, the two tests differ in that in the X-C test the staining of the seeds occurs in dead and damaged areas, while in the TZ test staining occurs in live and healthy portions (Simak, 1974a; 1974b). The recent introduction of vapourous contrast agents in place of liquid contrast agents has simplified the X-C methods so that draining and drying the seeds after staining is unnecessary; this revision will probably encourage more seed testing facilities to use the X-C test. To stain a sample of seeds, approximately 100 ml of chloroform (or other organic solvent rich in chlorine molecules) are poured into a flask and the seeds are suspended in mesh bags for several hours above the vapours. After exposure, the seeds are removed, placed on top of the X-ray film, and X-rayed. X-ray interpretation of seed quality is based both upon the degree of staining and the degree of endosperm and embryo development (Müller-Olsen, Simak, and Gustafsson, 1956; Kamra, 1971).

Comparison of the tetrazolium chloride, hydrogen peroxide, and X-ray contrast quick tests

The principal criterion in choosing a quick test should be how well the quick method predicts actual germination. Studies conducted in our laboratory provide an example of how effectively the TZ, H_2O_2, and X-C quick tests assessed seed quality. British Columbia seed sources of *Abies amabilis, Picea glauca, Pinus contorta, Pseudotsuga menziesii,* and *Tsuga heterophylla* were tested by each of the quick test methods. Standard germination tests were used as the controls. Both quick and standard germination tests were conducted on 100-seed samples withdrawn from reasonably good quality lots, and treatments were replicated four times. In Figures 1-3, the percentage germination predicted by each quick test is compared to the percentage of seeds which actually germinated in a standard test (C). Percentages marked with an asterisk (*) denote assessments which were significantly different from the controls at the 5% level.

Assessments of seed quality provided by the TZ test agreed reasonably well with standard germination results for three of the five species, but TZ results were significantly different for *Tsuga heterophylla* and *Abies amabilis* (Figure 1). The H_2O_2 test poorly predicted germination performance in all species except *Picea glauca* (Figure 2). Hydrogen peroxide predictions tended to be too conservative, underestimating actual germination in all five species. Of the three quick tests, X-ray contrast predictions of seed lot quality most often agreed with standard germination test results (Figure 3). Only the quick test results for *Abies amabilis* were significantly different from control germination results. However, *A. amabilis* is frequently known to exhibit pronounced dormancy, thus the discrepancy between the X-ray contrast predictions and control percentages may likely reflect shortcomings in our understanding of the germination requirements of *A. amabilis* rather than inherent difficulties with the X-C test. Nevertheless, the X-ray contrast test appears to have good potential, so our studies are continuing.

OTHER INDICATORS OF SEED LOT QUALITY

The successful interpretation of X-rays does not always require the use of contrast agents, nor are X-rays limited to predicting germination performance. X-ray radiographs can be used to monitor and evaluate many aspects of cone and seed processing and storage. A substantial amount of information may be gained from the use of the X-ray technique. Cone collection supervisors who are interested in endosperm and embryo maturity before cone collections can easily trace the course of crop development by X-raying seed periodically throughout the growing season (Figures 4-8). Radiographs can assist pathologists and entomologists in the early diagnosis of disease and insect attack before major problems develop in seed orchards and wild stands (Figures 9-10). X-rays can monitor the

