Collection

I. Genetics and Seed Source

A. Introduction

Seed quality involves both the genetic and the physiological quality of seeds. In this section, the general principles and methods for selection of seed source and improvement of seed quality through genetic selection are presented. Genetic improvement of seed quality is based on the seeds' ability to produce trees that are genetically well suited to the sites where planted and for the products desired. In later sections, the physiological quality of seeds will be considered. Good seeds are those that have both high physiological quality and genetic suitability.

B. Objectives

1. Recognize the importance of seed origin (provenance) and recommend general rules for seed movement.
2. Review the advantages and disadvantages of exotic tree species and interspecific hybrids for tree improvement.
3. Define factors that must be considered when a tree improvement program is initiated.
4. Identify the conditions required for genetic improvement of tree seeds (genetic gain concept).
5. Distinguish between a minimum initial strategy of genetic improvement and a maximum long-term strategy.
6. Identify some terms and concepts of new biotechnology for genetic improvement.

C. Key Points

The following points are essential to understanding seed source and genetic improvement:

1. A successful tree improvement program should not be tried in another country or region without considering desired products and available sites.
2. Knowledge of phenotype and genotype is necessary to understand genetic improvement of trees.
3. The genetic gain equation explains the advantages of one improvement method over another.
4. Genetic gains can be obtained from selections among species, provenances within species, and/or trees within provenances.
5. The primary risk of using exotics or nonlocal provenances is planting on unsuitable sites.
6. Test plantings are the only sure method to determine genetic quality of seeds.
7. Without results of test plantings, the safest rule is to use seeds from phenotypically selected stands or trees in the local provenance for native species or land race for exotic species.
8. The seed orchard concept has two parts—the breeding program and the production program.
9. Seed orchard breeding programs involve progeny tests and selection for the next advanced generation of genetic improvement.
10. Seed orchard production programs are managed to maximize seed production through protection and cultural treatments.

D. Tree Improvement

1. **Tree improvement** begins with the decision to use artificial rather than natural regeneration. Tree improvement is the development and application of genetically improved trees and intensive cultural practices to increase forest productivity through artifical regeneration.
2. **Tree improvement programs** are plans of action to bring about desired objectives. The following factors should be considered when a tree improvement program is initiated:
   a. The products desired determine what species can be used and what traits should be emphasized when breeding for genetic improvement.
   b. The geographic location and physical and climatic characteristics of the sites to be regenerated determine what species and seed sources can be used.
   c. Only species and provenances that are adapted to the planting sites should be used to avoid failure or substandard performance.
   d. Conservation of forest gene resources should be planned from the beginning to maintain genetic diversity.

E. Strategies for Genetic Improvement

1. **Genetic gain**
   a. Genetic improvement (genetic gain) is accomplished by:
      (1) Having a population of trees with genetic differences
      (2) Selecting the genetically desirable trees to serve as parents for production of seeds
   b. The amount of genetic gain *(R)* to be captured from phenotypic selection of parent trees for a particular trait can be expressed as:

$$R = i\ Vp\ h^2$$

where i = the intensity of selection

h^2 = the heritability of the trait

V_T, = the amount of phenotypic variation.

c. Gain can be obtained from selection among species (R_s), selection among provenances within species (R_e), or selection among individual trees within provenances (R_I). The total gain (R_T) is the sum:

$$RT = R_s + Rp + R_I$$

2. Species selection

a. Species-site studies provide information about the relative performance of different species when planted together on various sites.

b. Exotic tree species should be used only when the desired product cannot be obtained with native species at a comparable cost.

c. Interspecific hybridization has been used to obtain unique combinations of valuable traits (combinational hybridization) and to obtain hybrid vigor (e.g., *Populus* and *Pinus*).

r Seed source

a. Provenance refers to where the mother trees were growing and the seeds were collected. The stand may be indigenous or nonindigenous. Seed source is the same as provenance. Origin refers to where the original progenitors of nonindigenous stands were growing in natural forests and where their genetic characteristics developed through natural selection. For an indigenous stand of trees, origin, provenance, and seed source are the same. Some foresters in the United States use the term "provenance" in place of "origin" when referring to nonindigenous stands.

b. The largest, cheapest, and fastest gains in most tree improvement programs can be made by ensuring the use of adapted, productive provenances of the desired species. "Local" sources should be used until provenance test results are available.

c. Provenance tests should be conducted during the early stages of a tree improvement program so that geographic collection and planting zones can be delineated. Results of provenance tests include:

(1) Mapping patterns of geographic genetic variation

(2) Delineating provenance boundaries

(3) Determining provenances best adapted and most productive for specific geographic areas.

d. The general results of provenance testing are:

(1) Wide seed transfer is safer near the center of a species' range than near its edge.

(2) Where environmental gradients are steep, movement of material must be restricted.

(3) Provenances from harsh climates (cold or dry) are slower growing but more hardy because of the stress factor than provenances from milder climates.

4. Improvement strategies

a. The initial strategies for a new program are:

(1) Collect available information.

(2) Select among indigenous tree species.

(3) Select seed production areas within the "local" seed sources near the planting site.

(4) Remove phenotypically inferior trees from seed production areas.

b. The long-term strategies for maximum and continued gains are:

(1) Collect all existing information.

(2) Select several species for the program, and begin supplemental tests (species-site, exotic, or interspecific hybridization) to obtain missing information on these and other promising species.

(3) Conduct provenance tests or use existing provenance tests in the area to delineate optimal provenances for the planting sites.

(4) Select the phenotypically "best" trees from the best provenances.

(5) Establish a first-generation seed orchard from the phenotypically selected trees.

(6) Test the progeny of the selected trees.

(7) Remove genetically poor trees from the orchard.

(8) Select the best individuals from the best families in the progeny tests and place these in a second-generation seed orchard.

(9) Test the progeny of these second-generation selections and repeat steps (6), (7), and (8) above for subsequent generations. Search con-

tinually for new first-generation selections or for selected clones from other programs to incorporate into the program (enrichment).

c. New strategies for genetic improvement are:
   (1) Gene transfer, using recombinant DNA technology, to insert a desired gene into a species where it does not occur.
   (2) Cell selection in a cell-suspension culture to screen for resistant cells to a pathogen, toxin, or herbicide, and developing these cells into mature plants by tissue culture techniques.
   (3) Fusion of protoplasts (without cell walls) to create a new hybrid cell with two sets of chromosomes.
   (4) Somaclonal variation, which is genetic variation among individual propagules regenerated from cell and tissue culture of the clone. It provides a new source of genetic variation for selection.

F. The Seed Production Program

The seed production program may be combined with the breeding program or may be kept separate. The objective of a seed production program is to produce sufficient quantities of genetically high-quality seeds to meet seed needs.

1. **Seed Production Areas**
   a. Seed production areas (SPA's), or seed stands, are existing stands of natural or plantation origin that are selected for phenotypic superiority and managed for production of seeds.
   b. SPA's are used on an interim basis until seed orchards come into production.
   c. SPA's can use genetic improvement from superior provenances.
   d. SPA's can provide seeds for minor species having small planting programs.
   e. Practices to improve genetic quality of seeds include:
      (1) Removing phenotypically undesirable trees
      (2) Establishing a pollen dilution zone around the SPA
   f. Practices to increase seed production include:
      (1) Thinning the stand
      (2) Fertilizing
      (3) Establishing access roads (for protection and for seed collection)

2. **Seed orchards—A** seed orchard is a collection of selected trees established and grown together under intensive management for production of genetically improved seeds.
   a. There are two types of orchards: seedling seed orchards and clonal seed orchards.
      (1) Seedling seed orchards involve progeny tests that are rogued (poor families and individuals removed) so that the remaining trees can cross-pollinate and produce seeds.
      (2) Clonal seed orchards are collections of vegetative propagules (usually grafts) of select trees. The propagules are establised together, progeny tested when they flower, and then rogued based on progeny test results.
   b. The genetic quality of seeds is increased by:
      (1) Reducing inbreeding through nonrandom assignment of clones or familes to the orchard.
      (2) Establishing a pollen dilution zone around the orchard.
      (3) Separating provenances into different orchards.
   c. Seed production from orchards is increased by:
      (1) Establishing the orchard where soil and climatic conditions are most favorable for seed production.
      (2) Spacing wide enough for maintenance of a full crown but not so wide that cross-pollination is reduced.
      (3) Applying fertilizers to increase the number of flowers and the portion of the crown bearing flowers.
      (4) Irrigating all year during dry periods to stimulate flower production. (Irrigation has not provided consistent results.)
      (5) Subsoiling to improve health and wind firmness of orchard trees and to stimulate flower production.
      (6) Protecting flowers, fruits, cones, and seeds from insects by periodically applying insecticides.
      (7) Protecting flowers from late spring freezes through cold water irrigation.
      (8) Ensuring supplemental mass pollination.

