NURSERY TECHNOLOGY OF PINE SEEDLING PRODUCTION IN KOREA

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Abstract.-- In the beginning the current status of improved pine seed supply, tree nursery statistics, amounts of nursery stork production, and nursery catergories operated currently are presented. As to the standard nursery operations particularly for pine seedlings, seed storage method and test, seed sowing practices, standard dimension for nursery stock for outplanting, and finally the growth of pine seedling are presented. Some problems to raise better planting stock are hinted.

Additional keywords : *Pinus rigida*, *P. taeda*, nursery practice nursery stock production in Korea

The pine species native to Korea are Japanese red pine(*Pinus densiflora* S. et Z.), Japanese black pine(P. thunbergii parl), as diploxylon pines and Korean pine(*P. koraiensis* S. et Z.), oriental whits pine(*P. parviflora* S. et Z.) and oriental stone pine(*P. pumila* Regel) as haploxylon pines. Through the long time of human existence in this country, the above mentioned were the major pine species that supplied necessary wood materials. The pines introduced from U.S.A. that have been using in reforestation work are pitch pine(*Pinus rigida* mill.), loblloly pine(*P. taeda* L.), hybrid pine produced between *P. rigida* and *P. taeda*, and northern white pine(*P. strobus* L.) virginia pine(*Pinus virginiana* mill.) is considered to be promising very recently.

Nowadays, with the merit of fast growing, straight boleness and easiness of stand establishment by artificial way, these introduced pines have been planted, according to their suitability of planting sites. However, in case of loblloly pine, the plantable area is very limited due to the low winter temperature. This pine can hardly do good beyond the area of cold index colder than -5^{o} or -6^{o}. This implies only the narrow belt-like zone along the southern sea coast of Korean penninsula is able to accept it. On the contrary, the mentioned hybrid pine can extend its growing area to further north, provided that the soil is moderately deep and fertile. *Pinus rigida* can cover almost all the area of this country, withstanding rather poor site and cold temperature.

To raise healthy and genetically improved pine seedlings, more researches are needed.

1. TREE NURSERY STATISTICS

The number and area of tree nursery and the number of owners and nursery stocks produced during the last five years, ignoring the kind of species, are shown in table 1. It tells us that the decrease of seedling demand for reforestation work, the nursery area has been decreasing accordingly.

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The seedling production has been practiced by several categories of producers, for example, private commercial nursery owners, nursery operated by Forest Owner Association or by Gevernmental Regional Forest Offices, Village nursery (run by the villagers to earn for their common use) and provincial Forest experiment Station Nursery.

The figure 1 shows the number of outplanting stocks (not those for transplantling production purpose) produced by nursery categories.

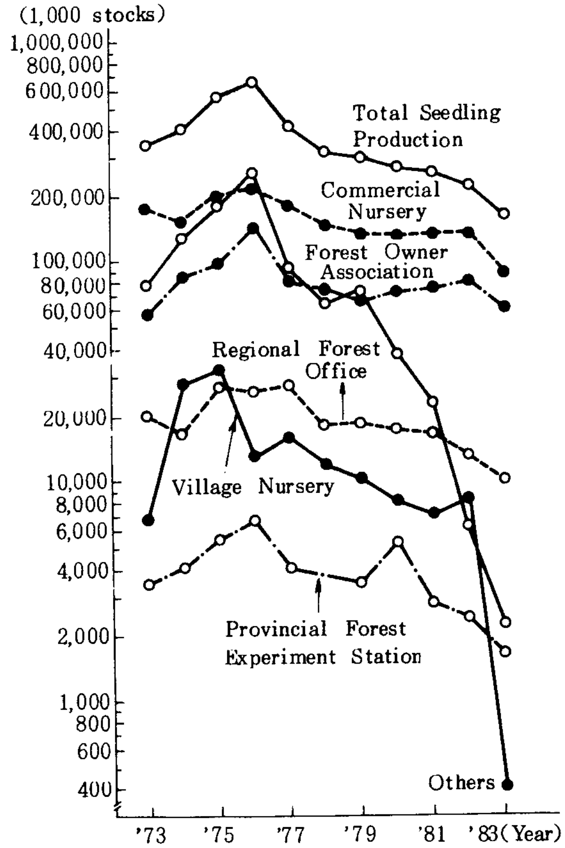

Fig.1, Number of outplanting stocks produced by nursery category.

Table 1. Number and area of nursery and total seedling production without regard for species. Area, m^2 ; seedling, 1000 stocks

Year	No. of nursery	No. of Nursery owner	Total area	Number of seedling produced	
				Total	for outplanting
1979	5,308	2,740	22,555	785,671	308,300
1980	3,958	1,510	19,359	656,471	274,806
1981	3,942	1,075	17,502	608,164	263,751
1982	1,689	578	12,199	567,918	244,496
1983	721	378	8,704	422,955	165,591

Table 2 shows the number of seedlings of U.S.A. origin used in reforestation work. It is clear that the number of Pinus taeda has been decreasing abruptly, presumably with the decrease of plantable area. On the contrary, the number of hybrid pine seedlings is increasing. The seeds of the hybird pine is produced from the hybrid pine seed orchard established with Pinus taeda and P. rigida planted in alternate rows. The hybrid pine seedlings can be screened at the end of the first growing season due to its dimension and appearances without difficulty.

Table 2. Number of pine seedlings used in reforestation, (1,000 stocks)

Year	P. taeda	P. rigida	P. rigida x P. taeda
1980	5,301	27,858	4,906
1981	330	25,631	3,692
1982	5	11,912	6,960
1983	-	17,462	10,058

2. IMPROVED SEED PRODUCTION

There are a few ways to produce the genetically improved pine seeds. Aiming at this purpose, at first, seed collection stands were selected to supply seeds of better quality until the seed production from seed orchard established by plus trees, both clonal and seedling, meets the requirements. In regard this, the very difficulty is the seed collection practice from tall trees standing at steep or rugged mountain area.

The amount of improved seed production from seed orchard is presented in table 3. There are big gaps between demand and supply. The target year in which the seed supply suffices is expected to be 2010, 790 kg of pinus rigida and 3000 kg of pinus rigida x P. taeda.

Table 3. Amount of improved seed produced from seed orchard (unit, kg)

Species	1979	1980	1981	1982	1983
P. rigida x P. taeda	82	99	100	91	60
P. rigida	8	-	10	22	28
P. koraiensis	34	8	123	126	108
P. densiflora	4	-	4	5	13
P. thunbergii	5	-	3	9	9

3. THE STANDARD NURSERY OPERATIONS FOR CONIFER SEEDLING

The standard nursery operations applicable for conifer seedling production habe been described in the book titled literally "Forestry Technology" published by the Forestry Administration. The extracts of major importance are given as follows.

Seed storage and test

The pine seed are generally stored in a dry place of room temperature until seed sowing season. Any special storage conditions are not usually required.

If not a special seed lot, seed quality test including purity and germinability percent are not necessitated for the seeds selected by a water soaking method. However, if feel necessary, any one can ask Forest Fesearch Institute for the test by paying applicable fees. With this reason, the seed sowing rate is chiefly determined by past experience with little difficulty.

As an exception, Pinus koraiensis seeds must be stored under open ground for overwintering or in condition of cold moist stratification because having strong seed coat dormancy.

Seed sowing practice

As to nursery site selection, sandy loam at flat or gentle slope site or river side area is prefered. Irrigation and drainage conveniences are considered to be important. A windbreak on northern edge of a nursery to reduce the winter wind effect, is strongly recommanded.

Tillage is emphasized to improve soil nature and increases its productivity. Therefore it is tilled to a depth of 20 to 30 cm as the root system developes that much. Mechanical tiller and pulverizer are used. Chemical fertilizers and well matured organic manure are mixed into the soil and at the place where insect damage is likely to take place, insecticides are spread and tilled into the soil. Before seeding, the bed surface is leveled. Pine seeds are always broadcast. After sowing, the seed is covered with soil by using a wire sieve. Clean river sand is distributed over this soil cover to reduce the incidence of soil microorganisms. Then again shredded straw are scattered over to hold more soil moisture of seeding beds. To prevent birds, the bed is necessarily covered with nylon screen which gives the drought preventing effect too.

Weeding

In commercial scale tree nursery in this country, in order to meet the shortage of labor supply and to reduce weeding cost, the herbicides shown in table have generally been used particularly for raising conifer seedlings.

The statistics says that when it is used in transplanting nursery beds, about 48 percent reduction of weeding cost compared with hand weeding is possibly expected.

Table 4. Herbicides used in conifer nursery and application

name	brand name	component	application and effectiveness
prometryne	Gesagare	2-methylthi 4, 6 bis(iso-propylamino) s-triazine	3 to 4 times a year ; first application, soon after seed sowing and thereafter 40 to 50 days interval ; effectiveness, ca 97%
nitrofen	TOK	2.4-dichlorophenyl-4-nitrophenyl ether	do.
simazin	simazine	2-chloro 4-6-bis(ethylamino) S-triazine	2 to 3 times a year ; use only for transplanting beds ; first application after transplanting work and thereafter 40 to 50 days interval ; effectiveness, ca 98%

4. GROWTH OF PINE SEEDLING

Nursery operators pay a great attention to the growth of nursery stock to attain the standard length and diameter at the end of growing season. The growth is controled through irrigation and fertilization.

The present author made measurements of some characteristics of nursery stocks produced at private commercial nurseries (Table 5).