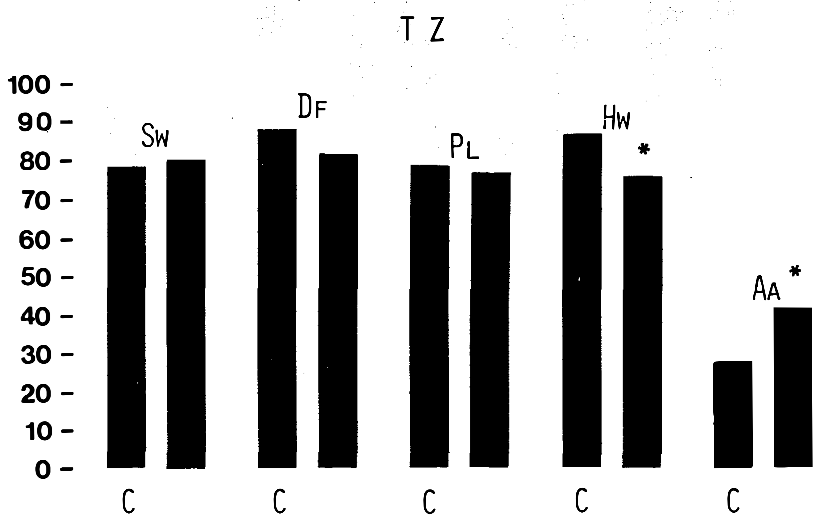


FIGURE 1. COMPARISON OF TETRAZOLIUM CHLORIDE QUICK TEST AND GERMINATION PERFORMANCE OF 5 CONIFERS

Explanation of notations for Figures 1 to 3. The percentage germination predicted by each quick test is compared to the percentage of seeds which germinated in the control (C). Controls were stratified for 3-4 weeks at 2 C, then germinated under 8-hr days at 30 C/20 C (or 20 C constant for western hemlock) for 3-4 weeks in a controlled environment incubator. Percentages marked with an asterisk denote assessments which were significantly different from controls at p = 0.05. The t-test was used to make statistical comparisons. Species abbreviations are Sw=white spruce *(Picea glauca)*; Df=Douglas fir *(Pseudotsuga menziesii)*; Pl=lodgepole pine *(Pinus contorta)*; Hw=western hemlock *(Tsuga heterophylla)*; Aa=Amabilis fir *(Abies amabilis)*.