G. Sources
For additional information, see Burley and Styles 1976, Khosla 1982, Nienstadt and Snyder 1974, Rudolf and others 1974, Wright 1976, Zobel and Talbert 1984, Zobel and others 1987.

II. Production

A. Introduction
Most tree-planting programs are begun by collecting seeds from in-country sources, both natural stands and plantations. To plan these collections effectively, seed managers should understand the factors that affect tree seed crops and generally know what seed yields may be expected. With this basic information, opportunities may arise to stimulate seed production in key areas, such as seed orchards or managed seed stands.

B. Objectives

1. Recognize the problem of periodicity of seed production in trees.
2. Learn how environmental factors affect seed production.
3. Learn how seed production can be stimulated in trees.

C. Key Points
The following points are essential to understanding seed production:

1. Many tree species bear good crops in cycles.
2. Production is less frequent in high latitudes and high altitudes and among heavy predator populations.
3. Environmental factors influence flower production, pollination, and seed maturation.
4. Several options are available to stimulate seed production.
5. Except for seed orchards of a few species, production data are extremely variable.

D. Periodicity of Seed Crops

1. **Temperate species**
   a. Many conifers bear in cycles, producing good crops every 3 to 4 years.
   b. Some trees, mainly angiosperms, produce good seed crops every year (e.g., *Acer, Betula,* and *Fraxinus).*
   c. As latitude or altitude increases, the interval between good crops and the frequency of crop failure increase.
2. **Tropical species**
   a. Periodicity may depend on wet/dry cycles. In Nigeria, good seed years occur after very dry weather in August.
   b. Some species (e.g., *Tectona grandis)* usually flower each year, with bumper crops every 3 to 4 years. Other species (e.g., *Pinus kesiya, Cassia siamea, Cupressus lusitanica,* and *Delonix regia)* produce good crops most years. Bawa and Webb (1984) found 93 percent flower abortion in seven Costa Rican tropical hardwoods within 2 days, but the reasons for the abortion are largely unknown.
   c. Dipterocarps in Malaysia bear irregular heavy seed crops at 1- to 6-year intervals.
   d. Some *Eucalyptus* species have large crops more regularly when grown in plantations perhaps because of the concentration of pollen in a pure stand. In the United States, the same finding may be true for many genera, especially *Liriodendron* and *Platanus.*
3. **Genetics — Fecundity** is an inherited trait.
4. **Documentation—There** have been many observations but few detailed physiological studies on periodicity of seed crops.

E. Effects of Environment During Flowering

1. **Temperature**
   a. During hot summers, trees usually produce many floral buds and thus large crops of seeds the next year, but the reason is not known. It may be related to partitioning of carbon within the tree.
   b. Late freezes can destroy flowers; sprinkler irrigation can provide some protection.
   c. The combination of hot summers and late freezes suggests that orchards should be moved to warmer climates (also to escape insects). However, *Pinus taeda* orchards were once moved to south Texas, but without success.
2. Light – The effect of light has not been studied extensively. In the Northern Temperate Zone, southern and western sides of crowns have the largest flower and fruit crops. The reason could be light, temperature, or pollen supply. A study of *Acer pennsylvanicum* found an increase in female-to-male flower ratio as crowns closed in the stand. The reason could be environment or internal physiology.
3. **Photoperiod** does not appear to have a direct effect on trees.
4. **Moisture**
   a. Drought, coupled with high temperatures, seems to stimulate flower production the following year.
   b. Excessive rain during pollination leads

to low seed yields in wind-pollinated species.

5. **Mineral nutrients—Some** general observations and weak study results suggest that trees on fertile sites flower and produce more fruit than trees on infertile sites. Nitrogen and phosphorous are most important for flowering, but the reasons are still unknown.
6. **Biotic agents—Insects,** birds, mammals, and micro-organisms can destroy flowers, especially in the following tropical species:
   a. *Triplochiton scleroxylon;* attacked by *Apion ghanaense* (weevil)
   b. *Tectona grandis;* attacked by *Pagyda salvaris* larvae
   c. *Pinus merkusii;* attacked by *Dioryctria* spp. (cone worms)

F. Pollination Agents

1. **Wind pollination** occurs among all conifers and most Temperate Zone hardwoods of commercial value.
   a. Wind pollination requires:
      (1) Lots of pollen
      (2) Pollen shed coinciding with receptivity
      (3) Relatively close spacing of plants
      (4) Good weather — low rainfall, low humidity, and good winds
   b. Supplemental mass pollination (SMP) has been used in United States southern pine orchards.
   c. Contamination in orchards is a concern. The degree of contamination can be determined by isoenzyme analyses.
2. **Animal pollination**
   a. Insects pollinate many temperate hardwoods. (e.g., *Liriodendron* and *Prunus).*
   b. Bats and birds pollinate many tropical hardwoods, such as honeyeaters in *Acacia.*
   c. Animal pollination is usually common in tropical forests with:
      (1) High species diversity and wide spacing
      (2) Abundant foliage to filter out pollen
      (3) High humidity and frequent rainfall
      (4) Absence of strong stimuli to coordinate flowering (day-length and temperature changes)
      (5) Abundant animal vectors

G. Stimulation of Flowering

Flowering can be stimulated in seed production areas and seed orchards by fertilizing, girdling and other wounding, thinning, growth regulator treatment, and supplemental mass pollination.

1. **Fertilizing**
   a. Use primarily nitrogen and phosphorous, but frequently potassium. Spring and summer application in pines of the Southern United States usually increases flowering and cone production. Zobel and Talbert (1984) recommend the following annual fertilizer levels for loblolly pine orchards: 400 kg/ha nitrogen, 80 kg/ha potassium, 40 kg/ha phosphorous, and 50 kg/ha magnesium.
   b. Irrigation at the same time as fertilizing may also help; however, success has not been universal. Many orchards use drip-irrigation techniques.
   c. Hardwoods may react favorably; e.g., *Acer, Fagus,* and *Juglans.* In Hungary, 200 kg/ha nitrogen and 240 kg/ha phosphoric acid more than doubled nut production and tripled the number of sound seeds.
2. **Girdling and other wounding**
   a. Girdling and other wounding are used to produce the so-called "stress crops."
   b. Girdling is supposed to inhibit downward translocation of carbohydrates, thus improving the carbon/nitrogen ratio. The optimum time to girdle Douglas-fir is 1 month before vegetative bud burst.
   c. Girdling has increased production somewhat in hardwoods; e.g., *Castanea* and *Fraxinus.*
3. **Thinning—In** pine orchards, the benefits of thinning are apparent 3 to 4 years after thinning. The goal is full crown development but not so much open space as to reduce cross-pollination.
4. **Growth regulator treatment — Great** strides have been made with gibberellins (GA) applied to conifers by Ross and Pharis (1976) in Canada.
   a. Water-based foliar spray is best.
   b. A GA 4/7 mixture is most effective.
   c. Both pollen and seed cones are induced.
   d. Apply at bud determination.
   e. Mode of action is still not known.
   f. Treatments are most successful when applied with girdling, root pruning, or moisture stress.
5. **Supplemental mass pollination (SMP)** has been used in pine orchards in the Southern United States.

H. Postfertilization Problems

1. **Insect damage to cones—A** major cause of losses in conifers.