Table 5. Mean measurement of nursery stocks, sample size, 80

species	age	location of nursery	stem length	root collar diameter	above ground weight	root weight	T - R ratio
			cm	mm	gr.	gr.	
P. rigida x P.taeda	1-0	Seoul	15.1±2.7	2.8±0.9	3.3±2.2	0.7±0.5	5.3±2.9
"	1-1	Seoul	29.2±7.7	6.5±1.6	22.2±12.5	6.5±3.5	3.7±1.3
P. rigida	1-0	Osan	13.9±3.3	3.0±1.0	4.3±2.2	1.1±0.5	4.1±2.0
	1-0	Seoul	16.1±3.1	2.4±0.7	2.8±1.7	0.7±0.4	4.0±1.5
	1-1	Osan	36.2±6.7	8.1±1.6	37.8±20.0	11.9±7.7	3.5±1.0
P. koraiensis	1-0	Seoul	4.7±0.9	2.3±0.4	1.5±0.6	0.9±0.3	1.8±0.3
	2-0	Seoul	7.9±0.6	3.6±2.4	5.2±2.3	1.9±0.8	3.1±1.5
	2-0	Chunchon	7.6±2.5	3.8±0.8	6.3±2.6	2.0±0.9	3.3±1.5

Note ; ± standard deviation

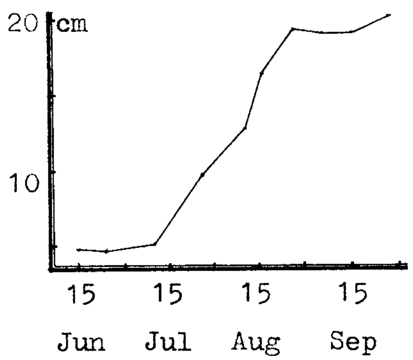

Fig.2, Height growth of 1-0 *Pinus rigida* seedlings

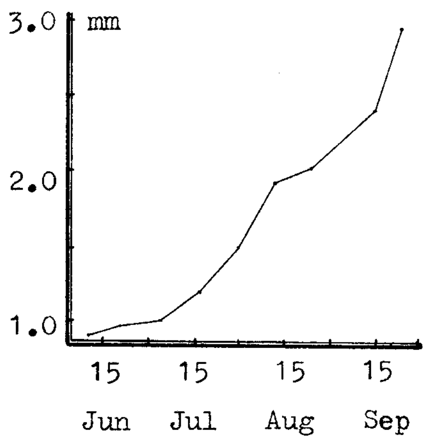

Fig.3, Root collar diameter growth of 1-0 *pinus rigida* seedlings

We also observed the process of stem height and root collar diameter growth of 1-0 *Pinus rigida* seedlings during from June 15 to September 30. The different patterns of growth between height and diameter were seen.

5. STANDARD FOR PINE SEEDLING

In grading nursery stok, age, stem length, root length, and root collar diameter are used. Table 6 shows the standards for pine seedlings for outplanting with one exception of 1-0 seedlings

Table 6. Standard for pine seedlings for outplanting

Species	age	Stem length	root collar diameter	root length
		cm	mm	cm
P. rigida x P. taeda	1-0	18	4	15
" "	1-1	35	7	15
P. rigida	1-1	25	6	18
P. densiflora	1-1	16	5	18
P. koraiensis	2-2	22	6	18

The seedlings which are smaller or shorter than the indicated standards are never allowed to be traded according to the regulation established by the government.

6. CONCLUSIONS

In this paper, attempted are to present nursery statistics and the scale of seedling production as a whole, improved seed production particularly in regard with pine species, some standard nursery operations for conifer seedlings and growth of _Pinus rigida_ x _P. taeda_ and _P. rigida_.

We have many problems on raising pine seedlings, namely, more strict control of seed origin and quality, mechanization of nursery operation, methods of nursery stock quality check, grading and packing and others.

The containerized seedling production must also be considered to increase the suruival rate after outplanting and to extend the planting period in respect to labor shortage.

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HEAT UNIT SUMMATION THEORY IN COMMERCIAL NURSERY MANAGEMENT

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Abstract.--Heat unit summation as a predictor for seedling growth can be used in container nurseries for operations scheduling. Data are presented for southern pines and other species. The practical application in a commercial nursery is illustrated.

Additional keywords: Degree-day, Degree-hour, Photothermal Units, *Pinus patula*, *Pinus elliottii*, *Pinus taeda*, seedling growth.

INTRODUCTION

The principle objectives of a commercial nursery are to produce:

1. The right plants (quality)
2. At the right price
3. At the right time

The Heat Unit Summation Theory (Anon. 1960) can be used to improve management efficiency and achieve these objectives.

HEAT UNIT SUMMATION THEORY

The Heat Unit Summation is a method for studying plant-temperature relationships through the accumulation of daily mean temperatures above a certain threshold temperature (Base temperature) during the growing season.

This concept was first published in 1735 and adaptations and improvements have been published since then. Most notable being the "Photothermal unit" (P.T.U.) and "Degree hours" (D.H.) (Anon. 1960):

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$$P.T.U. = \sum_{Dp}^{Dm} (T - T_b)\, t_s$$

Where Dp = planting date

Dm = date of maturity

T = Daily mean temperature, °C

T_b = base temperature, °C

t_s = day length (hours)

$$D.H. = \frac{12\,(h - t)^2}{h - w}$$

Where h = daily maximum temperature, °C

w = daily minimum temperature, °C

t = base temperature, °C

However, the most practical form and that used in agriculture in the Republic of South Africa (Dickinson & Buys, 1974) is Degree-Days:

$$D°_t = \frac{\text{Daily max. temp + Daily min. temp}}{2} - t$$

Where t = base temperature, °C,

and negative values are taken as zero.

The sum of degree-days required for a crop to reach maturity has been assumed to be a constant value and is termed the varietal constant. This approach assumes that the rate of growth is directly proportional to the increase in temperature.

Methods of establishing the correct base temperature (lower limit of plant growth) have been described by Arnold (1959). When the selected base temperature is too high the heat unit summation required will increase with the mean temperature and if the selected base is too low the reverse will occur. This is illustrated in the hypothetical example in Table 1.

Table 1. The Effect of Base Temperature on Degree-Day Summation (Arnold, 1959)

		Base Temperature								
		5° *			10°			2°		
Mean Temp	Days to Maturity	Daily Error	Total Error	Final Sum	Daily Error	Total Error	Final Sum	Daily Error	Total Error	Final Sum
12°	219	0	0	1533	-5	-1095	438	+3	+657	2190
22°	90	0	0	1530	-5	- 450	1090	+3	+270	1800

* It is assumed that 5° is the correct base temperature for the variety and that it takes 1530 degree-days for the plant to mature on this base.

BASE TEMPERATURE

Base temperatures for some common crops are:

Maize	10,0°C	
Wheat	4,4	
Sunflower	7,2	
Peas	3,7	
Oats	4,4	
Grapes	10,0	(Anon, 1984)

In a study of Pinus patula (Schlect, & Cham.) seedlings raised in 36ml cavity Speedling trays,** Hodgson (1982) recommended a base temperature of 3°C.

An investigation of Pinus patula seedling growth in open-root nurseries in South Africa by Donald and Young (1982) indicated that a base temperature of 1°C was marginally better than 3°C. They also recommended a base temperature of 1°C for Pinus elliottii, var. elliottii (Engelm.) P. taeda (Linn.) and P. radiata (D. Don.)

Recent empirical work at Natal Forest Nurseries (N.F.N) Republic of South Africa has indicated that a base temperature of 10°C is applicable to Eucalyptus grandis (Hill ex Maiden) and to Acacia mearnsii (De Wild).

** Registered design of multiple cavity expanded polystyrene seedling tray.)

VARIETAL CONSTANT

The sum of degree-days required for the crop to reach maturity is called the varietal constant. Maturity, or definition of "the right plant," is a complex topic, reviewed by Donald (1976) in respect of South Africa.

Seedlings are required to survive the limitations of available moisture on a planting site. Container plants need only be very small and young to be established on an easy site. The most difficult sites experience severe drought for up to five months each year and adequate survival can only be obtained by using large, well-balanced container plants.

The growth of tree seedlings in dry weight accumulation or stem length elongation when plotted against time is exponential. Relationships have been illustrated by Donald and Young (1982) and Hodgson (1982) for different nursery systems in different environments.

Individual curves should be established for each species in a particular nursery. From these curves varietal constants can be read for a required plant quality.

Varietal constants used at N.F.N. with a standard cultural procedure are listed below:

Species	Varietal Constant	Stem Length (mm)	Dry Weight (g)
Pinus patula	2750 D_3^o	100	1,2
Pinus elliottii	2300 D_3^o	150	1,0
Pinus taeda	2300 D_3^o	150	0,8
Pinus roxburghii	2500 D_3^o	150	1,0
Eucalyptus fastigata	1800 D_3^o	200	0,8
Eucalyptus macarthurii	2750 D_3^o	200	0,8
Eucalyptus radiata	2750 D_3^o	200	0,8
Eucalyptus elata	2750 D_3^o	200	0,8
Eucalyptus smithii	2750 D_3^o	200	0,8
Eucalyptus grandis	600 D_{10}^o	200	0,7
Acacia mearnsii	700 D_{10}^o	200	1,0

The Germination Period

Degree-days as determined for seedling development cannot be reliably applied to the period of germination. The base temperature for pine seedling growth is lower than the minimum temperature required for germination. For example *Pinus elliottii* seed can be stratified at a temperature of 5°C (41°F) (Schopmeyer, 1974) whilst as a seedling at this temperature it would grow with a heat unit accumulation of $4D_1^o$ each day.

An allowance must be added to the varietal constant for the germination period. At N.F.N. 250 D_3^o is allowed for pine germination and 200 D_3^o or 80 D_{10}^o for Eucalypts. No sowing is undertaken during the Winter months from April to August.

MANAGEMENT BY HEAT UNIT ACCUMULATION

Trees can be planted throughout the year in South Africa using container seedlings, though demand and species vary with season. The customer can be best satisfied by seedling deliveries adhering to a schedule. Schedules can be established with the varietal constants of each crop for a particular nursery.

Schedule Construction

An example of a nursery schedule is illustrated in Figure 1. The months are scaled according to the mean heat unit accumulation from meteorological records. The data applied at N.F.N. are given in Table 2.

Table 2. Heat Unit Summation (D_3^o) at Natal Forest Nurseries, 1984.

Month	Expected D_3^o (Anon. 1984)	Actual D_3^o 1984	Cumulative Deviation
January	558	592	+ 34
February	529	510	+ 15
March	546	555	+ 24
April	479	435	- 20
May	386	347	- 59
June	309	222	-146
July	315	264	-197
August	353	307	-243
September	387	387	-243
October	450	471	-222
November	474	465	-231
December	553	533	-251

Each line in Figure 1 represents a nursery unit. At N.F.N. this is a rack, of 100 000 seedling capacity, which will receive individual treatment.

To satisfy a particular order, sections of a line are reserved for the required period (in degree-days), by working retrogressively from the required delivery date.

To optimise utilisation of nursery space the allocations may be exchanged. Once a crop is sown the allocation is committed and denoted in Figure 1 by cross hatching.