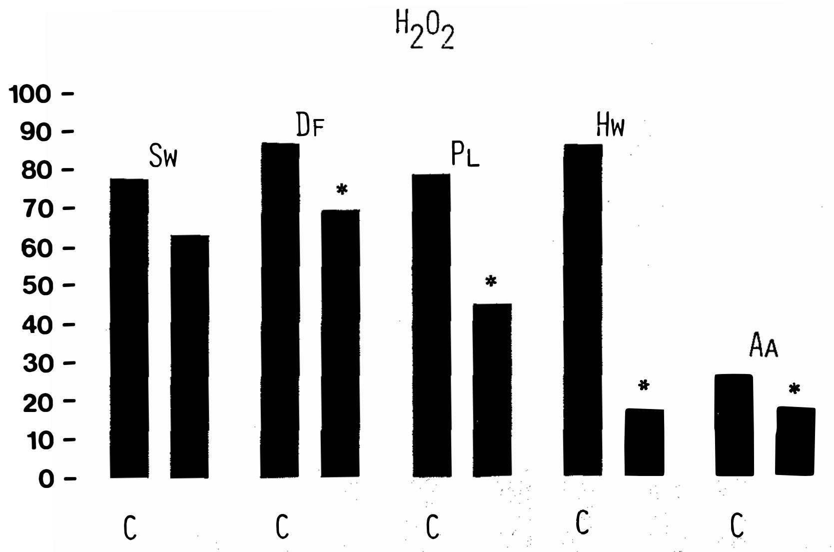


FIGURE 2. COMPARISON OF HYDROGEN PEROXIDE QUICK TEST AND GERMINATION PERFORMANCE OF 5 CONIFERS

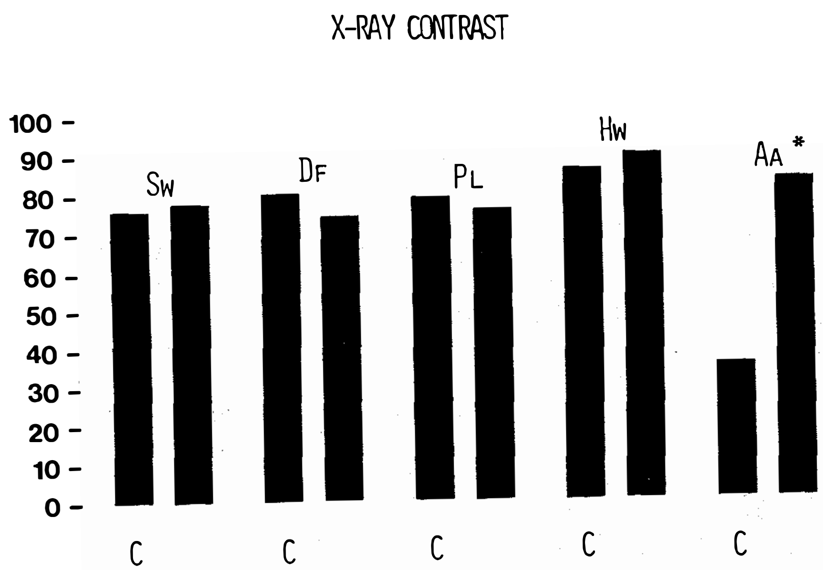
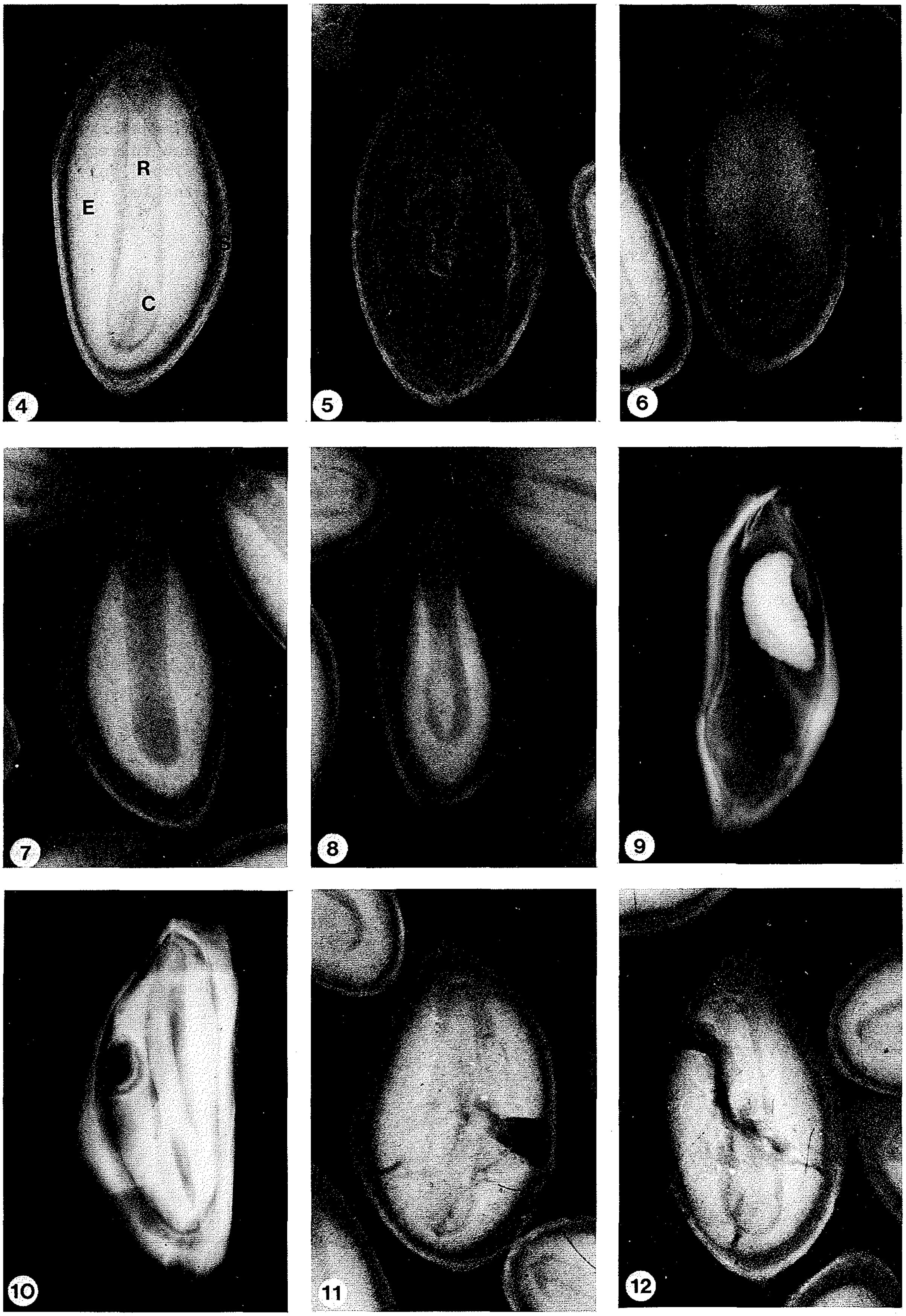


FIGURE 3. COMPARISON OF X-RAY CONTRAST QUICK TEST AND GERMINATION PERFORMANCE OF 5 CONIFERS

FIGURES 4 - 12. SELECTED RADIOGRAPHS OF CONIFEROUS SEEDS.

All X-rays are longitudinal sections. Species shown are *Abies amabilis* (Figures 9, 10) and *Pinus contorta* (Figures 4-8 and 11-12).

Fig. 4. Normal, fully developed seed. Embryo completely fills the embryo cavity. Cotyledons (C) and radicle (R) can be easily seen. Gametophytic tissue (endosperm, E) surrounds and provides nourishment for the developing seedling. The seed coat (S) is the hard outer covering which protects the fleshy endosperm and embryo. Germinable.	Fig. 5. Empty seed. Neither endosperm or embryo has developed, but the seed coat is clearly visible. Nongerminable.	Fig. 6. Undeveloped seed. There is no embryo development and the endosperm has developed only slightly. Nongerminable.
Fig. 7. Incompletely developed seed. The endosperm has developed, but does not completely fill the seed. The embryo is missing. Nongerminable.	Fig. 8. Incompletely developed seed. The endosperm does not fill the seed and the embryo occupies only half of the embryo cavity. In some instances seeds of this type can be allowed to mature so that full development can occur. May be germinable.	Fig. 9. Insect damage. A seed chalcid larva (*Megastigmus* spp) has consumed the entire contents of the seed. Nongerminable.
Fig. 10. Insect damage. An insect has eaten part of the endosperm, but the embryo remains intact. It is possible that this seed might germinate if sown, but probably would be subject to deterioration in storage from fungus or other pathogens.	Fig. 11. Mechanical damage. Cracks can be seen in the endosperm and the embryo, but the seed coat is still entire. Nongerminable.	Fig. 12. Mechanical damage. A large portion of the seed coat is missing, and the inner contents of the seed have been broken in half. Nongerminable.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various stages of cone extraction to detect mechanical seed damage from processing equipment (Figures 11-12). With the use of polaroid X-ray film (Edwards, 1973) or similar quick processing methods, X-ray results can be received in sufficient time to adjust equipment and prevent further damage to seeds. Regular X-ray assessment during and after seed lot processing can be used to check the efficacy of cleaning operations and final lot purity. Figures 4 to 12 give an indication of the versatility of radiographs. X-rays could potentially be employed during all stages of seed procurement and use, from the initial stages of seed development to the final determination of lot purity before sowing.