2. **Drought — Extremely** dry weather during seed development and maturation may cause cone drop (e.g., *Pinus monticola)* and losses in seed weight. Russian data show lower seed weight in *Robinia;* the same reaction occurs with *Pinus* and *Quercus.*
3. **Cone drop — Postfertilization** cone drop in *Pinus is* not common except for insect loss.
4. **High winds** — Late summer storms can cause great losses of large cones (e.g., *P palustris* and P *elliottii* in the Southern United States).

I. Production Data

Production data include the following published yield figures:

1. ***Pinus* seed orchard production—In** 15- to 20-year-old orchards in the Southern United States, *Pinus* produced these crops: *P taeda,* 98 kg/ha; *R elliottii,* 86 kg/ha; and *P. strobus,* 24 kg/ha. These values should increase as the orchards get older. If 1 kg of seeds produces 17,000 plantable seedlings, 1 ha of orchards yielding 50 kg should produce enough seeds annually to plant 600 ha.
2. ***Pinus elliottii* in Brazil** produced up to 94 kg/ha of seeds with 500 trees per hectre in a natural stand, not an orchard.
3. **Hardwoods**
   - a. *Cecropia obtusifolia,* a Mexican dioecious pioneer, produced 2 to 3 kg/ha of seeds in a mature forest. The average was 900,000 plus seeds per tree per fruiting (Estrada and others 1984).
   - b. *Quercus* spp., in the North Carolina mountains, produced 16,500 to 236,500 seeds per hectre and 3,700 kg/ha (5 species).
   - c. *Liquidambar styraciflua,* in the Mississippi River floodplain, had twice the seeds per fruit head as did trees in Coastal Plain sites; the former were almost twice as "fruitful" also.
   - d. *Acacia albida,* in Sudan, produced 0.5 million seeds from mature trees (Doran and others 1983); and in South Africa, large trees produced several million seeds. In the Sahel, 125 to 135 kg of pods per tree, 400 to 600 kg of pods/hectre and ±- 20 seeds per pod were produced, but 95 percent may have been lost to insects.
   - e. *Tectona grandis,* in Thailand, produced 1 kg per tree at age 10 with 8- by 8-m spacing (1,000 seeds per kilogram).
4. **Trade-off—In** Temperate Zone species, radial growth could be decreased 30 to 40 percent in good seed years because of carbon allocation. This means that the current year's carbohydrates are used in cone growth. For *Picea abies* in Poland, growth was less in good seed years. The researchers concluded that selection for fast growth is also a positive selection for fecundity. It may be more important in other species; foresters must decide whether to select for growth or seeds. The agroforestry aspect must also be considered.

J. Sources

For additional information, see Franklin 1982; Owens and Blake 1985; Rudolf and others 1974; Sedgley and Griffin 1989; Whitehead 1983; Willan 1985, chap. 3; Zobel and Talbert 1984.

III. Collection Operations

A. Introduction

Successful collection of tree seeds is usually the result of detailed early planning. Ample time must be allowed to plan an efficient and practical collection strategy and to assemble the resources necessary for its implementation. Key elements include a good estimate of crop size, proper equipment, and a well-trained crew. Comprehensive collections for research certainly require more detailed planning than routine bulk collections and may require a lead time of 1 to several years depending on the circumstances.

B. Objectives

1. Identify simple techniques for seed crop estimation.
2. Determine the factors that should be considered when collections are planned.
3. Understand the importance of documentation.

C. Key Points

The following points are essential for planning collection operations:

1. The best seed sources available must be selected.
2. Good planning requires advance estimates of the seed crop and, at a later date, estimates of seed yield per fruit.
3. Large collection planning must include choice of personnel, training, transportation, collection equipment, safety of workers, labeling of seedlots, description of sites and stands, etc.

D. Seed Source

Seed source is extremely vital for all seed supplies; this point must never be underestimated. (See "Genetics and Seed Source.") Terms used in genetics are:

1. **Origin—the** natural stand location of the original mother tree.
2. **Provenance—the** place where mother trees that produced the seeds are growing. Seed source and provenance are the same. (Origin and provenance are usually reversed in the United States.)
3. **Land race — exotics** that adapt to develop improved sources.
4. **Seed zone maps — necessary** for a good program to eventually develop seed zone maps (figs. 14 through 16) [no equivalent figures in Student Outline].

E. Estimating Seed Crops

If seeds are in short supply, all possible seeds should be collected, stretching crews and equipment. If the location of large crops is known, more seeds can be collected for a given amount of cost and effort. Seed crops can be estimated by any of the following five methods:

1. **Flower counts—only** feasible with large, showy flowers. *Pinus* spp. strobili are about the minimum size.
2. **Immature fruit and seed counts—useful** in the collection zone before seed maturity because many flowers may abort.
3. **Fruit counts on standing trees—work** best when seeds are nearly mature.
   a. Total counts are feasible only for light seed crops.
   b. Crown sampling is most common and uses portions of the crown (10 or 25 percent). [Do the exercise in exercise 2 if there is time.] A 5-percent sample of orchard trees in midsummer gave a good estimate in *P taeda* in Virginia. Some people use a two-person system (one on each side of the tree).
4. **Rating systems — Examples** of rating *systems* are the Tanzania rating system (table 4) [no equivalent table in Student Outline] and a North American rating system for conifers (table 5) [no equivalent table in Student Outline].
5. **Cross-section seed counts—Cones** are cut lengthwise (or perpendicular to the axis for round fruits), and exposed filled seeds are counted (table 6) [table 3 in Student Outline]. This number can be related to total good seeds per fruit. Enough seeds must be counted to calculate a simple regression. [Do the exercise in exercise 2 if fruits are available.]

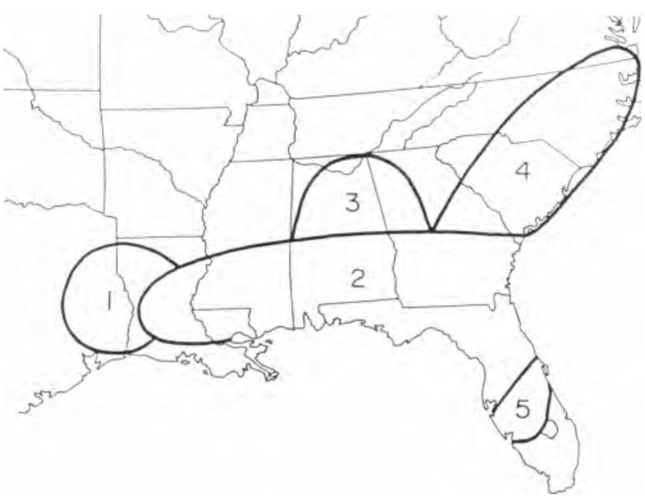


Figure 14. —*Recommended seed collection and planting zones for* Pinus palustris *in the United States (Lantz and Kraus 1987) [no equivalent figure in Student Outline].*

F. Planning Considerations

The steps of planning a collection are:

1. **Define the objectives**
   a. For effective planning, the coordinator of collecting operations needs a clear statement of objectives. Prior knowledge of species and provenance priorities, sampling strategy, the standard of documentation, and amount of seeds required is important to assemble the resources needed for the type of collection proposed.
   b. Flexibility should be built into the planning to allow collectors to make decisions about unforeseen circumstances. For example, it would be highly wasteful for collectors to return empty handed from remote areas because of restricted or narrowly defined aims and procedures when an alternative and potentially valuable seed harvest was available for collection.