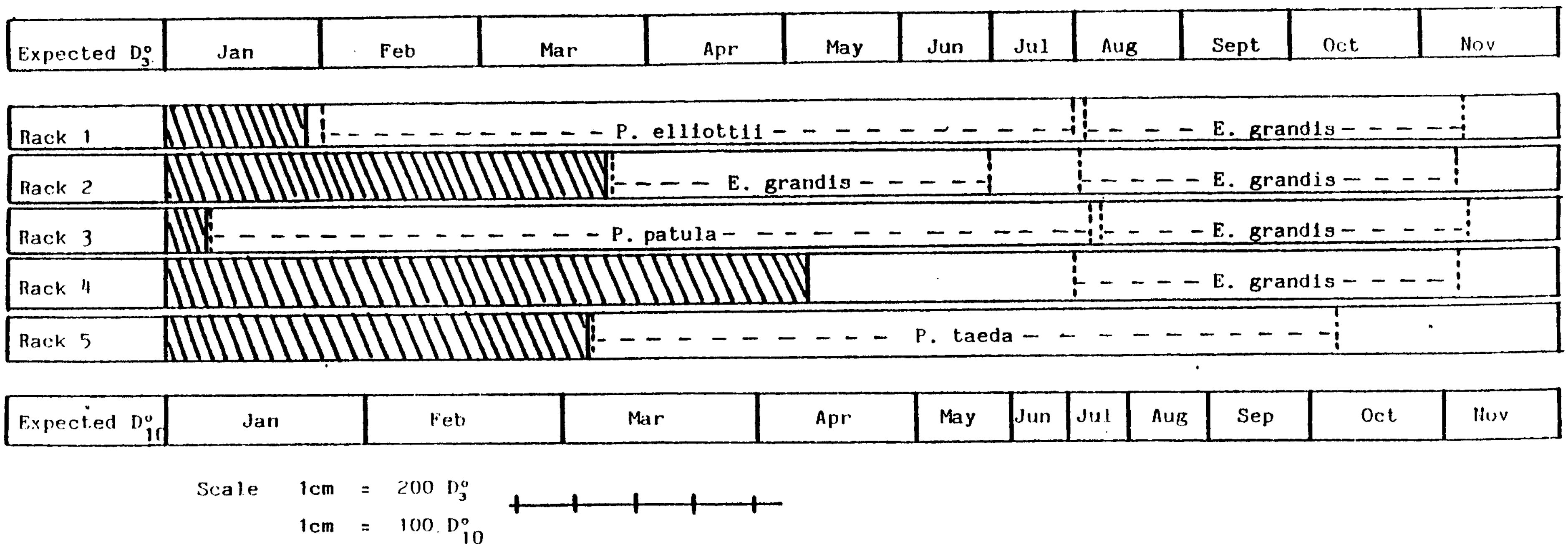
Actual vs Expected Accumulation

If the season is hotter than expected the delivery dates can be advanced. Conversely, if the season is cooler than expected the delivery dates will be delayed. For example, *P. patula* sown at N.F.N. at the end of March 1984 would have been scheduled for delivery on 20th November. However, by the end of July a half month delay could be forecast (ref. Table 2.), and communicated to the customer.

These forecasts can be made from the schedule by movement of the month line to the left or right according to the cumulative deviation in degree-days.

The need to move allocations and even the title line makes the use of printed forms impractical. Magnetic cal can be cut into strips representing in length the heat unit requirement for a species or the expected heat units of the months. This material can be placed on a metallic board demarcated for nursery units.

Figure 1. Seedling raising schedule for Natal Forest Nurseries.



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BARE-ROOT VERSUS CONTAINER PRODUCTION OF PINES IN THE AMERICAN TROPICS

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Abstract.--The traditional container systems used in the tropics, along with performance of pine seedlings in newer small-volume containers and with new bare-root outplanting techniques, are reviewed. The movement to use of small-volume containers has resulted in higher quality plants, but it has also necessitated the development of cultural regimes that are specific for this system. Successful planting of bare-root nursery stock is now possible in the tropics, but it requires elaborate care to keep the root systems wet and to plant shortly after lifting.

Additional keywords: *Pinus*, polyethylene-bag containers, small-volume containers, cultural techniques, bare-root nurseries

The level of nursery production for the tropics and subtropics is not accurately known, but the seedling output probably surpasses the one-half billion mark per year. Production is about evenly divided between hardwood and pine seedlings. However, interest is naturally high for planting subtropical pines because of their value as sawtimber and long fiber pulp.

The pine species most extensively planted in the tropics is *Pinus caribaea* var. *hondurensis*, and a number of projects are being funded to develop additional reforestation and growth information (Liegel et al. 1985). However, *P. oocarpa*, *P. merkusii*, *P. kesiya* and *P. radiata* are also widely planted. Perhaps *P. oocarpa* is overall a better tree as far as wood properties are concerned, but this species has generally been considered to be better adapted to higher elevations. However, recent results from international provenance trials have shown that selected provenances of *P. oocarpa* outperform *P. caribaea* (Liegel 1984, Greaves 1980) on a variety of sites and elevations. Thus more options are available now for those countries interested in introducing conifers.

Nursery production in the American tropics can be divided into two types of operations. One type of nursery operation is characterized by intensive hand labor, is small scale in scope, and can be either on a permanent or temporary site. Seedling production at such nurseries usually does not exceed 50,000 per year and often is no more than 10,000 seedlings annually. The

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other type of nursery operation is located in a permanent site where 1 to 20 million seedlings are produced per year. Often as many as 40 different species will be produced in such nurseries. Both types of nurseries usually produce both container and bare-root stock, and many hardwood seedlings are produced also as either bare-root or stump plants (Hornick et al. 1984).

In the majority of the Caribbean islands and bordering nations, forestry programs are oriented toward supplying seedlings for small scale operations (1-5 ha) such as woodlots, which produce poles and posts and firewood for family use. Very little of this wood is sold commercially. Typically, seedlings are produced in containers, delivered to the farmer (generally 2,000 to 5,000 seedlings), and planted when he has time. Often the seedlings will remain in pots at the planting site for 4 to 6 weeks before they are planted.

TRADITIONAL CONTAINER SYSTEMS FOR THE TROPICS

The most popular seedling container in the tropics is the polyethylene bag which is filled with a soil-sand mix. The volume of polyethylene bags ranges from 450 to 650 cm^3. Because of the use of large polyethylene bags, nursery managers have serious problems when they attempt to grow seedlings using local potting mixes. Dvorak (1985) has indicated that abnormal development of _P. tecunumanii_ seedlings was related to the nursery potting medium rather than special mycorrhizae requirements or genetics differences (table 1). He recommended that nursery managers use 2 parts soil and 1 part sand with no organic matter. This mixture reduces the risk of seedlings becoming waterlogged, a problem which causes stunting. The lack of a uniform and consistently effectove potting mix is a major problem in producing containerized seedlings in the tropics.

Table 1.--Performance of _Pinus tecunumonii_ in the nursery (from Dvorak 1985)

Organization	Elevation (m) of nursery site	Soil mixture	Soil pH	Description of Growth	Time needed to produce plantable seedlings
Carton de Colombia	1750	2 pts sand 1 pt soil	5.2	uniform but extremely slow	10 months
CONARE (Venezuela)	1300	unknown	5-6	extremely variable	10 months
RESA (Brazil)	1200	unknown	5-6	uniform development; better than _P. oocarpa_	5 months
Weyerhaeuser (Brazil)	570	2 pts soil 1 pt sand	5-6	uniform development; slower than _P. oocarpa_	4-5 months

It is difficult for foresters and nursery managers from more economically developed countries to comprehend this problem because they have commercially prepared potting mixes and fertilizers readily available, or are able to mix their own. One can gain an appreciation of the problem if told to produce 20 million seedlings, but also told not to use sphagnum, peat, vermiculite, or pine bark. These supplies do not exist in the tropics or are much too expensive to purchase and transport. Tropical nursery managers are thus forced to rely on local available potting media for propagating seedlings.

The polyethylene bag is a poor container for producing quality seedlings. Because of the bag's flexible form, it must be hand-filled. Such bags are bulky. Poor drainage and aeration in the bags result in extensive root deformation. Root balling in the bottom of the polyethylene bag is common (figure 1). In contrast, the well-known root form of a seedling grown in a Styroblock® or similar type container has an air-pruned, nonentwined root system, (figure 2).

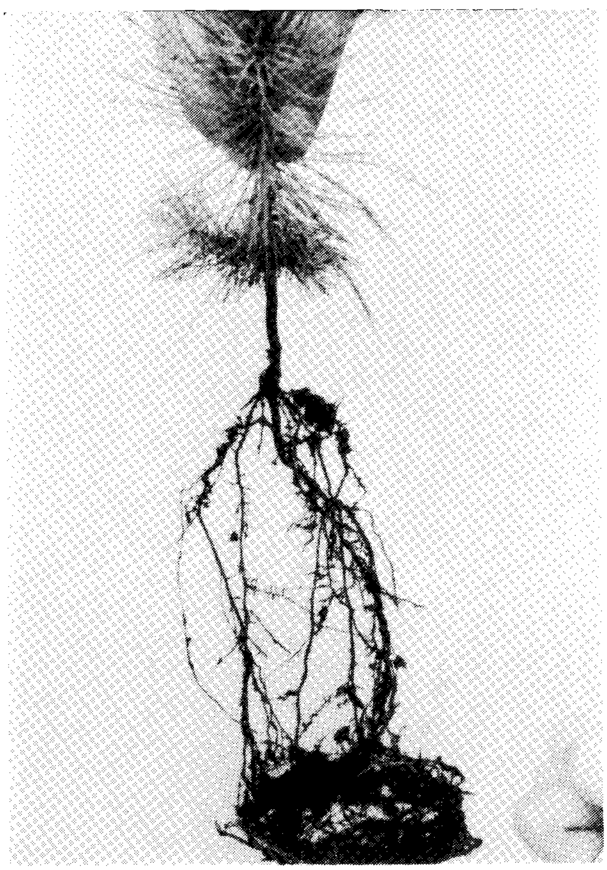

Figure 1.--Entwined root system of 8-month-old P. radiata seedling grown in a soil filled polyethylene bag of approximately 600 cm^3 volume.