It should be realized that quick tests are not as reliable as standard germination tests; also, while they provide the analyst with some data on a seed lot in less time than a standard germination test, most quick tests require more analyst hours to complete. The estimate of seed quality that they provide are frequently only approximately related to actual germination, whether this be in the field or the laboratory. However, whatever the means of assessment, the final determinant of seed quality will be careful handling of the seed itself.

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MEASURING QUALITY OF TREE SEED

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INTRODUCTION

As we have advanced into the phase of intensive forest management recently, the current annual requirements for tree seed for reforestation has been estimated at 4.1 billion viable seeds in Canada and this is expected to increase to 7.3 billion by 1987 (Morgenstern 1978). The productivity and the establishment of stands depend upon the quality of seeds used. Although we have no forest statistics of losses of productivity or reforestation due to the use of inferior seed quality on hand, estimated agricultural crop losses in the United States were reported ranging from 5% up due to the use of inferior seeds and 1-2% loss due to blind sowing without a knowledge of seed quality at time of sowing. The situation in forestry practice is probably much worse than in agriculture for we have to deal with unfamiliar wild populations and harsher environments. It was from this background that the importance of measuring seed quality was recognized, developed and practised.

It has been pointed out by foresters that better forests are from better seeds (Isaac 1949; Orr-Ewing 1957). For this reason, we should strive not only for improving seed quality but also for efficient utilization of seed through proper assessment of its quality. If the economic use of seed in forestry practice follows a course of development similar to agriculture, it is conceivable that the quantity of seed required for reforestation in the future may decrease due to rapid improvement in seed quality, methods of seed treatment and sowing, and seedbed preparation (Scott & Longden 1972).

This paper describes the various established methods used for measuring seed quality and discusses its value to reforestation.

WHAT IS SEED QUALITY?

Seed quality is the function of seed source, genetic improvement, germinability and vigour. It includes genetic and physical and physiological qualities. As we are still dealing with wild population in forestry, the genetic quality of tree seed has to be determined by provenance research and certified at source. The physical quality covers characteristics such as size and shape, 1000-seed weight, purity, number of seed per unit measure (g or kg), moisture content, and damage from insects, diseases and processing. In practice, the last five characteristics are most important. Physiological characteristics include viability, germinability and vigour.

WHY MEASURE SEED QUALITY?

It is very risky to sow seed of unknown source and quality. To avoid failure and minimize loss and waste, especially when genetically improved seeds are used in the future, it is essential that seed quality be tested for determining sowing rates in nursery and greenhouse stock production, direct seeding or marketability of commercial seeds. While only seedlots of highest quality are economical for use in container seedling production, seedlots requiring special pre-treatments for maximum germination such as breaking dormancy, surface sterilization, recleaning etc. will be detected by seed quality evaluation.

WHEN IS SEED QUALITY MEASURED?

Although the physical quality of seedlots does not change much under normal storage conditions, physiological quality changes from the time of harvesting. The rates of physiological change in seed depend upon the species, its initial quality and storage conditions. For operational practice, seed quality, especially physiological quality, should be measured at least on two important occasions: immediately after seed processing, and immediately before sowing if the seed has been stored.

WHERE IS SEED QUALITY MEASURED?

The assessment of seed quality requires special techniques, equipment and trained personnel. In the seed trades the demand for such service has led to the development of standard prescriptions for testing seed quality and the formation of the Association of Official Seed Analysts (A.O.S.A.) in 1908 and the International Seed Testing Association (I.S.T.A.) in 1924.

Services for standard seed quality testing are available from officially accredited seed testing laboratories which conduct requested tests strictly according to the established standard prescriptions in published rules and procedures, and issue test certificates at reasonable fees. However, as pointed out by Bonnor (1974), the value of standard testing of seed quality cannot be over emphasized because the basis for the development of such rules is a compromise of accuracy, uniformity, practicality and economics. Rules for testing seed quality are up-dated from time to time based on new research findings.