Table 4. — *Tanzania rating system for seed crops (adapted from Willan 1985) [no equivalent table in Student Outline]*

Crop rating		
Numerical	Wording	Criteria
0	None	Trees without flowers and fruits
1	Weak	Flowering and medium-sized seed crops on free-growing trees and on trees on free borders of stands
2	Medium	Flowering and very good seed crops on free-growing trees and on free borders of stands; trees within stands bearing seed crops at top of crowns
3	Very good	Flowering and very good seed crops on most trees

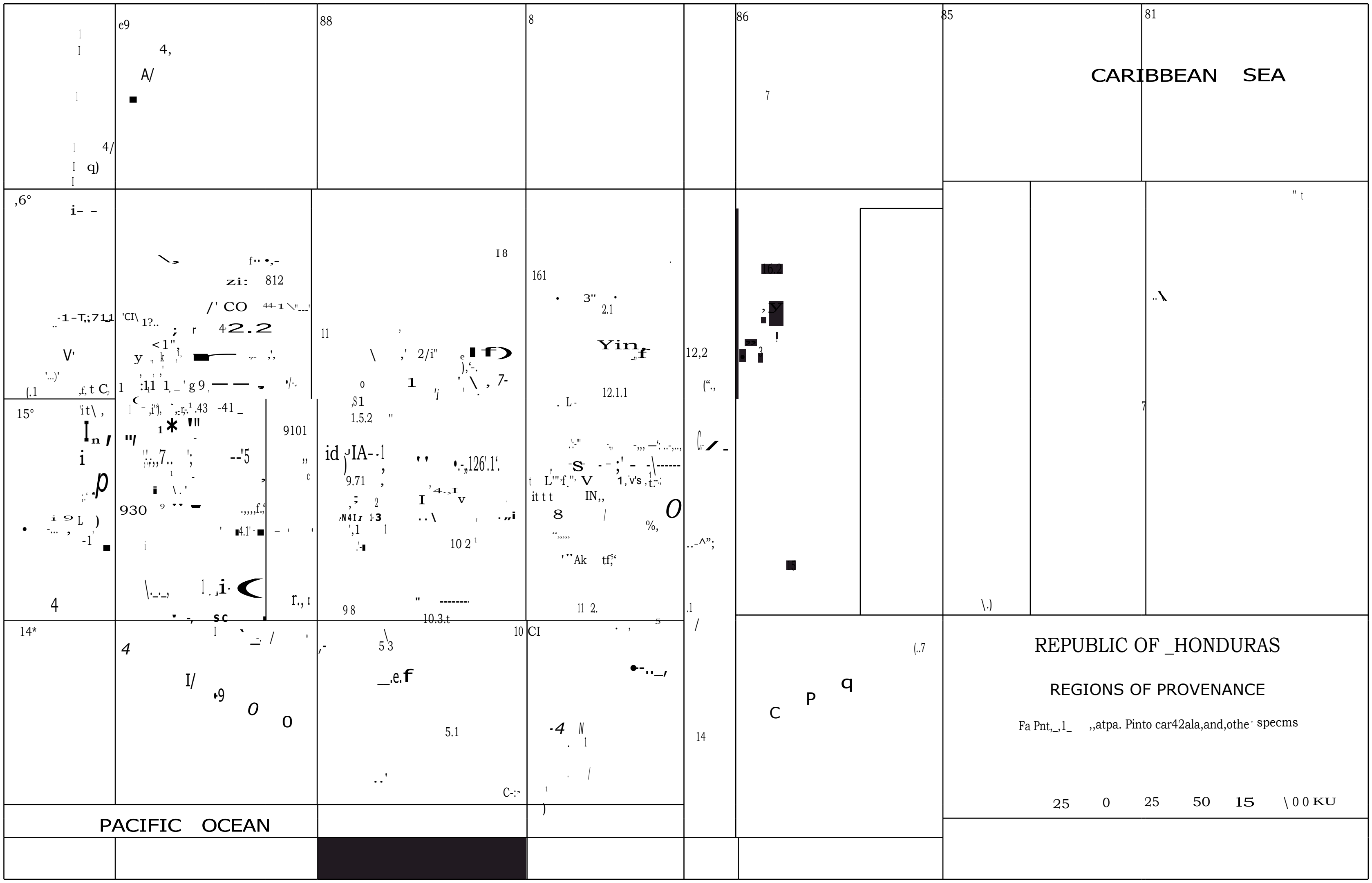
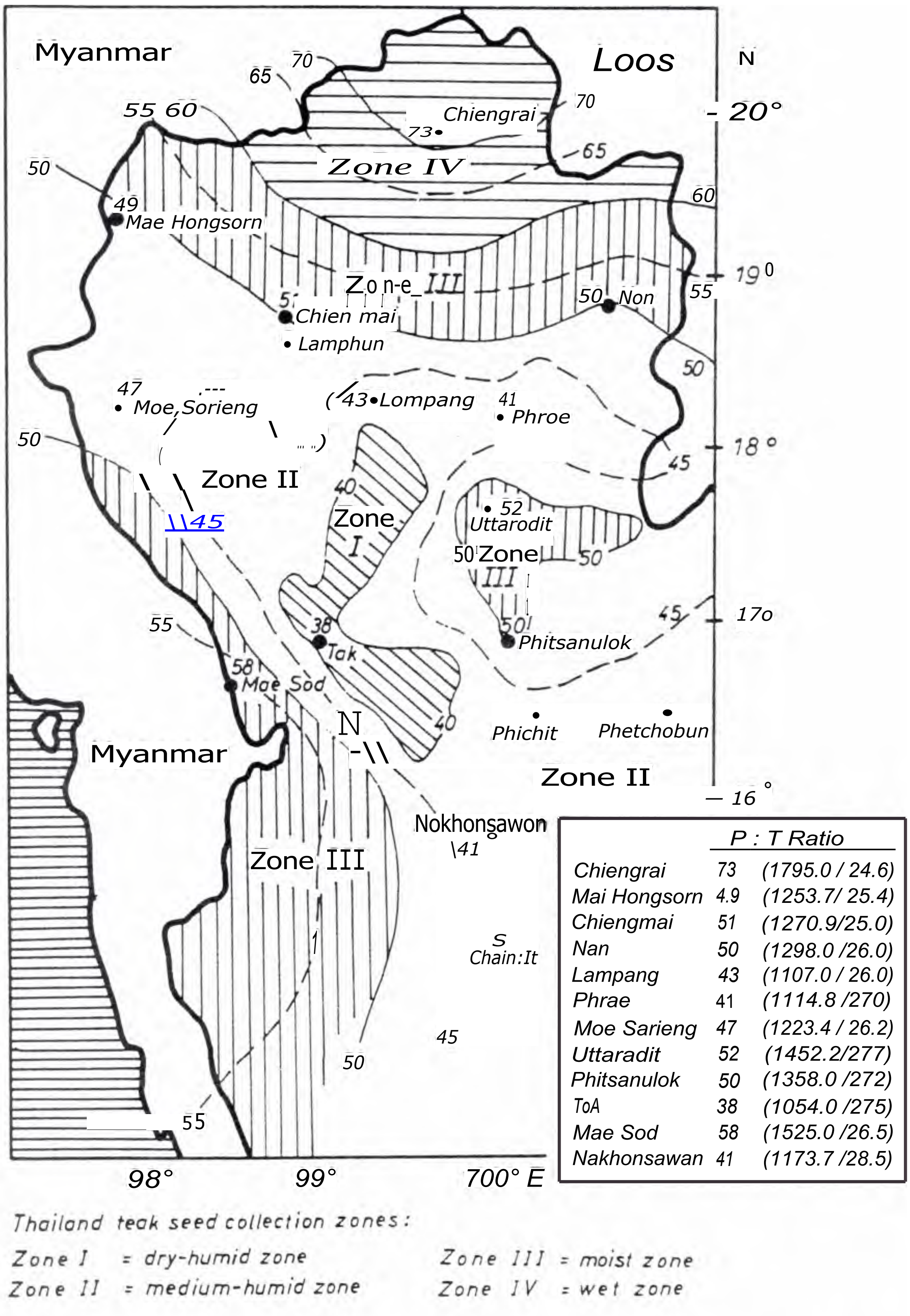


Figure 15. — *Seed zones for pines and other species in Honduras (Robbins and Hughes 1983) [no equivalent figure in Student Outline].*



P : T Ratio

Chiengrai	73	(1795.0 / 24.6)
Mai Hongsorn	4.9	(1253.7/ 25.4)
Chiengmai	51	(1270.9/25.0)
Nan	50	(1298.0 /26.0)
Lampang	43	(1107.0 / 26.0)
Phrae	41	(1114.8 /270)
Moe Sarieng	47	(1223.4 / 26.2)
Uttaradit	52	(1452.2/277)
Phitsanulok	50	(1358.0 /272)
ToA	38	(1054.0 /275)
Mae Sod	58	(1525.0 /26.5)
Nakhonsawan	41	(1173.7 /28.5)

Figure 16.—*A proposed seed zone map for teak* (Tectona grandis) *in Thailand based on the annual precipitation/mean annual temperature ratio moisture index value for 1951-1975 (Kaosa-ard 1983) [no equivalent figure in Student Outline].*

Table 5. —*North American rating system for conifer seed crops (adapted from Willan 1985) [no equivalent table in Student Outline]*

Crop rating*		
Numerical	Condition	Criteria
1	Failure	No cones to a few scattered on a few trees
2	Very light	Some cones on some trees
3	Light	Good to fair cone crop on 50 percent of exposed crown of 50 percent of trees
4	Medium	Good to medium cone crop on 75 percent of exposed crown on most trees
5	Heavy	Good cone crop on all exposed crowns of most trees.