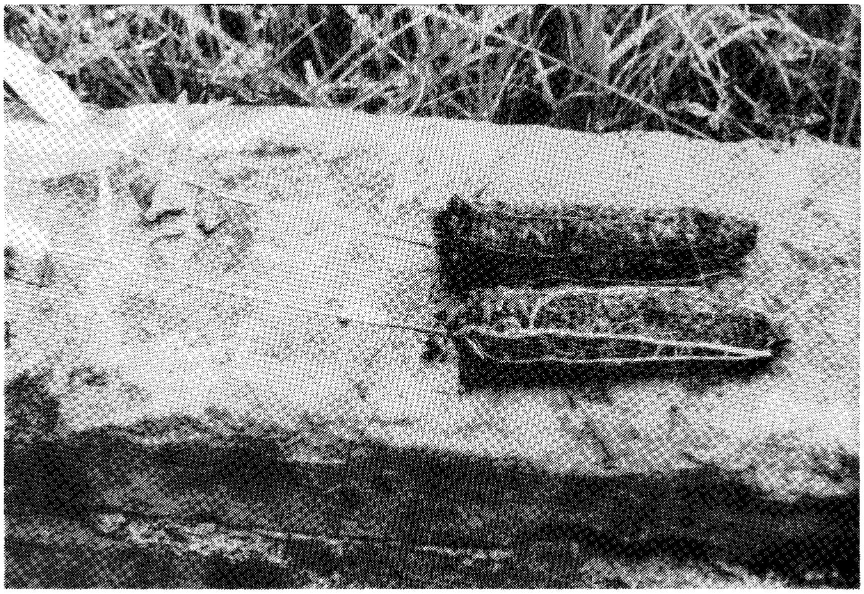

Figure 2.--Typical well developed root system of a seedling grown in a Styroblock-8 cavity. This Eucalyptus globulus seedling is 4 months old and was grown in a 30 percent volcanic soil and 70 percent wheat hull mixture

Another common container used in the tropics is the rolled newspaper pot. This container is rolled and stapled, then a bottom is made by tamping soil to form a plug. Seedlings approximately 25 cm tall are dug from bare-root nursery beds and transplanted into the newspaper pots, which may last up to 6 months before degrading. This container and transplant system is not as negative as it may first appear. Venator and Liegel (1985) discuss in detail a modified method of transplanting large seedlings from bare-root beds into containers in order to produce seedlings capable of surviving on dry sites.

MODIFIED CONTAINER SYSTEMS

In the modified system described by Venator and Liegel (1985a), seedlings are lifted from the nursery beds, their roots oriented lengthwise on a newspaper with soil, and more soil spread on top of the roots. The paper is rolled around the roots and stapled or pasted together to form a tightly packed containerized seedling. The seedlings are carefully tended to maximize transplanting survival. New roots normally begin to develop in about 30 days after potting. Seedlings are outplanted within 4 to 6 weeks to minimize deformity as new roots grow. Thus, these potted bare-root seedlings are effectively converted to containerized seedlings.

This system is similar to that used in the Wind River Nursery reported by Betts (1974). It is interesting that tropical nursery managers have never become very sophisticated about root regenerating potential (RRP), although the principal of RRP is embodied in their production system. They realize that seedlings, after lifting, quickly develop new roots. An important aspect of this transplant-potting process is to outplant the seedlings after root regeneration begins but before their roots are entwined. Obviously, it is important, on dry, harsh sites, to outplant only seedlings that have begun to regenerate new roots. Careful management of RRP in the transplant nursery beds makes this system both practical and functional. It is a labor-intensive system because one worker can transplant only about 800 seedlings per day. For those countries where labor costs are low and degraded, and dry, harsh sites need reforestation, the system is adequate. About 50 million seedlings are produced each year under this transplant-potting system in the American tropics.

BARE-ROOT NURSERY SEEDLING PLANTING

Foresters from temperate climates perhaps do not appreciate the importance of planting bare-root pine seedlings because it is such a widespread practice. However, only in relatively recent years have techniques been developed that permit tropical foresters to plant bare-root pine seedlings, although establishment of plantations with bare-root plants had been attempted for more than 50 years.

Techniques to successfully plant bare-root pine seedlings in the tropics were developed by Venator and others (1972, 1977). These techniques are relatively simple, and perhaps it is worthwhile to review the development of the process. In the initial study, trays or bags of seedlings with soil protecting their roots were transported to the planting site and the soil was completely removed from the roots by submersion in water. These seedlings were then quickly planted. This was in all respects a very careful handling of bare-root seedlings. Additional treatments were added in a series of trials where seedlings were lifted from trays or bags at the roadside then carried for 30 minutes, with roots submerged in water, to the planting site. Also the seedlings were lifted from the nursery, stored in a pail of water, and planted within 24 hours and 48 hours. The results clearly indicated that *P. caribaea* var. *hondurensis* seedlings could be succesfully bare-root planted simply by lifting, transporting seedlings in water, and outplanting as rapidly as possible. It was shown that survival is directly related to length of time between lifting and planting (Venator et al. 1972). Currently, large plantations using bare-root pine seedlings are routinely established in several tropical countries using variations and modifications to the system. The CONARE (Compania National de Reforestation) project in Venezuela and the JARI and AMCEL projects in Brazil are excellent examples of this outplanting technique (McDonald and Fernandes 1984).

SMALL VOLUME CONTAINERS

The production of seedlings in small volume containers such as the Styroblock®, Roottrainer®, RL Leach Single Cell® [1/] or other similar products has not been fully explored in the tropics (Venator and Munoz 1974). Walters

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1/ Use of trade names does not imply endorsement by the U. S. Department of Agriculture. They are used solely to identify materials.

(1974) successfully produced seedlings of several species in Hawaii with a variety of containers. Venator and Rodriquez (1977) tested the use of Styroblocks® for growing P. caribaea var. hondurensis seedlings and found that seedlings could be propagated without major problems.

In the late 1960's, Dutch foresters began to mass produce high quality seedlings for large scale reforestation in the lowland rainforests of Surinam. They developed a highly efficient nursery production system using tarpaper pots that were manufactured at the nursery and filled with local soil mixes. This system was adopted by the CONARE project in the Venezuelan Llanos and in Brazil. Although highly efficient in some aspects, the system was relatively expensive. The CONARE project soon switched to growing seedlings in Styroblock containers until the late 1970's when another shift was made to bare-root stock.

The production of seedlings in small volume containers emphasized the problem of attempting to produce seedlings with a new system while using traditional nursery methodology. One of the first problems was the need to determine the correct shade levels necessary to produce high-quality seedlings. Traditionally, small nurseries in the Caribbean use heavy shade levels when propagating seedlings in polyethylene bags. These shade levels are often 70 percent or more. Studies were installed in Puerto Rico to determine the effect of shade intensity on growth and shoot and root biomass development of P. caribaea var. hondurensis seedlings. The results are summarized by Venator and Liegel (1985b). Quality seedlings are assured only when 35 percent or less shade is used (Table 2). When 77 percent shade was used, the seedlings were spindly and succulent and had less than 20 percent of the root biomass of these seedlings grown under full sunlight or with 20 and 35 percent shade. Extraction success of root plugs from cavities was less than 10 percent for the seedlings grown under 77 percent shade.

Table 2.--Mean dry weights of P. caribaea var. hondurensis shoots and roots and shoot/root ratios after 4 months of growth under full sunlight and 77, 35 or 20 percent shade

Shade treatment	Shoot	Root	Shoot/root ratio
	------Dry weight (mg)-----		
Sunlight	713 ± 190	367 ± 132	2.17
20 percent	706 ± 148	446 ± 164	1.87
35 percent	726 ± 182	379 ± 142	2.27
77 percent	509 ± 132	70 ± 44	9.83

Another major problem with producing seedlings in small-volume containers is that of finding an adequate potting mix with good water-holding capacity, adequate drainage, light weight, proper pH, and some nutritional value. Canadian sphagnum peat has the above qualities and is almost universally used in northern countries with temperate climates. Commercial pine bark based mixes are also fairly popular and are acceptable for growing pine seedlings in small volume containers. The problem in the tropics is that insufficient peat or pine bark exists for preparing large quantities of nursery mixes.

The Ecuadorian Forest Service plans to produce between 25 and 30 million seedlings yearly, using 120 cm^3 cavities. This is a very large undertaking, but an alternative to propagating seedlings in polyethylene bags is needed. The Ecuadorian production program is based upon a potting mixture of 30 to 50 percent "turba" (a volcanic duff with 40 to 60 percent organic matter) and 50 to 70 percent of either pumice, rice hulls, or wheat hulls. Rice hulls and wheat hulls mixed with "turba" appear to form a successful medium. Seedling growth is adequate; the major drawback may be in water retention capacity of this mix. Rice hulls degrade or decompose slowly; thus mixtures with a high rice hull content tend to dry out more quickly than peat. Wheat hulls appear to decompose more rapidly, and they form a mixture with greater water-holding capacity. However, the decomposing wheat hulls may create a nitrogen deficiency and possibly a disease problem because of fungi associated with decomposing organic matter. In either of these potting mixes strong vigorous roots do develop.

Changing to a small volume container greatly reduces seedling container weight. Workers can carry up to 350 seedlings in small volume containers, whereas only about 40 can be carried in polyethylene bags. This is an important consideration on the steep hillsides typical of the Latin American interior.

Growing seedlings in small-volume containers requires fertility regimes to support seedling growth. Fortunately fertilizer regimes that have been worked in the temperate climate areas can be generally applied in the tropics. In Puerto Rico, nursery research in the mid-1970's showed that a 20:20:20 NPK water-soluble fertilizer with minor elements applied in dilute solutions 2 to 4 times a week was adequate to produce vigorous seedling growth. More effective fertility regimes need to be developed. Moreover, these must take into account effects of fertilization on mycorrhizal development.

OUTPLANTING SITE CONDITIONS

Not all tropical areas are wet or humid. Harsh, dry sites cause a serious problem for most tropical planting programs. Such dry areas may not be ideal pine sites because of excessive weed and vine competition. Another planting site problem is demonstrated by most Andean and Caribbean sites, which receive adequate rainfall but have steep, eroded slopes, and quick rainfall run-off. Thus, in large areas of the Andean Mountains, overgrazing and soil erosion due to poor cultivation techniques have caused a desertification process (figure 3). Forest protection is urgently needed in vast areas and only container stock will permit successful reforestation. To cope with the problem of quick run-off of rainfall and shallow humus layer to hold rainwater, it is necessary to plant the seedlings in water-catchment holes (figure 4). This process adds to the cost of plantation establishment. More research is needed to determine if seedlings propagated in small volume containers can be cultured to withstand the rigors of outplanting on these harsh, dry sites. Prelminary results from Ecuadorian research trials on dry sites indicate that seedlings produced in 120 cm^3 cavities will survive outplanting. Thus, continued expansion of this production system in the forest nursery modernization program is warranted.