HOW IS SEED QUALITY ASSESSED?

One of the major problems in seed quality assessment is sampling. Fortunately equipment and procedures have been developed to draw and handle unbiased representative samples to be tested.

For various standard tests of seed quality, one should consult the rules and procedures described in the rules for seed testing (A.O.S.A., 1970; I.S.T.A. 1976) and Bonnor (1974) for the required size of seed samples and their sampling and handling procedures.

Purity Analysis

Purity analysis is to determine what proportion of the working sample is pure seed of the test species and what proportion is made up of other species and non-seed material. This is done by separating the working sample into three components: (1) pure seed of the test species, (2) other seeds and (3) inert matter (leaves, broken twigs, broken scales, wings, rocks and other non-seed material). The working sample is a reduced sample from the submitted sample. Each component is weighed and expressed as a percentage by weight of the total working sample as follows:

$$\text{Purity (percent)} = \frac{\text{weight of the test species component}}{\text{weight of the working sample}} \times 100$$

Purity is important for calculating sowing rates especially for small sized seeds such as birches which usually have low purity because of difficulty in removing inert matter in seed processing. Since purity analysis is the first test to be made, it provides pure seeds for other tests such as germination.

Moisture content

Moisture content is determined with the submitted seed sample and not the pure seed component. It can be measured by quick but not so accurate electric or electronic moisture meters, or by an oven-drying method. The standard oven method is to dry seeds of prescribed sample size according to species at 105°C for 16 hours.

Moisture content of seeds can be expressed as a percentage of their wet or dry weight, although wet weight is used in international trade.

Genuineness and Source

One should always examine seed samples carefully to check whether the seeds are true to the species name on the label. Source would be difficult to distinguish except by certification at the collecting points. However, seeds of certain species can be distinguished by broad geographic source (e.g., Douglas-fir from coastal sources vs. interior sources) (Allen 1960).

Germination Potential

Germination potential of seeds can be tested either by growth tests or by quick biochemical or excised embryo tests. Since the quick test techniques will be discussed by Dr. Carole Ledum, this paper will focus on growth tests.

The growth test principle of both A.O.S.A. and I.S.T.A. is to use the most favourable environments possible and practical, so that test results reflect the maximum germination potential of the seed. Germination tests are conducted with the seeds from the pure seed component of the purity analysis. Usually, samples of at least 400 seeds have to be used for each test and the seeds have to be divided into replicates of 100, 50 or 25 seeds.

Testing regulations prescribe the germination medium, temperature, moisture, photoperiod, time and pretreatment to be used, as well as procedures for counting and evaluating germinants, and reporting of results, etc. (I.S.T.A. 1976).

Since laboratory testing is conducted under the most favourable germination conditions, how could the test results be used for nursery or field sowing? Ideally, laboratory test results and nursery emergency results are perfectly correlated with a correlation coefficient of 1. However, this has rarely happened. Stein (1967) has demonstrated the actual correlation between laboratory test results and nursery performance (Figure 1).

In examining the reasons for the discrepancy, one cannot help but find the following factors:

(a) the differences in test and application environments;

(b) failure to compensate some of the key factors influencing field seed germination;