*A numerical rating of 4 or 5 is a good prospect for all collectors. A rating of 3 has possibilities for more experienced collectors. A rating of 1 or 2 is a poor prospect for all collectors.

Table 6. —*Sound seed yield per cone for four* Pinus *species as estimated from the number of sound seeds exposed when cones are bisected longitudinally (Derr and Mann 1971) [Table 3 in Student Outline]*

Sound seeds exposed	*P. palustris* (Louisiana)	*R taeda* (Louisiana)	*R elliottii* (Louisiana)	*R elliottii* (Georgia-Florida)	*P echinata* (Virginia)
	Sound seeds per cone				
2	23	31	20	31	12
4	35	44	35	50	22
6	47	57	50	69	31
8	59	70	65	87	41
10	71	83	80	106	51
12	83	96	95	124	60
14	95	109	110	143	70

2. Gather background data

a. A literature search may provide information on the natural distribution of a species — its habitat, ecology, and genetic variability — and on fruiting and flowering times in different parts of its range. A visit to regional herbaria to examine relevant herbarium specimens may add significantly to the published information on species distribution, variability, and reproductive phenology. Personal contact with botanists, field foresters, rural people, and others who study or use a species can also help.

b. If the collections are wide ranging and cross political boundaries, early official contacts with the forest services in the States or countries concerned are essential to develop a good working relationship of mutual benefit to all parties.

c. All available information should be collected and summarized. Data on natural occurrence are best plotted on maps detailed enough to show the main transportation systems (e.g., roads, rivers, railways, and airstrips), topography, and other information that may assist in selecting collection sites. Seed-zone overlays for these maps are very useful.

d. Field reconnaissance is essential, preferably including adequate seed crop estimates and samples of fruits and seeds.

e. The coordinator of collecting operations must determine the number of personnel needed for the collecting team and must verify that they have the skills to meet the stated objectives. Key personnel should be selected early so that they can familiarize themselves with the project and species and, if necessary, be trained in the techniques they will be using in the field. Collection team leaders are responsible for the discipline, morale, and safety of personnel and the success of the operation.

3. **Collect field data**

The field data provide the information for relocating the site in future years for further work and provide the background essential for interpreting the results of the experiments. The data to be gathered at each collection site must be specified, and systems must be developed to make their collection as reliable and easy as possible for the worker in the field. Specially prepared field data sheets are recommended to ensure that uniform records are obtained from all sites. The standardized "Seed Collection Report" sheet adopted for the Fuelwood Project of the FAO and the International Board of Plant Genetic Resources and the "Seed Data Sheet" of CSIRO are good examples (figs. 17, 18) [no equivalent figures in Student Outline]. Significant features of these documents are:

a. Locality as indicated by latitude and altitude is essential to define the provenance area. They should be stated accurately and concisely so that future collectors can return with certainty to the same collection site. Distances from the nearest town, village, or geographical feature (river or mountain), the forest district, and any other facts that will assist future field parties should be recorded. Maps (hand drawn if others are not available) and aerial photographs showing the stands and the position of seed trees are useful and should be filed with the data sheets for ease of reference.

b. Aspect, slope, climate, soils, and associated species help to build a picture of the environment and ecology in which the trees grow and may help in interpreting experimental results. The collector should encourage relevant comments from local people on the history of the area and its climate. Recording tolerance to such features as alkalinity or salinity in the soil, seasonal inundation, etc. may be important later.

c. Individual tree descriptions (e.g., height, diameter, stem form, and branching habit) and the number of trees in a provenance are of obvious importance to any future tree-breeding work. Photographs are a useful adjunct to written descriptions.

d. Collecting herbarium specimens of little known or variable species allows for later scrutiny by botanical experts. Care is needed in handling the specimens, and it is best, after drying, to dispatch them to the base at the earliest opportunity to prevent damage.

e. Other data and notes that may be of great value to future collectors are crop and seed details, collection methods, etc.

f. It is paramount in provenance work to adopt foolproof systems for maintaining the identity and purity of each collection. Systems must prevent any seedlot from being contaminated with the seeds of another lot through all steps, from collection to registration in the seed store. Careful labeling through each process is essential and can be facilitated by using preprinted durable labels. A well-proven method of numbering collections used by CSIRO is based on party leaders' assigning numbers to the collections in numerical sequence, prefixed by their initials. The number assigned to a particular tree appears on and in the collection sacks and seed bags, on the herbarium voucher specimen, and on the photograph, and it identifies any other sample or recording of that tree. The provenance number is not assigned until the seeds are ready for storage.

4. **Plan the itinerary:**

a. Reaching the collection region well in advance of the proposed date for beginning the collection is important. In developing an itinerary for the collection team, team leaders must be aware of this point.

b. Organizing the sequence of operations in a particular region may require 2 to 4 weeks. Extra permits may have to be obtained, labor recruited and trained, and reliable transportation arranged.

c. Make the schedule flexible. The itinerary is important as a guide, but it must be flexible to account for the unexpected

FAO PROJECT ON GENETIC RESOURCES OF ARID/SEMI-ARID ZONE ARBOREAL SPECIES:

SEED COLLECTION RFPORT

Location

Collection No. ....

Species: ....

Country' ....

Province: .... District: ....

Lat: .... Long- .... Elev. ....

Topography: Flat/hilly

Slope: steep/medium/gentle

Soil: Deep/shallow/intermediate

Drainage: ....

....

Stoniness: ....

Texture: ....

....

pH: Acid/neutral/alkaline

Sketchaw

Rainfall: **Mean annual** .... **mm; Wet** months: .... **Dry months:** ....

Temperature: **Mean annual:** .... °C; **Mean max:** .... **C;** **Mean min-** .... °C

Frost: .... **days/year**

Stand: **Natural: Groups/open** **Thin/dense**

Toung/middle—aged/old

Plantation: Age .... years........................**Height** **m......Diem** .... **cm**

Original source: ....

Associated species: ....

Form: **Boles:** **Single/multiple** **Straight/fair/poor**

Crowns: Flat/narrow/average/wide

Seed crop: **Light/medium/heavy**

Seed collection: **No. of trees** .... **kan. distance apart:** .... ***m; Kg:*** ....

Remarks: ....

....

....

Date of collection: ....

....
Officer in Charge

Figure 17. —*Seed collection report form used in the FAO Project on Genetic Resources of Arid/Semi-arid Species (Willan 1988) [no equivalent figure in Student Outline].*

ca
rn

CSIRO Division of Forest Research
PO Box 4008
Canberra ACT 2600

SEED DATA SHEET

Species: Seedlot No.