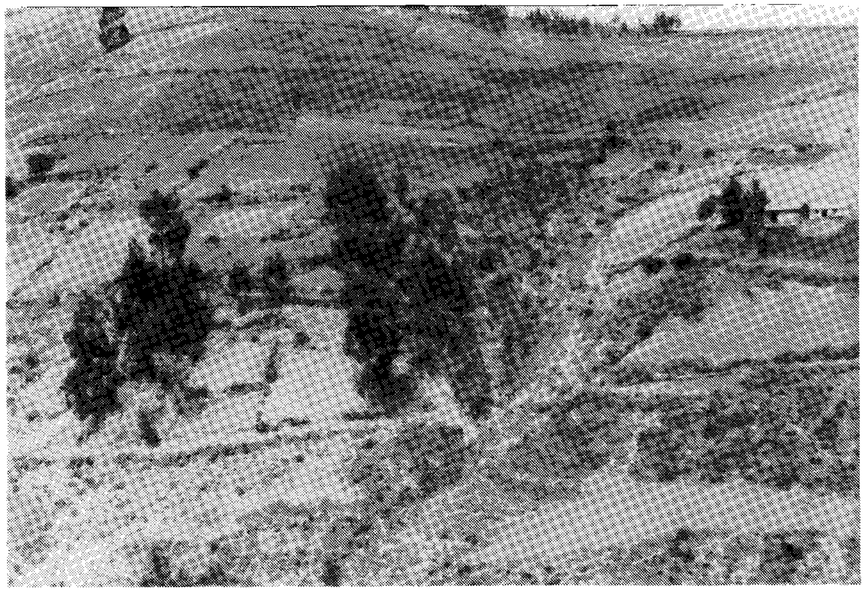

Figure 3.--The beginning of desertification as a result of poor cultivation practices. Note that trees will do well on this site.

CONCLUSIONS

The results of planting pine seedlings in the subtropics and tropics clearly show that both bare-root and container-grown seedlings have a place in reforestation. The techniques to plant bare-root pine seedlings developed in Puerto Rico on an experimental basis have been put into widespread practice in the Venezuelan Llanos, and the JARI and AMCEL projects of Brazil. Large-scale bare-root plantings have been successful in Columbia as well as in Australia. In essence, bare-root planting will be successful if the seedling roots are kept moist and shaded, and the seedlings are planted within 36 hours after lifting. The experience of large-scale planting success in the Venezuelan Llanos, which has an annual rainfall of less than 1000 mm, illustrates that total rainfall may not be that crucial. However, it is important to outplant at the onset of the rainy season.

Container production will always remain an important aspect of tropical reforestation efforts because of the greater flexibility in supplying the thousands of small woodland plantings. Containerized seedlings can be held for several weeks prior to planting, whereas bare-root stock must be planted immediately. Container planting systems can be successfully converted from the undesirable polyethylene bag and resulting root deformation to a smaller-volume container. Often planting sites are considerable distances from the roadside; thus, the value of using a smaller volume and lightweight potting mix is self-evident. Research on potting media in Ecuador may soon result in a medium that can be adapted in other tropical countries. The most important aspect of developing a new potting mix is not to reduce the time required to produce seedlings in the nursery, but rather to produce a high quality, lignified seedling able to survive outplanting on eroded, dry, harsh sites. Until an adequate potting mix is developed, along with a container that is amenable to a semi-mechanized production system, nursery managers will continue to be plagued by the same problems that they currently face when attempting to grow containerized seedlings.

Figure 4.--A 50 cm x 50 cm deep planting hole designed to catch and concentrate water around the seedling roots.

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THE SEPARATION OF FULL DEAD SEED FROM LIVE SEED IN PINUS ELLIOTTII

D. G. M. Donald[1/]

Abstract.--The technique introduced by Simak for the separation of full dead seed from live seed was developed and tested for *Pinus elliottii*. It is concluded that a meaningful improvement in viability can be obtained and that the technique is sufficiently flexible to be applied on a field scale.

INTRODUCTION

The need for high quality seed for plant propagation purposes has become increasingly evident as the intensity of nursery operations has risen. Today, with the widespread use of precision sowing by machine, empty seed or dead seed cause direct losses to the nurseryman through vacant cavities in containers and uneven spacement in nursery beds.

The separation of empty seed from the seed mass by water soaking and removal of the flotant is relatively straight forward for many pine species and is widely practiced in South African forest nurseries (Donald, 1968 & 1985). Removal of full dead seed has proved virtually impossible until quite recently, when Milan Simak (1983) of Sweden provided a possible solution to the problem.

Simak's so called "I.D.S." technique (I = incubation, D = drying, S = separation) which allows for the removal of full dead seed from a seed lot was a major break through in seed treatment before sowing. It was developed initially for *Pinus contorta* and has also been tested successfully on *P. sylvestris* (Bergsten, 1983), both small seeded pines. This paper describes trials done to test the technique on larger seeded species, in this case *P. elliottii*.

METHODS

Seed history

Seed of *P. elliottii*, Forest Dept. Seed Store stock number 28429, derived from the 1977 Futululu seed orchard crop, was used for the initial work. Routine seed testing was done in 1979, when the seed was purchased by the Forestry Faculty, and again in 1984 when these trials commenced. The seed had been stored at -18°C between the two tests at an initial moisture content of 8%. Viability initially was 88,5% (SD 5,0) and dormancy 20,7% (SD 5,2). This did not differ significantly from the 1984 test results given in Table 1.

One kilogram of seed was soaked for 24 hours in water and the flotant (dry weight 29,7g) removed. The seed was then dried to below the critical storage moisture content, in this case to 6,6%.

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Incubation & drying

Sixteen sub-samples each of 50 g seed were taken from this seed lot, soaked for 24 hours in a 1:500 Kelpak solution and incubated between wet kleenex tissue wrapped in polythene at 15°C for 63 hours. Each sub-sample was then surface dried, weighed and placed on newspaper in a warm atmosphere (25°C) to dry.

Separation

Four replicates, chosen at random from the available 16, were weighed every two hours to determine the moisture content. After weighing, each replicate was separated into live and dead fractions by putting the seed into water for five minutes and then collecting the two fractions - floating/dead and sunk/live. Each fraction was surface dried for ten minutes and its moisture content determined.

Moisture contents of the seed before separation and of the two fractions after separation were plotted against time to determine the period required to effect adequate separation of the two fractions. Separation appeared feasible after approximately six hours and remained so for the remainder of the test period.

Having determined the approximate time required to get separation, the exercise was repeated and separation done after 7, 8, 9 and 10 hours drying, following an incubation period of 88 hours of moist storage at 15°C.

After separation and surface drying, each fraction was split into two parts, one being used to determine the moisture content and the other used for X-ray and germination tests.

The above tests gave acceptable information on the moisture content of the seed mass at which separation could be done.

Stock number 28447 was used to test the effect of separation based on Radson seed moisture meter readings. The short incubation period recommended by Simak (1983) was compared with 30 day stratification as a means of imbibing the seed. Stratification at 2-3°C for 30 days is standard pre-sowing practice for most nurseries growing P. elliottii in S. Africa (Donald, 1984). Seeds were separated when the moisture readings indicated an MC of 21, 20 and 19%.

A further three stock numbers from the Futululu seed orchard specially selected by Seed Store for their low viability were also used to test the IDS technique using the Radson meter.

Table 1 gives the results of routine seed tests for stock numbers 28429 and 28447.

Figures 1 and 2 show the effect of drying at 25°C on the moisture content of stock number 28429 as a whole and of its fractions.

Table 2 reflects the germination capacity of the two fractions following separation after 7, 8, 9 and 10 hours drying at 25°C and the percentage of the seed lot in each fraction

RESULTS

Table 1.--Results of routine seed testing of Pinus elliottii used for IDS trials.

Stock no.	% purity	No. of seed/kg	% Full seed	Germination capacity	% dormancy
28429	99,7	29200	100,0	83,5	27,9
± SD	0,26	465	0,0	7,6	5,3
28447	99,7	28200	99,8	78,2	6,7
± SD	0,05	775	0,71	5,3	3,8

Table 2.--Germination capacity & percentage mass of P. elliottii stock no.28429 in the two fractions following separation by the IDS technique.

Drying period	7 hr	8 hr	9 hr	10 hr	Control
Float (% mass)	13,8 (5,1)	16,2 (5,9)	10,0 (6,2)	16,2 (7.1)	83,5
Sink (% mass)	93,0 (94,9)	92,0 (94,1)	94,0 (93,8)	94,4 (92,9)	

An analysis of variance of the germinative capacity of the sinking seed showed that differences between the control and the treatments were significant, but that the differences within the treatments were not.

Table 3 summarizes the effect of the different incubation methods and different Radson meter readings on the viability of stock No. 28447.

Table 3.--The efect of incubation method and Radson moisture meter reading on the mass and the germination capacity of Pinus elliottii fractions separated by the I.D.S. technique.

	Incubated 3 days @ 15°C			Stratified 30 days @ 2-3°C				
Moisture content	21	20	19	21	20	19	Means	Control
Float	7,0	28,0	39,0	17,0	26,0	38,5	25,9	78,2
% Mass	2,9	6,7	17,2	6,3	9,8	18,1	10,2	
Sink	81,5	87,0	91,0	85,5	86,0	88,0	86,5	
% Mass	97,1	93,3	82,8	93,7	90,2	81,9	89,8	

An analysis of variance of the 28 observations (7 treatments & 4 replications) for germinative capacity of the sunk seed indicated no differences due to the incubation technique and a linear relationship between moisture content and germination capacity. The 19% moisture content giving the best results (significant at P.06 level). This agrees well with the time study which showed 9 hours and 19% to be satisfactory for separation of stock No. 28429.

Germination capacity of the three remaining stock numbers as determined by routine-testing was particularly poor:

St No	28498	6,0	Sd ± 2,83
St No	28501	9,5	Sd ± 1,91
St No	28502	36,0	Sd ± 1,63

Table 4 gives the viability of the fractions when separated by IDS technique following two incubation methods and drying to 19% moisture content.

Table 4.--The effect of incubation method and separation following drying to 19% moisture content on the germination capacity of three poor quality P. elliottii stock numbers. % Mass in each fraction given in brackets.

Stock no.	Incubated at 15°C for 3 days		Cold stored at 2-3°C for 30 days		Controls
	Float	Sink	Float	Sink	
28498	1,5 (92,5)	44,0 (7,5)	0,0 (89,9)	0,0 (10,1)	6,0
28501	0,5 (14,7)	46,0 (85,3)	0,0 (17,9)	7,0 (82,1)	9,5
28502	1,0 (31,1)	51,0 (68,9)	0,0 (30,5)	17,5 (69,4)	36,0

DISCUSSION

The IDS technique can improve the viability of fresh or properly stored P. elliottii seed which has a reasonably high germination capacity.

A 19% moisture content of the seed mass before separation allows the separation of the seed lot into two fractions, but is not critical, 20 or 18 being as good. The MC% can be determined by timing the drying gravimetrically or by electrical resistance moisture meter.

No difference could be detected between incubation for short periods at 15°C or longer periods at 2-3°C for fresh seed.