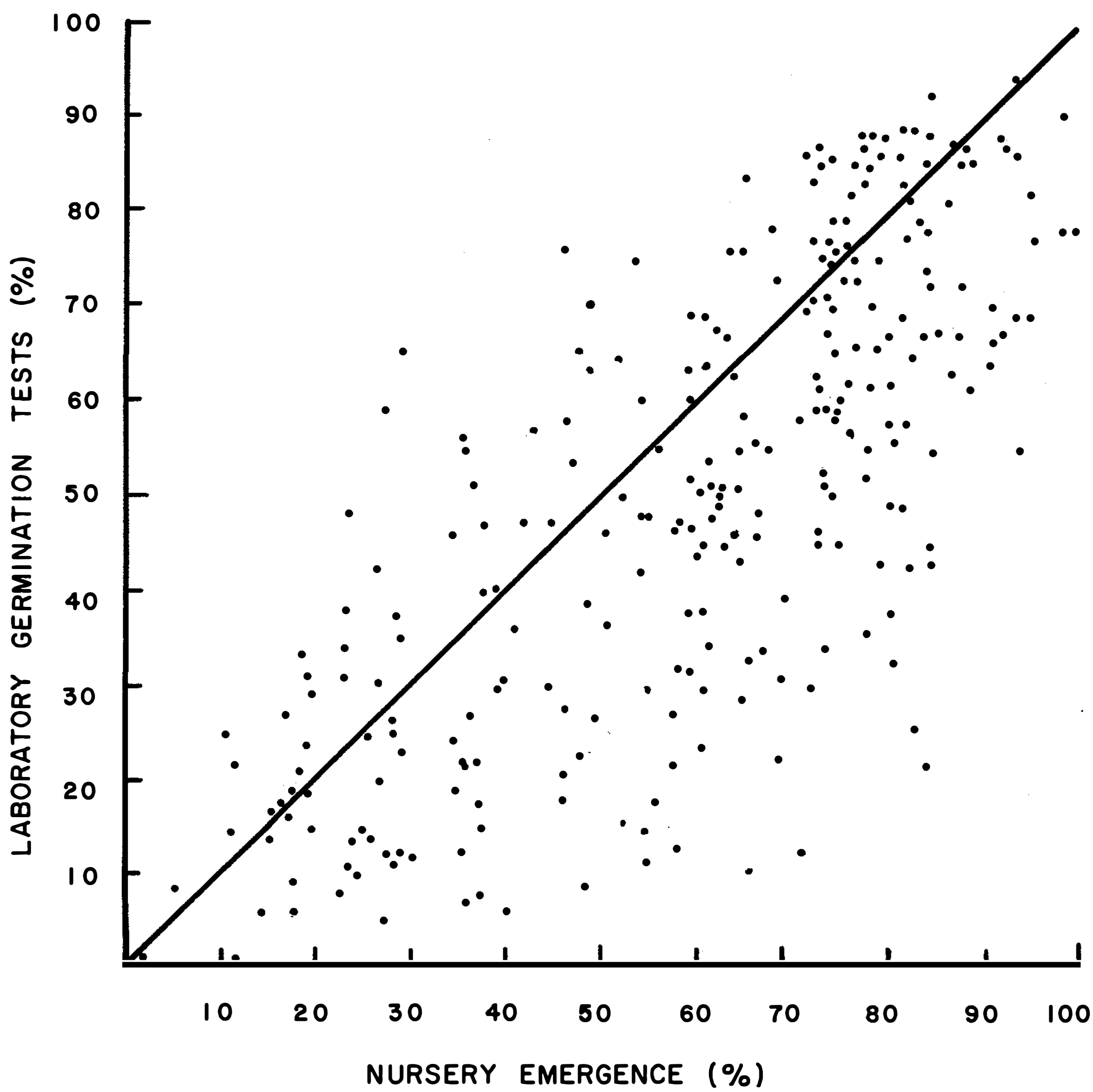
(c) lack of proper seed preparation and pretreatment; and

(d) need for improving laboratory test criteria for proper germinant evaluation.

To solve these problems, one should use complementary testing techniques such as vigour testing and stronger, vigorous seedling criteria for germinant evaluation within the specified test period. This will discount any seeds germinated weakly with low vigour. Light is often a critical factor for seed germination in the field as sown seeds are usually covered by a layer of soil or mulch material. Also, temperatures in the field are often far from optimum or rarely within a range favourable to some seeds. All these can be completely or partially overcome by prechilling pretreatment.

FIGURE I

COMPARISON OF LABORATORY GERMINATION TEST RESULTS WITH NURSERY EMERGENCE FOR 250 SEEDLOTS OF DOUGLAS-FIR (STEIN 1967).



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IMPACT OF SEED QUALITY ON COSTS OF NURSERY STOCK

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The meaning of "high quality seeds" is usually limited to those physical and biological conditions of the seeds most obvious to the nursery operator. That is, seeds must be clean, sound and consistently produce thrifty, vigorous seedlings (Deneke and Landis 1978). Most reforestation programs now recognize the importance of using planting stock from seed sources of proven adaptability to the planting site, so seed source must also be included as a component of seed quality. This paper is limited to the economic impact that physical quality of seeds may have on the production of seedlings, since genetic quality considerations are discussed elsewhere (see Pollard 1981).

As with most other commodities, high quality usually means high cost and two major components of the cost of high quality seeds are recognizable: the cost of seed procurement and the cost of maintaining high viability until the seeds germinate in the nursery. However, low seed quality is also associated with high cost seedling production. Deteriorating seed quality may be caused by inferior seed processing, improper storage or other factors, and to illustrate how this may affect nursery costs, consider the hypothetical example shown in Fig. 1.

The number of seeds that will germinate and result in an established seedling is correlated directly with seed viability (disregarding losses to diseases and pests). The amount of seeds required to produce a given number of seedlings depends not only upon seed viability, but also upon species and seedlot. In this example, it has been assumed that 200 g of seeds with a viability of 90% (point W) will produce 10,000 seedlings. As quality decreases, the amount of seeds must increase to yield the same number of seedlings - twice the amount at 45% germinability (X), three times at 30% (Y) and more than four times at 20% (Z). The lower set of numbers (Fig. 1, italicized) shown opposite the four points on the graph represent seed costs based on a unit price of $45/kg, which might be the current price of seeds collected from wild stands. Although the cost of such seeds is low relative to the cost of the overall reforestation process, it should not be overlooked.