Collection locality:

Latitude: ° ,S Longitude: o ,E Altitude:(m) Aspect Slope

Climatic zone: Met. Station:

Association includes:

Geology and Soil: pH:

Collection no.	Bot. spec.	Photo. no.	Ht (m)	dbh (cm)	Tree description	Seed wt (9)	No. of viable seed /10 g

Work supervised by: Date:

Figure 18. —*Seed data sheet used by CSIRO (Willan 1985) [no equivalent figure in Student Outline].*

problems that invariably arise in the field. Overly restrictive schedules may lead to loss of accuracy and attention to detail, and to lower worker morale.

5 **Organize equipment permits and transportation**

a. Team leaders must specify at an early stage what equipment is to be used if long delays in purchase or delivery are anticipated.

b. Identify applicable government regulations. Most countries have regulations governing collection, export, introduction, and, perhaps, movement of seeds. Official permits may be required for any of these procedures, and, in some cases, separate permits are needed for each collection site and for each individual seedlot exported or introduced. Customs officials and plant health authorities may seriously delay the operation or even destroy seeds if the full entry procedures are not followed. For some seeds, extra delays of even a few days in transmission can be fatal.

c. Use care between the collection of the seeds and their arrival in the seed laboratories. This period is critical to their viability and vigor. Transportation must be where it is wanted when it is needed; thus, prior organization is essential to minimize transit time.

G. Collection Equipment —A Comprehensive List

:le following items are necessary for collection operations:

Administrative items:

a. Movement approvals
b. Collection authorities
c. Radio transmission permits
d. Drivers' licenses
e. Firearm permits
f. Facilities for purchasing stores; e.g., gasoline (petrol) and oil

2. **Literature:**

a. Road, topographic, and soil maps to cover the collection route itinerary
b. Literature on the genera and species to be collected

1. **Collection equipment:**

a. Notebooks, recording forms, pens, and pencils
b. Binoculars
c. Markers; e.g., colored plastic ribbon
d. Camera and accessories
e. Tree-measuring instruments; e.g., diameter tape, height-measuring instrument, and length tape
f. Soil sampler, pH testing kit, and soil charts
g. Compass
h. Altimeter
i. Hand lens
j. Large collecting sheets; e.g., 4 by 4 m of heavy duty plastic or canvas
k. Small collecting sheets; e.g., 2 by 2 m of calico or other finely woven cloth
l. Seed bags made of finely woven cloth of various sizes; e.g., 100 by 100 cm to 10 by 20 cm for small seed samples, all with ties
m. Large grain bags for dispatching seeds
n. Cutting equipment; e.g., secateurs, long-handle pruning saws, shears, ladders, chain saws with fuel and accessories, bowsaws, flexible saws, throwing ropes, axes, rifles with ammunition, and rakes
o. Safety gear; e.g., steel-capped boots, leather gloves, safety helmets, and safety belts
P. Weatherproof tags for labeling each seedlot, to prevent the markings from becoming illegible when wet or abraded
q. Tags for botanical specimens; e.g., white cardboard "jewelers" tags
r. Plant presses for botanical specimens
s. Papers to dry specimens in the plant presses
t. Plastic bags
u. Specimen bottles with preservative fluid
v. Containers for soil samples
w. String

H. Sources

For additional information, see Barner and Olesen 1984; Bramlett and others 1977; Doran and others 1983; Ontario Ministry of Natural Resources 1983; Willan 1985, chaps. 3, 4, 5 + appendices 1, 5, 6.

IV. Maturity

A. Introduction

Choosing good stands and trees for seed collection means nothing if fruit or seed maturity cannot be easily identified on the trees by unskilled workers. If seeds are disseminated immediately at maturity, workers must know how much in advance of maturity seeds can be collected without collecting seeds that will not germinate. If predators inflict large losses on mature seed crops, a similar problem exists. Good maturity indices are often the keys to successful collection.

problems that invariably arise in the field. Overly restrictive schedules may lead to loss of accuracy and attention to detail, and to lower worker morale.

5. **Organize equipment permits and transportation**
   a. Team leaders must specify at an early stage what equipment is to be used if long delays in purchase or delivery are anticipated.
   b. Identify applicable government regulations. Most countries have regulations governing collection, export, introduction, and, perhaps, movement of seeds. Official permits may be required for any of these procedures, and, in some cases, separate permits are needed for each collection site and for each individual seedlot exported or introduced. Customs officials and plant health authorities may seriously delay the operation or even destroy seeds if the full entry procedures are not followed. For some seeds, extra delays of even a few days in transmission can be fatal.
   c. Use care between the collection of the seeds and their arrival in the seed laboratories. This period is critical to their viability and vigor. Transportation must be where it is wanted when it is needed; thus, prior organization is essential to minimize transit time.

G. Collection Equipment —A Comprehensive List
The following items are necessary for collection operations:

1. **Administrative items:**
   a. Movement approvals
   b. Collection authorities
   c. Radio transmission permits
   d. Drivers' licenses
   e. Firearm permits
   f. Facilities for purchasing stores; e.g., gasoline (petrol) and oil
2. **Literature:**
   a. Road, topographic, and soil maps to cover the collection route itinerary
   b. Literature on the genera and species to be collected
3. **Collection equipment:**
   a. Notebooks, recording forms, pens, and pencils
   b. Binoculars
   c. Markers; e.g., colored plastic ribbon
   d. Camera and accessories
   e. Tree-measuring instruments; e.g., diameter tape, height-measuring instrument, and length tape
   f. Soil sampler, pH testing kit, and soil charts
   g. Compass
   h. Altimeter
   i. Hand lens
   j. Large collecting sheets; e.g., 4 by 4 m of heavy duty plastic or canvas
   k. Small collecting sheets; e.g., 2 by 2 m of calico or other finely woven cloth
   l. Seed bags made of finely woven cloth of various sizes; e.g., 100 by 100 cm to 10 by 20 cm for small seed samples, all with ties
   m. Large grain bags for dispatching seeds
   n. Cutting equipment; e.g., secateurs, long-handle pruning saws, shears, ladders, chain saws with fuel and accessories, bowsaws, flexible saws, throwing ropes, axes, rifles with ammunition, and rakes
   o. Safety gear; e.g., steel-capped boots, leather gloves, safety helmets, and safety belts
   p. Weatherproof tags for labeling each seedlot, to prevent the markings from becoming illegible when wet or abraded
   q. Tags for botanical specimens; e.g., white cardboard "jewelers" tags
   r. Plant presses for botanical specimens
   s. Papers to dry specimens in the plant presses
   t. Plastic bags
   u. Specimen bottles with preservative fluid
   v. Containers for soil samples
   w. String

H. Sources
For additional information, see Barner and Olesen 1984; Bramlett and others 1977; Doran and others 1983; Ontario Ministry of Natural Resources 1983; Willan 1985, chaps. 3, 4, 5 + appendices 1, 5, 6.

IV. Maturity

A. Introduction
Choosing good stands and trees for seed collection means nothing if fruit or seed maturity cannot be easily identified on the trees by unskilled workers. If seeds are disseminated immediately at maturity, workers must know how much in advance of maturity seeds can be collected without collecting seeds that will not germinate. If predators inflict large losses on mature seed crops, a similar problem exists. Good maturity indices are often the keys to successful collection.

B. Objectives

1. Learn the common indices of maturity employed in tree seed collections.
2. Recognize how these techniques can be adapted for new species.

C. Key Points

The following points are essential to recognizing seed maturity:

1. Seed moisture content is very important, but direct measurement in the field is impractical; indirect estimates may be substituted.
2. Color changes are the most common indices.
3. Chemical indices are possible but impractical.
4. Artificial maturation of immature seeds is an option for some species.

D. Successful Collection

The following points are essential to successful collection:

1. **Biological ideal—to** collect seeds at the peak of their physiological maturity; however, this ideal is not possible for large-scale collections. First, physiological maturity, maximum food reserves, minimum moisture content, and ideal regulator balance must be defined. For example, ideal regulator balance is expected at abscission/dispersal, but it may not occur then.
2. **Practical collection—In** most collection operations, fruits and seeds are:
   a. Collected from the ground after dissemination (good for large seeds only).
   b. Collected from logging operations.
   c. Collected from standing trees as close to full maturity as possible before dissemination.
   d. Collected from standing trees well in advance of maturity and ripen artificially.
   e. Both c and d require climbing and/or the use of special equipment.