The IDS technique is of little value for stock numbers of low viability as, even though it can separate live from dead seed, it can not separate live seed which germinate normally from live seed which germinate abnormally. The most striking feature of the last three stock numbers was the high proportion of retarded radicle development together with normal hypocotyl and cotyledon development.

These abnormal seedlings have no chance of survival and are counted as dead seed in the calculation of germination capacity. Stratification adversely affected the viability of the poor quality seed lots. Again the high proportion of undeveloped radicles was striking but there were still a high proportion of the sunken seed fraction in these lots which failed to germinate even partially.

On better quality seed the IDS can certainly improve the capacity of the seed which sinks. It cannot get the capacity to 100%, however, and even the flotant will contain viable seed although the lower percentage viability and the smaller quantity of seed in this fraction may not warrant sowing it. There did not appear to be discernable differences between germinated seedlings from either fraction and, certainly in South Africa, the floatant should be densely sown to provide seedlings to be pricked out in the few cavities and/or spaces left from the direct *in situ* sowing of the sunken fraction.

This technique is easy to apply, does not require sophisticated equipment and can make a meaningful improvement in the viability of the seed lot. Insufficient seed lots have been tested to say that 19% moisture content of the seed mass is acceptable for all *P. elliottii* seed, nor does it appear to be very critical. The technique should not be used on old, poorly stored or otherwise abnormal seed, however. Further improvements in germination capacity may be possible by first applying the pressure techniques of Bergsten and Lestander (1983; Bergsten, 1983) to remove physically damaged seed. This requires more sophisticated equipment and is unlikely to be applied in the forest nursery. In South Africa it would be preferable for both systems to be applied at the central seed store and the remaining seed re-dried for sale. Loss of mass and therefore revenue could be covered by the proposed move to sell seed per 1000 viable seed (Herps, 1985); a system which would be greatly welcomed by the S. African forestry fraternity.

X-ray

Softex X-ray plates were taken of each fraction of all seed lots following separation and the seeds then sown so that the individuals could be identified. Simak's contention that water soaking provides an excellent contrast medium to assist in determining viability in seed appears to be correct. The data will be presented in a separate paper.

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Optimum Germination Temperatures for Seeds of Six Central American Pine Species

Earl Belcher[1]

Abstract.--A constant 25 C is recommended for seeds of Pinus ayacahuite, P. caribaea, P. oocarpa, P. tecumumanii and P. pseudostrobus and an alternating 20-30 C for P. maximinoi Where a constant 25 C is not available, an alternating 20-30 C will provide acceptable results on all but P. ayacahuite. P. ayacahuite also has a seed coat restriction which must be removed for prompt germination.

Additional keywords: germination value, Pinus caribaea, P. oocarpa, P. tecumumanii,P.maximinoi, P. pseudostrobus and P. ayacahuite.

There is a growing demand in the international exchange of tree seeds, especially with tropical species. With the increased movement of seed among countries, there is need for evaluation of germination. At present the International Seed Testing Association (ISTA) lists the test requirements for 45 pine species (4). This number accounts for about one-third of the pine species of the world (2). The available rules include 21 species from the United States and Canada, 9 from Europe, 11 from Japan and Asia, 1 from Mexico, and 3 from Central America. The only Central American species currently listed are P. caribaea, P. oocarpa, and P. patula.

Material and Methods

Seed of P. caribaea Morlet, P. oocarpa Schiede, P. tecumumanii Schwerdtfeger (considered a variant of P. oocarpa by Standley & Steyermark (2)), P. maximinoi H.E. Moore (1) (considered P. tenuiufolia by some(2)), P.pseudostrobus Lindl. and P. ayacahuite Ehrenb.acquired from the Honduras Seed Bank were used in this study.

Two replicates of 50 seeds each were germinated on crepe cellulose paper at constant temperatures of 20 C, 25 C, 30 C, and an alternating temperature of 20-30 C. All tests were conducted with 8 hours of light. Seeds were considered germinated when the seed coat was lifted from the substrate and the hypocotyl was at least 1 cm long. Counts were made Monday, Wednesday and Friday for 3 weeks except for P. pseudostrobus and P. ayacahuite which required 4 and 5 weeks, respectively. Mean germination and germination values (3) were analyzed within each species by a Chi Square analysis.

Eight more tests of P. ayacahuite were prepared and each test was randomly assigned to one of four treatments to increase the rate of germination. The treatments included: (1) 15-day prechill, (2) 30-day prechill, (3) 45-day prechill and (4) removal of 3-4 mm of the seed coat at the radicle end. One set was germinated at 25 C and the other set at 20-30 C.

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Results and Discussion

Germination was prompt (Fig. 1) in all but P. ayacahuite. Most of these species responded equally well to a broad range of germination temperatures (Table 1). Higher constant temperatures, increased the rate of germination of P. maximinoi, P. pseudostrobus and P. ayacahuite but not the other three pines (Table 2). The rate of germination of P. oocarpa and P. tecumumanii was reduced when temperatures reached 30 C, even when the temperature was alternated between 20 C and 30 C. The constant 30 C was not desirable for any of these species because the higher temperatures also increased fungal growth. The increased fungal growth made evaluation of abnormal germination very difficult and would be expected to increase variation in tests among laboratories.

Table 1. Summary of germination adjusted to a full seed basis.

Species	Germination Temerature (C) 20	25	30	20-30
	-germination percent-			
Pinus maximinoi	80a	80a	69b	78a[1]
Pinus pseudostrobus	94a	95a	88a	85a
Pinus ayacahuite	93a	94a	67c	82b
Pinus caribaea	66a	71a	65a	77a
Pinus oocarpa	91a	88a	90a	86a
Pinus tecumumanii	91a	93a	87a	94a

1/ Figures within a species having a different letter after the number are significantly different at the 5% level of probability.

Table 2. Summary of germination values computed at the end of the test period.

Species	Germination temperature (C) 20	25	30	20-30
	-germination value-			
Pinus maximinoi	16.80b	21.90a	30.35a	28.89a[1]
Pinus pseudostrobus	23.99b	35.23a	20.54b	32.61a
Pinus ayacahuite	23.00c	38.37b	45.61a	38.42b
Pinus caribaea	22.58ab	25.17a	21.31b	21.68b
Pinus oocarpa	11.37a	9.98ab	7.72b	3.41c
Pinus tecumumanii	6.02a	6.27a	2.50b	2.52b

1/ Figures within a species having a different letter after the number are significantly different at the 5% level of probability.

An alternating 20-30 C germination temperature is generally recommended for pines by ISTA and was acceptable for all but P. ayacahuite. This is a higher elevation species and preforms better at cooler temperatures. Germination was the same at 20 C and 25 C but the rate was faster at 25 C. The test required 44 days for complete germination of P. ayacahuite, so additional treatments were evaluated. The germination rate increased with increasing length of prechill (Fig. 2) but the best response was obtained by clipping the seed coat (Table 3).

Table 3. Days for Pinus ayacahuite to reach 90% of the total germination after various treatments to hasten germination when germinated at 25 C.

Treatment	days to 90%
Control	28
15 day Stratification	26
30 day Stratification	21
45 day Stratification	15
Cut end of seed coat	17

In summary, 25 C is the most appropriate germination temperature, but the generally used 20-30 C provides acceptable results with all but P. ayacahuite. This species should be germinated at 25 C for 44 days, stratified or for only 28 days if 3-4 mm of the radicle end of the seed coat is removed. A summary of proposed test conditions is given below.

Species	Temperature	Days	Treatment
P. maximinoi	20-30	21	None
P. pseudostrobus	25 (20-30)	28	None
P. ayacahuite	25	28	Clip
P. caribaea	25 (20-30)	21	None
P. oocarpa	25 (20-30)	21	None
P. tecumumanii	25 (20-30)	21	None

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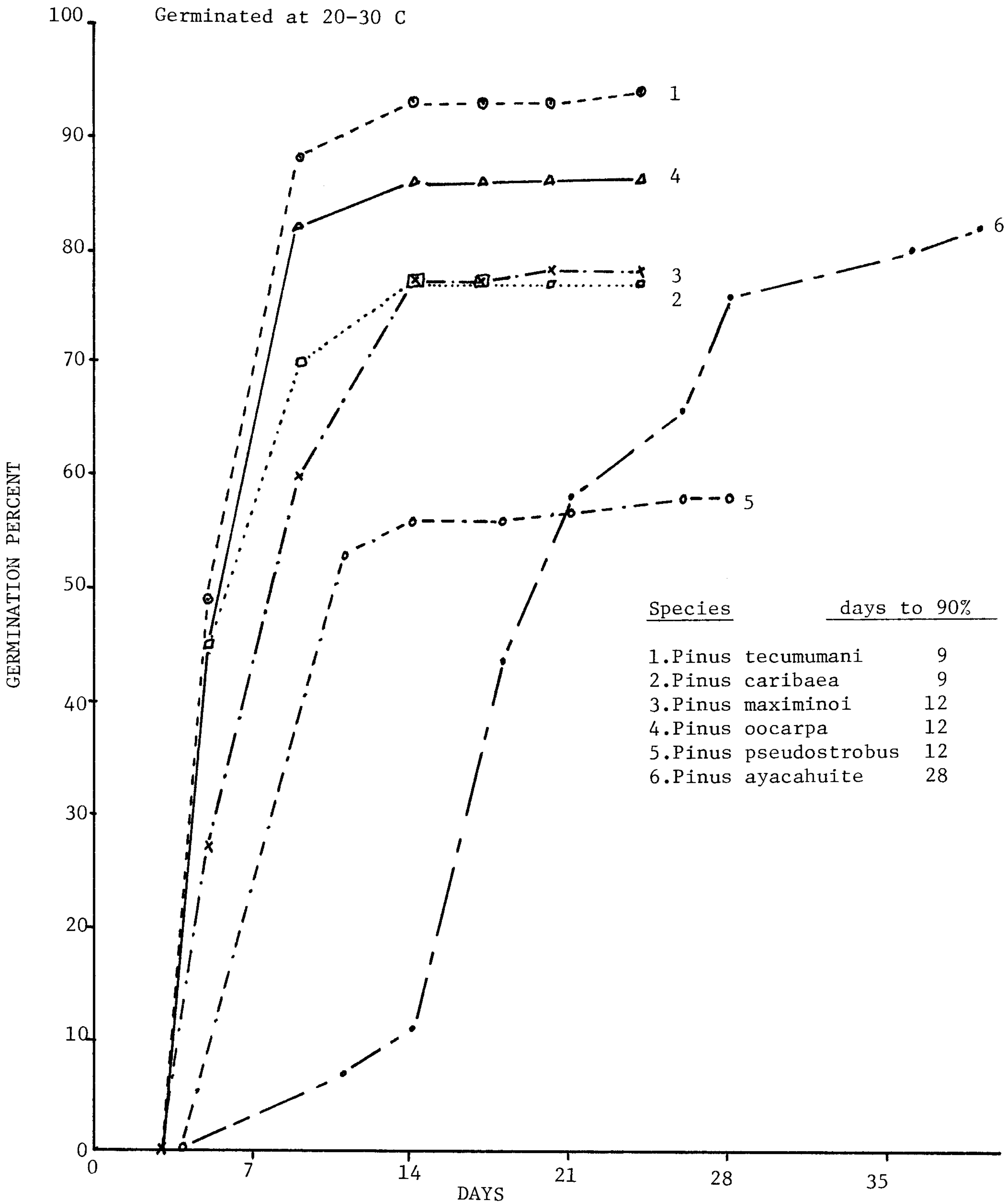

Figure 1. Graphic depiction of six pines without any prior treatment and the number of days required to reach 90% of the total germination.