Suppose, however, that seed-orchard, genetically improved seeds are to be used at a unit price of $300/kg. The corresponding seed costs are shown in bold face and it is clear that if the physical quality of seed-orchard seeds is low, seed costs become enormous. Even if these costs could be met, nursery production likely would be compromised since the additional quantities of such seeds might not be available.

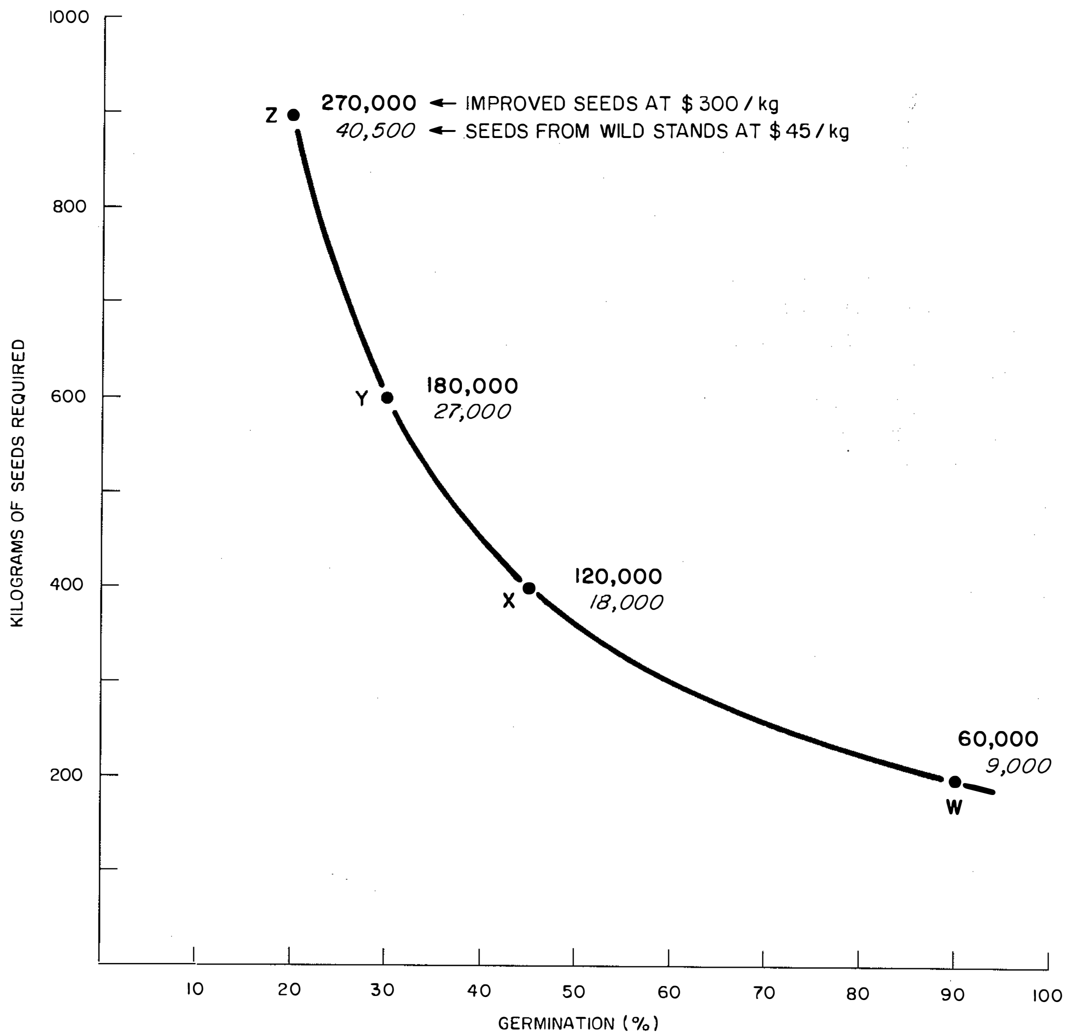

Fig. 1. The effect of seed quality on the amount of seeds required to produce 10,000 seedlings (hypothetical).