E. Collection after Dissemination

Seeds that can be collected after dissemination are primarily large, single-seeded fruits; e.g., those of *Quercus, Carya, Juglans,* and *Aesculus* (temperate), and dipterocarps, and other large seeds (tropical). However, the first seeds to fall are usually bad because of insect damage or an immature embryo. Workers must quickly collect the seeds before animals destroy them, especially in the Tropics.

F. Other Collection Strategies

Other collection strategies involve collection of seeds before dissemination. These collections would usually be from standing trees, although collection from logging slash would fall into this category also. These strategies depend greatly on the ability to judge seed maturity.

G. Maturity Indices

Maturity indices include physical and chemical characteristics. They are needed for all collection strategies.

1. **Physical characteristics**
   a. Color changes from green to yellow to brown or black (e.g., *Pterocarpus);* from green to red to purple or black (e.g., *Prunus);* from green to yellow; from green to yellow to purple (e.g., *Gleditsia triacanthos);* and from green to brown (e.g., conifers)
   b. Moisture content
      (1) There are three moisture trends during ripening:
         (a) In dry, orthodox seeds and fruits, moisture decreases slowly as seeds mature (fig. 19) [no equivalent figure in Student Outline].
         (b) In pulpy, orthodox fruits, moisture decreases at first, then increases mainly in the pulp (fig. 20) [no equivalent figure in Student Outline].
         (c) In recalcitrant seeds, moisture increases early, then slightly decreases (fig. 21) [no equivalent figure in Student Outline].
      (2) Moisture content is related to protein synthesis (see Rosenberg and Rinne [1986]). Seed moisture must drop below 60 percent to trigger protein synthesis. Without this happening, seedling growth is arrested. This may be true for all orthodox seeds. Ellis and others (1987) found a critical level of 45 to 50 percent moisture for six grain legumes.
      (3) Moisture content can be measured directly by oven methods; that is, cut cones, large fruits, or seeds; weigh; dry for 17 hours at 103 °C; and then weigh again.
      (4) Specific gravity is usually discussed separately, but it really is just an estimate of moisture content. Specific gravity has been measured in:
         (a) Conifers — See table 7 [table 4 in Student Outline] and fig. 22 [figure 7 in Student Outline].
         (b) *Quercus* data from Russian sources found significant changes in specific gravity in

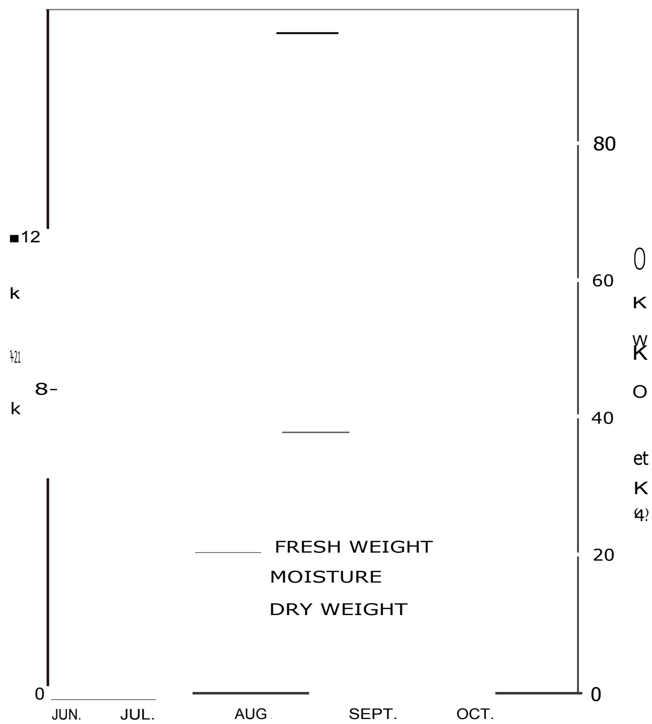


Figure 19. —*Seasonal changes in fresh weight, dry weight, and moisture content during maturation of fruits of* Platanus occidentalis *(adapted from Bonner 1972a) [no equivalent figure in Student Outline].*

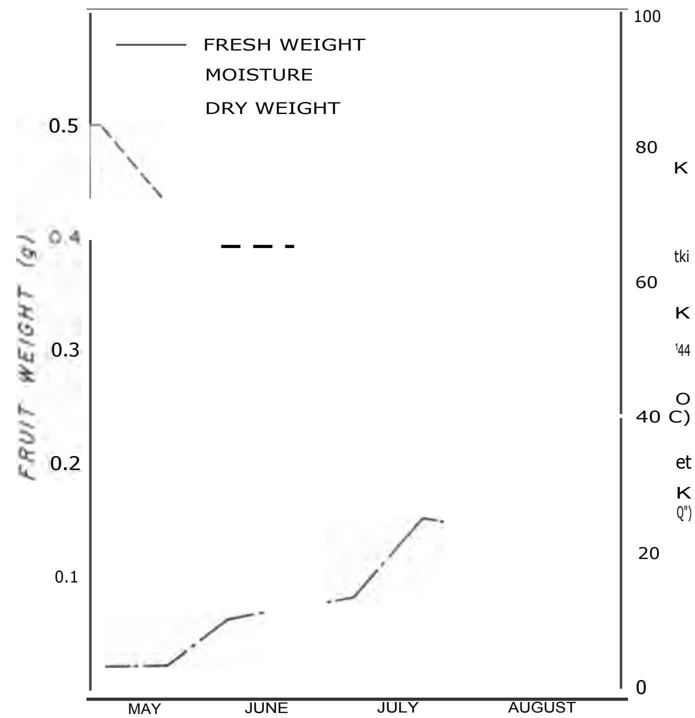


Figure 20. — *Seasonal changes in fresh weight, dry weight, and moisture content during maturation of* Prunus serotina *(adapted from Bonner 1975) [no equivalent figure in Student Outline].*

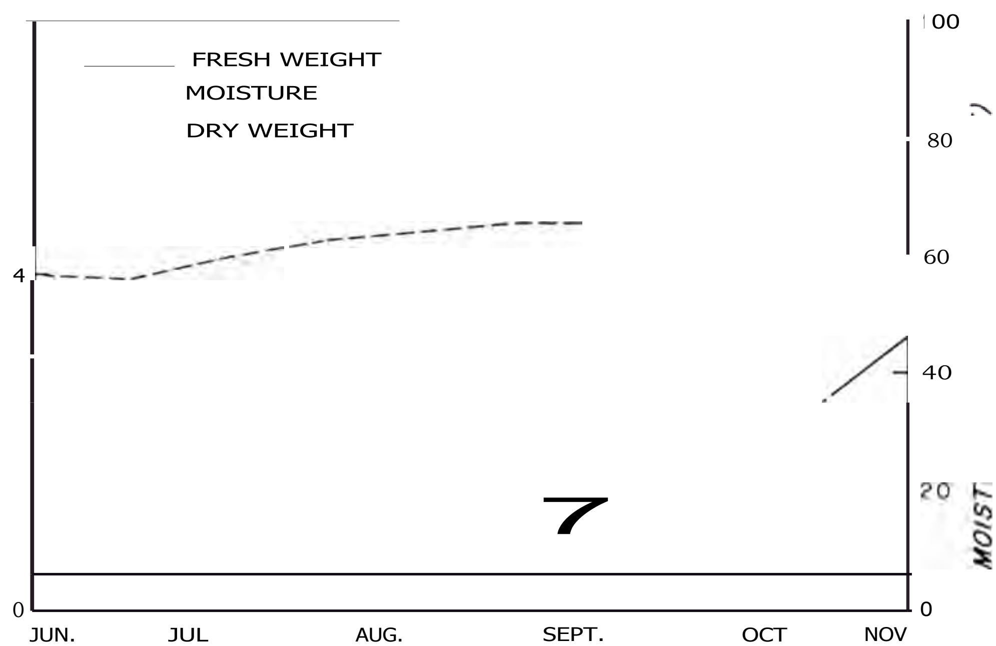


Figure 21. — *Seasonal changes in fresh weight, dry weight, and moisture content during maturation of* Quercus alba *(adapted from Bonner 1976) [no equivalent figure in Student Outline].*