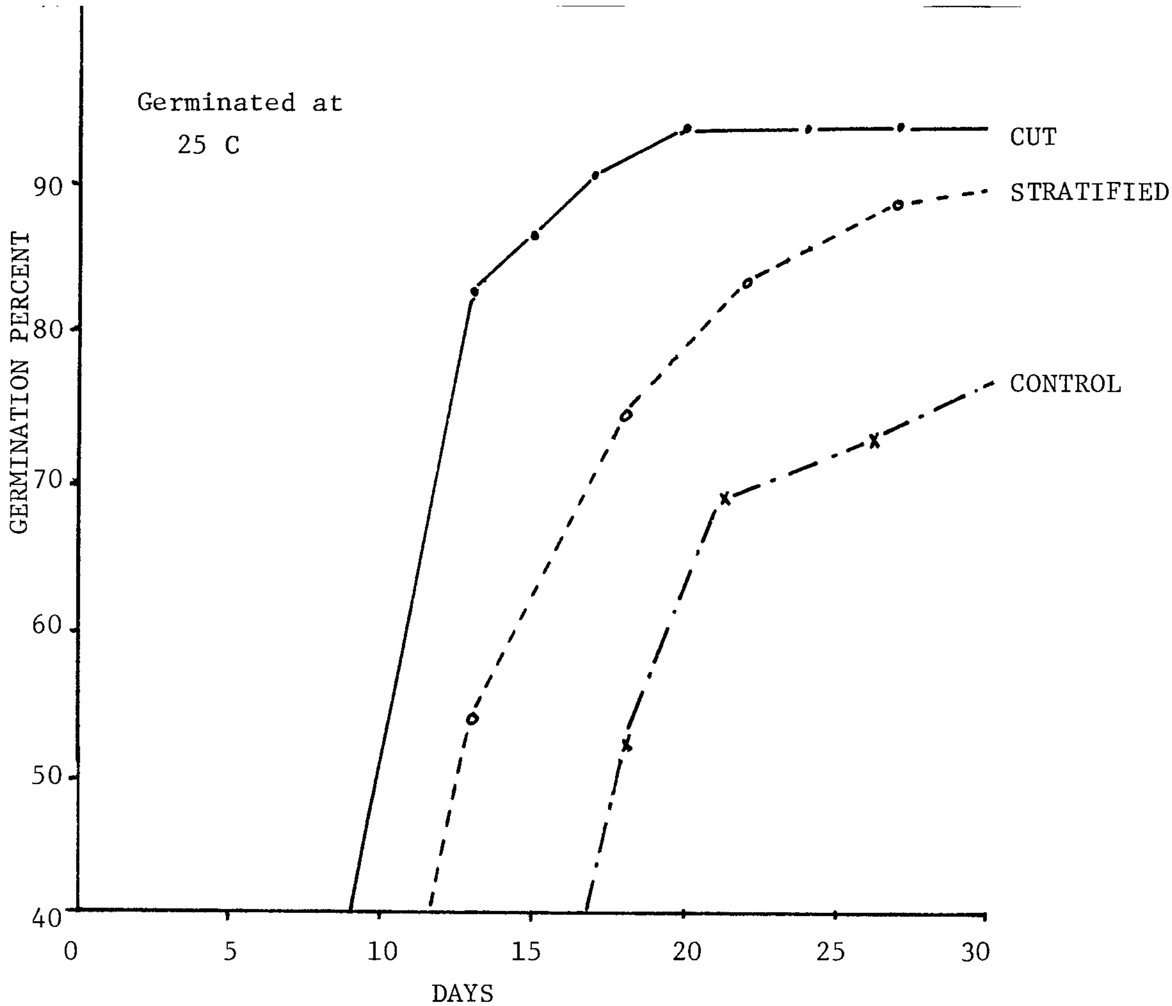

Figure 2. Effect of treatment on the germination of <u>Pinus ayacahuite</u>. (control had no treatment; stratification for 30 days was at 3 C on the media; and the cut treatment was removal of about 3-4 mm of the radicle end of the seed coat)

USING ELECTRICAL CONDUCTIVITY OF SEED LEACHATE AS A MEASURE OF SEED QUALITY IN SOUTHERN PINES

J. A. Vozzo and F. T. Bonner[1/]

Abstract.--Seeds of loblolly, eastern white, and longleaf pines readily indicate seed quality as measured by their leachate conductivity. Slash, shortleaf, and Virginia pine seeds also reflect seed quality by leachate conductivity, but not as strongly. Electrical conductivity meters (ASA-610 and ASAC-1000) give reproducible correlations between conductivity measurement estimations and laboratory germination or nursery emergence as well. In particular, the stronger correlations between conductivity measurements and nursery germination allow a rapid, easy, nondestructive measure of southern pine seed quality as a supplement to the standard germination test.

Additional Index Words: *Pinus echinata*, *P. elliottii*, *P. palustris*, *P. strobus*, *P. taeda*, *P. virginia*.

Can pine (*Pinus*) seed quality be predicted by measuring leached exudate conductivity using a simple, quick and nondestructive procedure? Considerable evidence since 1968 indicates that such a procedure is possible.

Matthews and Bradnock (1968) reported the inverse relation between exudate conductivity and field emergence in peas (*Pisum*) and French beans (*Phaseolus vulgaris* P.). They used a Wheatstone-bridge type of conductivity meter to measure leachate conductivity in distilled water.

Levengood, Bondie, and Chen (1975) described an instrument for identifying a seed's leachate conductivity after partial imbibition. Because its introduction led to interest and acceptance among seed researchers, conductivity tests have been included in vigor test methods by the International Seed Testing Association (1981). Bonner and Vozzo (1982) reported that pine seed quality could apparently be predicted by this conductivity meter. The instrument, a multi-probe ASA-610 distributed by Neogen Food Tech Corp. of Okemos, MI[2/], has also been used specifically to measure seed quality for other species, *viz*., soybean (*Glycine max* L.) by Woodstock (1983) and cotton (*Gossypium hirsutum* L.) by Perl and Feder (1983).

Other instruments for measuring seed leachate conductivity are also available. Hepburn, Powell, and Matthews (1984) used a single-probe conductivity meter and compared it with a multi-probe for measuring conductivity in pea and soybean seeds. They found the single-probe to favor more clearly related measurements predicting seed germination. All data reported here, however, were collected from multi-probe conductivity meters ASA-610 and ASAC 1000.

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2/ Mention of a trademark, proprietary product or vendor does not constitute a guarantee or warranty of the product by the U.S. Forest Service and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

METHODS

The ASA-610 and ASAC-1000 are basically similar, but the latter has the capability of programming and extended automatic sampling.

Basically, the instruments measure conductivity of a leachate in the distilled water of a cell having a volume of approximately 4 ml. There are 100 cells per tray, and each cell is filled to a standard level and then the seed is added. Seeds are imbibed directly in the conductivity trays. An electrode head containing 100 pairs of individual electrodes is placed over the conductivity tray so that one pair of electrodes is in each cell of the tray. The system supplies a variable voltage to each pair of electrodes, which then measure the current that passes through the water-exudate medium. This current is measured in microamps and is printed directly onto paper tape.

Calibrations allow selection of a partition value that represents a predetermined threshold of current. Seeds allowing enough leachate to have a greater µamp value than the selected partition value are considered to be of poor quality. However, the partition value is an incompletely defined variable, yet requisite to data interpretation. In earlier tests with pines, a single partition value was rejected in place of mean conductivity of the 100-seed sample (Bonner and Vozzo 1982).

Seeds of six southern pines were used as test specimens: shortleaf pine (*Pinus echinata* Mill.), slash pine (*P. elliottii* Engelm.), longleaf pine (*P. palustris* Mill.), eastern white pine (*P. strobus* L.), loblolly pine (*P. taeda* L.), and Virginia pine (*P. virginiana* Mill.). These six species were used to establish methodologies for forest tree seeds projected from the manufacturer's recommendations for agricultural seeds.

Seeds were imbibed in distilled water at 25°C for up to 48 hours before conductivity measurements were made. Seeds were also imbibed at 30°, 35°, and 40°C to determine whether soak temperatures influenced leachate.

Seeds from 17 seed lots of shortleaf, slash, and loblolly pines were sized with round screens (sizes 7 to 12) into three fractions to determine the influence of seed size on leachate conductivity.

Freshly collected loblolly seeds were measured for conductivity and then chilled at 3°C for 28 days, surface-dried, and remeasured to determine whether leaching normally affects prechilled seeds. These seeds were also sub-sampled to measure conductivity after drying to a moisture content of 15 percent.

Data from the ASAC-1000 were examined by the "Histogram Segment Method" suggested by the manufacturer. This technique allows for differences in the rate of electrolyte loss due to seedcoat thickness, seed size, etc., or any other factors that may be associated with seeds of a particular genetic identity.

A histogram of current frequencies at 5-µamp intervals was required. Starting at the current level at which seed count increases by at least 2 over the previous 5-µamp segment, a constant value was added to determine a partition value. This constant (perhaps different for each family, seed source, etc.) is called the histogram segment (HS) and is calculated by repeated comparisons of histograms and germination values.

Both mean conductivity (in μamps) and HS partition values were used to compare data from the six pine species. The data were used to estimate laboratory germination and, for some species, nursery emergence. Laboratory germination percentages were based on filled seeds only and include both dormant ungerminated seeds and abnormal germination. Our previous studies have indicated that seeds in these conditions leach electrolytes at similar rates to good, vigorous seeds and that conductivity measurements cannot distinguish between them.