Poor quality seeds involve not only greater seed costs because of the larger amounts that must be obtained and used, but also incurs the additional operational expenses of (i) preparing and sowing the extra seeds, and (ii) since sowing densities vary more as seed quality decreases, the cost of seedbed thinning. To compensate for the lack of germinants in some cavities, *i.e.*, "germinant downfall", container production systems use sowing devices that place several seeds in each container with each pass (or the containers are passed through the sowing device several times). For seedlots with 85% or higher viability, only one seed per cavity is required, while two seeds should be used for 75%-85% quality, and three seeds for 60-75% quality

(Vyse and Rudd 1974; Tinus and McDonald 1979). Multiple sowing increases the chance of having at least one seedling in a cavity because only a few cavities without seedlings can be tolerated as container-growing space is expensive. As a rule, seedlots of less than 60% viability should not be used, since this involves i) excessive thinning of multiple seedlings in some cavities later on, and ii) waste of valuable seeds (Vyse and Rudd 1974). Since this problem is a widely encountered one, a computer program for determining the number of containers expected to produce a certain number of seedlings, the optimum number of seeds to be sown in each cavity to minimize the amount of seeds used, as well as the amount of transplanting and thinning of excess seedlings necessary for a given seed quality has been developed (Balmer and Space 1977). Cost factors for the seeds used, and for the operations of sowing, thinning and transplanting may also be determined if there is adequate ancillary information.

The impact of poor seeds on operational costs was described by Van Eerden (1977)[1]. The British Columbia Container Nursery Working Group (CNWG) considered seed quality problems to be the most significant impediment to continued expansion of the container nursery program in 1975-1976. As a minimum acceptable standard of seed quality, it was suggested that only lots that produced a germinant in 80% of the cavities, after a single sowing, should be used. Owing to general seed scarcities and shortages of seeds from particular sources, seeds of less than 70% viability had continued to be sown, despite a recommendation (Vyse and Rudd 1974) that such lots should be rejected. The consequential costs of thinning seedlings, as well as the wastage of seeds, inherent in the practice of multiple seeding to compensate for germinant downfall, can be considerable (Van Eerden 1977)[2], as the following illustrates.

The B.C. Ministry of Forests' planting program requires about 75 million trees each year, which calls for approximately 1800 hectolitres (5000 bu) of cones, at an average cost of $200,000. Although no specific financial terms are available to describe the reduction in plant yields because of poor seed quality, it was estimated that seedling downfall (blank cavities) approached 30% which, in terms of 1977 dollars, cost approximately $560,000. Two-thirds of this downfall was attributed to poor seed quality and to problems in seed distribution (uniformity of sowing). Thus, the initial crop establishment problems with container stock resulted in a loss of $375,000 for 1977. When the cost of thinning multiple seedlings (about $100,000 for

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[1] Van Eerden, E. 1977. Review of statement of cone and seed research needs and priorities. Report to the British Columbia Joint Cone and Seed Comm., Dec. 1977, 4 p. Unpub.

[2] Van Eerden, E. 1977. loc. cit.

weeding and thinning the 1977 container-seedling crop) was added on, it was clear that the consequence of poor seeds created an operational loss of nearly $500,000 per year for container stock alone (Van Eerden 1977)[3]. Part of this expenditure could be saved by using the highest quality seeds.

The economic penalty incurred by using poor seeds is further exemplified in data (Table 1) for container-produced *Picea engelmannii* seedlings in Colorado (Deneke and Landis 1978). The difference in revenue produced ($66,800) is significant. Although seed quality costs are more substantial in container nurseries, they should not be overlooked in the more traditional bareroot nursery.

Table 1. *The effect of seed quality on production costs of 1 million Engelmann spruce seedlings in a container nursery.*

	SEED QUALITY (Germinability)	
	86%	38%
Seeds sown per cavity	3	6
Amount of seeds used (kg)	12	24
Seed cost at $60/kg	$720	$1440
Proportion of empty cavities	6%	34%
Number of seedlings produced	994,000	660,000
Seed cost/1000 seedlings	$0.72	$2.18
Revenue produced at $200/1000 seedlings	$198,800	$132,000

The use of seeds of known origin and those that are genetically improved means handling *smaller* seedlots and ensuring their absolute integrity as they progress through the nursery and onto the planting site, resulting in higher costs in all operations (cone handling, seed processing, storage, seeding and lifting, sorting and transportation of the resultant seedlings). Because all costs are greater with improved seeds, it is important that nursery operations ensure that the high quality of the seeds is protected and maintained, and that efficient use, *i.e.*, the highest recovery of plantable seedlings per unit of seeds sown, is made. To achieve this, the importance of testing germinability so that precise sowing rates can be calculated cannot be over-emphasized. By the same token, field foresters and seed orchardists should take the utmost care that cone collections are made at the right stage of cone maturity, and that cones are correctly cared for in the field and are properly transported since an unpredictable, but significant, loss in seed quality may occur before the seeds reach the processing plant (Deneke and Landis 1978). Similarly, seed processing staff must take every precaution to prevent extraction and processing damage, and strive to provide seeds of the highest quality so that optimal economies in nursery operations can be obtained.

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[3] Van Eerden, E. 1977. loc. cit.

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