Simple correlation coefficients have been the basic means of evaluation in our studies. Where laboratory germination estimates were made in this study, regressions of percentage of germination on conductivity data were calculated. In most cases, a linear model fit the data (Fig. 1), but for several species an exponential model was best (Fig. 2). The accuracy of germination estimates obtained from the regressions was tested with a modified form of the chi-square test in which the error limits at the 95-percent level of confidence of deviation of the estimate (conductivity) from the standard (laboratory germination test) measurement were calculated (Rennie and Wiant 1978). A detailed description of HS evaluation and usage is currently being published in another report (Bonner and Vozzo, in press).

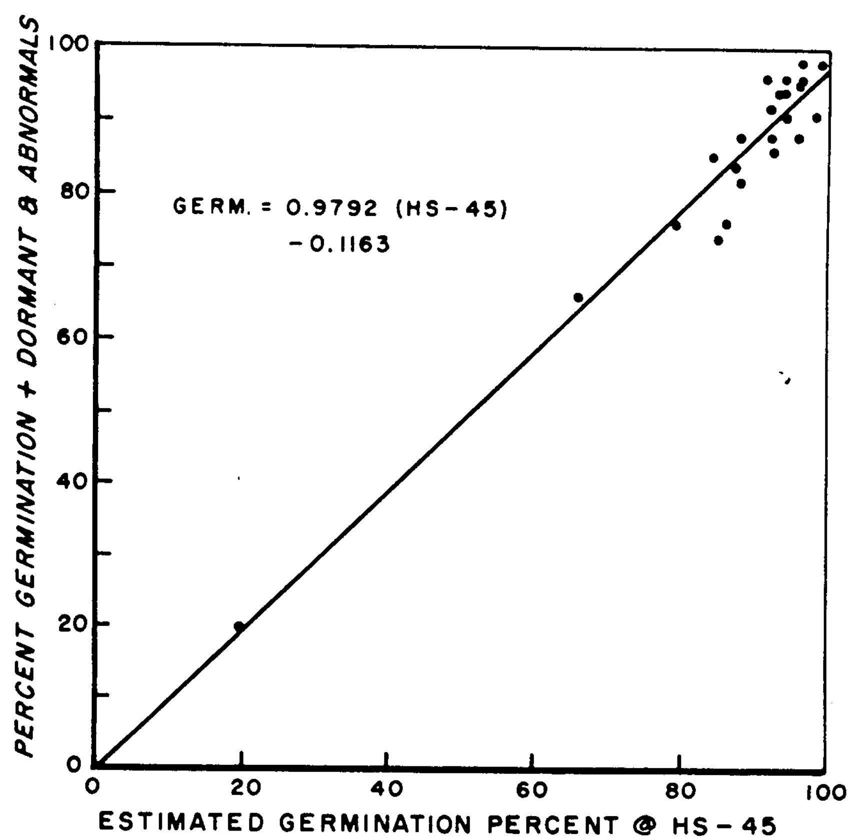

Figure 1. Regression of laboratory germination on ASAC-1000 estimates based on HS-45 for loblolly pine.

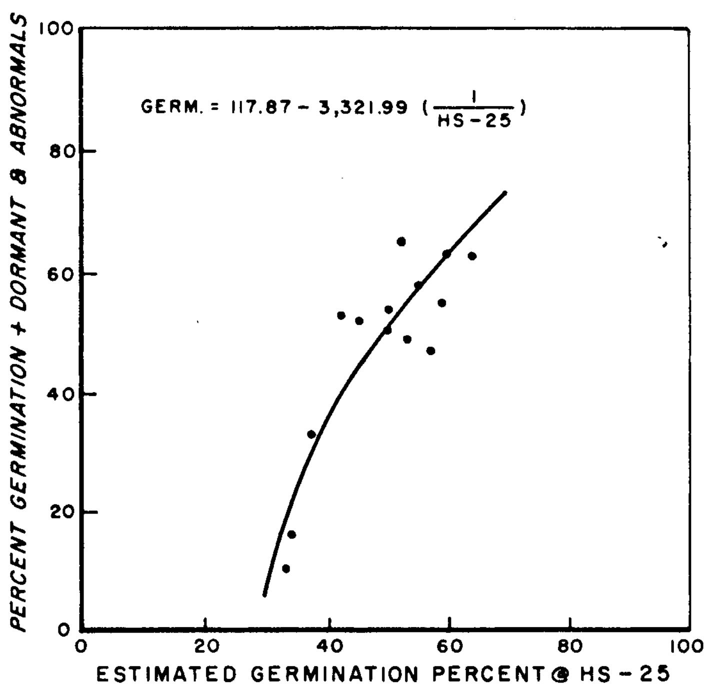

Figure 2. Regression of laboratory germination on ASAC-1000, estimates based on HS-25 for longleaf pine.

RESULTS AND DISCUSSION

Higher imbibition temperatures of 30°, 35°, and 40°C had no significant effect on leachate. However, the higher temperatures did adversely affect the soaking trays. As the warmer imbibition water temperatures were causing the soaking trays to warp, inconsistent conductivity measurements resulted when the electrode pairs did not seat properly in the individual cells.

Table 1 shows the effect of seed size on leachate conductivity for the larger slash and loblolly pine seeds. Slash and loblolly seeds averaged about 15,000 and 18,000 cleaned seeds per pound respectively (USDA 1974). The smaller shortleaf seeds averaged about 46,000 cleaned seeds per pound and did not follow the trend shown for slash and loblolly.

Table 1. Effect of seed size on leachate conductivity in loblolly, slash, and shortleaf pines, as measured on the ASAC-1000 Seed Analyzer.

			Leachate conductivity			
Species	No. lots	Voltage	Pre-sizing	Small	Medium	Large
		V.	------------------µamp	------------------		
Shortleaf	2	4	63	66	63	62
Slash	6	2	58	56	59	61
Loblolly	9	2	39	38	40	44

Previous work at our laboratory showed that seeds of southern pines could be immersed in a 16-hour running-water rinse and still have measurable leachate within 24 hours (Vozzo 1984). We expanded that study to include stratification with surface drying and moisture content reduction, as shown in Table 2. Stratified seeds were still measurable for leachate conductivity. The lots of good quality seeds continued to show similar readings after pre-chilling and comparable readings after redrying to 15-percent moisture content.

Table 2. Mean leachate conductivity for 10 lots of loblolly pine seeds in fresh, pre-chilled, and then redried condition.

Fresh	Pre-chilled for 28 days	Redried to 15% moisture content
	µamp	
182	138	66
124	114	76
90	90	68
88	90	86
65	65	53
65	67	62
62	57	50
61	64	54
57	58	55
56	55	52

Most measurements have been made on six common pines of the Southeast: loblolly, slash, longleaf, shortleaf, Virginia, and eastern white pine. For these six, the best estimates of laboratory germination can be obtained from regression equations based on HS partition values. The best HS ranged from 25 for longleaf and eastern white pines to 45 for loblolly pine (Table 3). Correlation coefficients ranged from a strong 0.9775 for loblolly to a weak 0.5342 for Virginia pine.

Table 3. Correlations of conductivity data with laboratory germination and calculated error limits for six pines species.

Species	Number of lots	Best histogram segment	Correlation coefficient	Error limit
			r	pct
Shortleaf	9	HS-35	0.7477	4.8
Slash	24	HS-40	.7806	7.2
Longleaf	14	HS-25	.9252	10.9
Eastern white	14	HS-25	.8546	13.6
Loblolly	24	HS-45	.9775	6.5
Virginia	11	HS-30	.5342	3.1

The calculated error estimates of 6.5 percent for loblolly and 7.2 percent for slash pine (Table 3) must be considered as good for a 24-hour test. These values mean that estimates of loblolly germination from conductivity data will not deviate more than 6.5 percent from a laboratory test mean at the 95-percent level of confidence. Estimates for shortleaf and Virginia pines were less than 5 percent, but they were not based on many seed lots. The error estimates of 10.9 percent for longleaf pine and 13.6 percent for eastern white pine are not very good, but improvement should come with additional work.

In the data presented here, there were a few cases of only slight differences between HS partition values. In loblolly pine, for example, HS-40 and HS-45 were very similar in average deviation. In future work it is reasonable to expect the establishment of different HS partition values for some geographic sources of the same species. For those seed managers who collect seed orchard material by family, HS partition values for each family are possible if necessary.

Conductivity measurements were also used to predict nursery emergence (Table 4), although the correlations were not as strong as those with laboratory germination. HS partition values ranged from 20 for longleaf to 45 for slash pine. Comparing correlation coefficients with those from laboratory germination also gives encouraging support for conductivity measurements and nursery emergence (Table 4). For the lots in our study, conductivity was better than laboratory germination in predicting nursery emergence of slash pine, but they were equal for longleaf. Laboratory germination was better than conductivity for loblolly and eastern white. The error limits for eastern white and loblolly pine seeds are recognizably high. Additional work is currently in progress to improve the estimates for all species.

Table 4. Correlations of laboratory germination and conductivity measurement with nursery emergence for four species at Starkville Forestry Sciences Laboratory nursery.

Species	Number of lots	Conductivity Measurement			Laboratory germination	
		HS	Correlation coefficient	Error limit	Correlation coefficient	Error limit
Slash	24	45	0.6974	9.8	0.5721	11.4
Longleaf	14	20	0.8360	9.5	.8063	9.4
Eastern white	14	25	0.7086	11.2	.8365	8.8
Loblolly	24	40	0.7122	17.4	.7950	14.6

Except for slash pine, HS estimates were better predictors for nusery emergence than simply using mean conductance. As expected, the higher correlation coefficients were genera-ly supported by lower error limits, except for loblolly (Tables 3 and 4).

In practical applications, some adjustments must be made to conductivity estimates of germination. Because the regressions included abnormal germination and dormant seeds, estimated germination values hould probably be cut 5 percent on very good lots (85 to 100 percent germination) and 10 percent on those not so good (65 to 85 percent). Below 65 percent, larger adjustments are probably needed, but the available data in this range are not sufficient to permit good estimates. Since measurements seem to overestimate germination for poor lots, it is possible that the exponential model will fit all species best when more data from poor lots are included. This problem is currently being addressed.

CONCLUSIONS

Experience with the ASA-610 and ASAC-1000 meters at the Starkville Forestry Sciences Laboratory indicates that seed quality of these six species can be estimated using electrical conductivity of seed leachate.

Histogram segment partition values are shown here to be practical and valuable supplements in judging seed quality. In particular, the data in Table 3 promised a genuine correlation between conductivity measurement estimations and laboratory germination. Similarly, nursery emergence can also be related to both conductivity measurement and laboratory germination, with stronger correlations between conductivity measurement and nursery germination (Table 4).

Conductivity meters provide one means of determining seed quality and should be used to supplement other approved methods.

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