Table 7. —*Cone specific gravity values that indicate seed maturity in some conifers [Table 4 in Student Outline]*

Species	Specific gravity	Reference
Abies grandis	0.90	Pfister 1967
Cunninghamia lanceolata	0.95	Jian and Peipei 1988
Pinus elliottii	0.95	Barnett 1976
P. merkusii	1.00	Daryono and others 1979
P. palustris	0.90	Barnett 1976
P. strobus	0.90	Bonner 1986a
P. taeda	0.90	Barnett 1976
P. virginiana	1.00	Fenton and Sucoff 1965

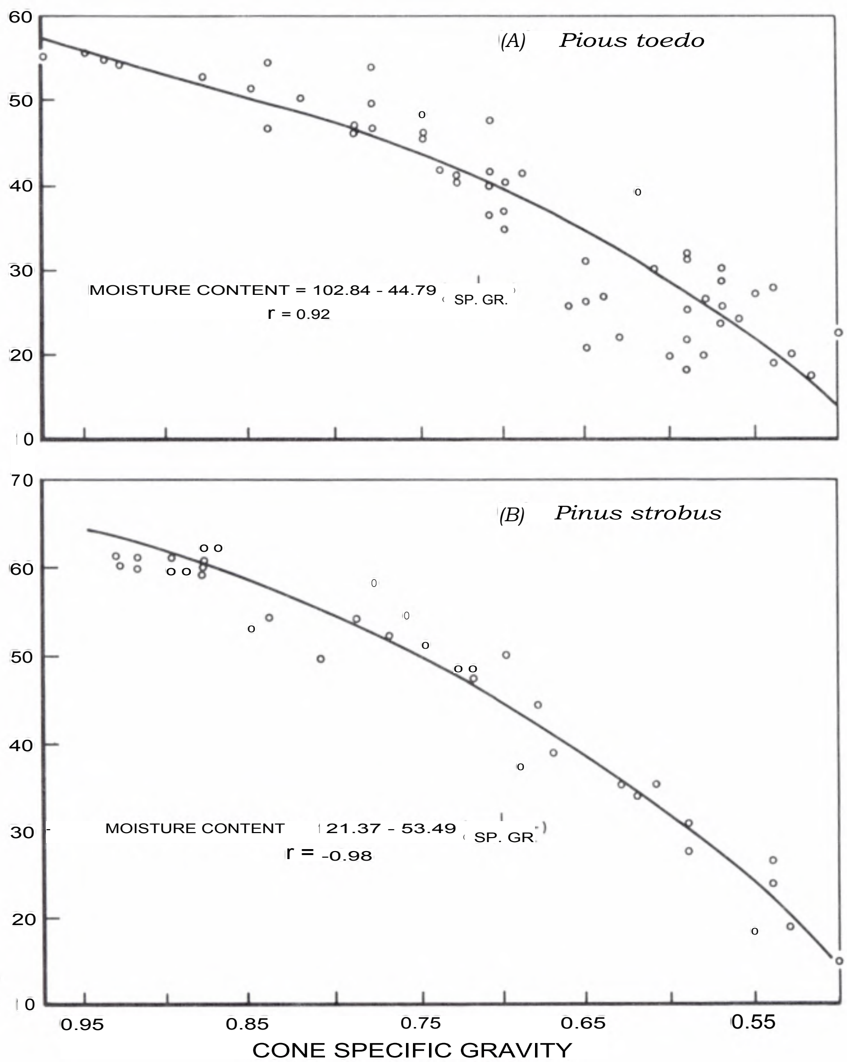


Figure 22. — *The relationship of moisture content to specific gravity for cones of* Pinus taeda *and* P. strobus *(Bonner 1991b) [figure 7 in Student Outline].*

acorns of some *Quercus* species as they matured, but results with North American species have been inconsistent.

(c) Other angiosperms — there is usually a flat line over maturation period (little success).

(d) Barnett (1979) developed a simple procedure for determining specific gravity using water flotation that is easy to perform (fig. 23) [figure 8 in Student Outline].

c. Other physical indices:

(1) Acorn cup release in *Quercus* is good; easy release signifies maturity.

(2) If bending *Pinus strobus* cones causes scales to "open," they are mature.

(3) When the white, brittle embryo in *Fraxinus* (and some other genera) is excised and bent, mature embryos will break.

(4) A minimum percentage of the embryo cavity must be filled; 75 percent is a general guideline for *Fraxinus excelsior* and *Pinus sylvestris* in northern Europe.

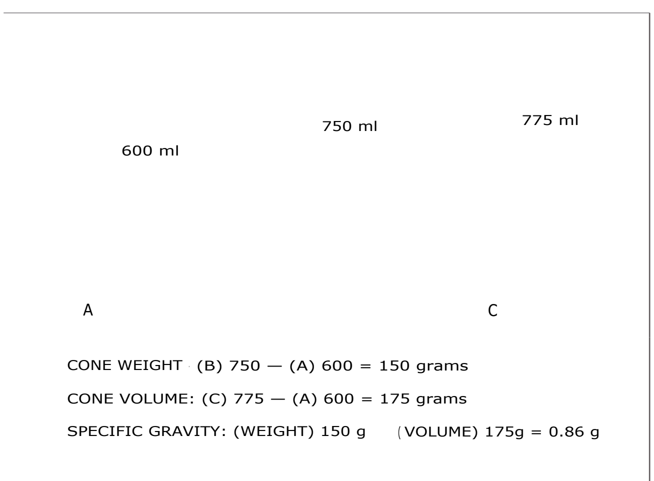


Figure 23.—*A simple technique for determining specific gravity of pine cones in the field using a graduated cylinder. (A) Fill the cylinder with water to the 600 mL mark. (B) Float the cone in the water and record the water level. (C) Using a pin or needle, submerge the cone enough to completely cover the cone with water, but no more. Record the new water level (adapted from Barnett 1979) [figure 8 in Student Outline].*

2. **Chemical characteristics**

Chemical indices are biologically sound but are not practical, even in sophisticated collection situations.

a. Accumulation of storage foods can indicate full maturity.

(1) Angiosperms of the Southern United States: *Liquidambar styraciflua,* 25 percent crude fat; *Fraxinus pennsylvanica,* 10 percent fat and 14 percent insoluble carbohydrates; *Quercus* spp. (red oaks), 20 percent fat and 25 percent insoluble carbohydrates; *Quercus alba* (white oak), 40 percent insoluble carbohydrates (figs. 24 through 27) [no equivalent figures in Student Outline].

(2) Western conifers: *Abies procera,* 25 percent crude fat; *Pseudotsuga menziesii,* 23 percent crude fat or 1.3 percent reducing sugars.

b. Elemental analyses of calcium, magnesium, and phosphorus have shown some good relationships in angiosperms of the Southern United States. Relative amounts will decrease in acorns and increase in small seeds; absolute amounts increase in all seeds as they mature (fig. 28) [no equivalent figure in Student Outline].

c. Growth substances. In Poland, auxins decrease in maturing *Quercus robur* according to Michalski (1969).

(1) Predicting *Picea abies* germination **by** level of indoleacetic acid (IAA) has even been proposed by several European workers.

(2) Gibberellin changes have been followed, and levels usually increase with maturation.

H. Artificial Maturation

Artificial maturation is an option for some situations. Immature seeds can be artificially ripened by storing them in cool, moist conditions. Krugman (1966) (Western United States) and Lantz (1979) (Southern United States) successfully used artificial maturation with *Pinus* spp. Bonner (1972c) (Southern United States) was successful with *Liquidambar styraciflua* and *Liriodendron tulipifera* but not with species of *Fraxinus* or *Quercus.*

1. **Single-seed versus multiple-seed fruits**

Single-seed fruits are cut off from all nutrition when picked, but multiple-seed fruits

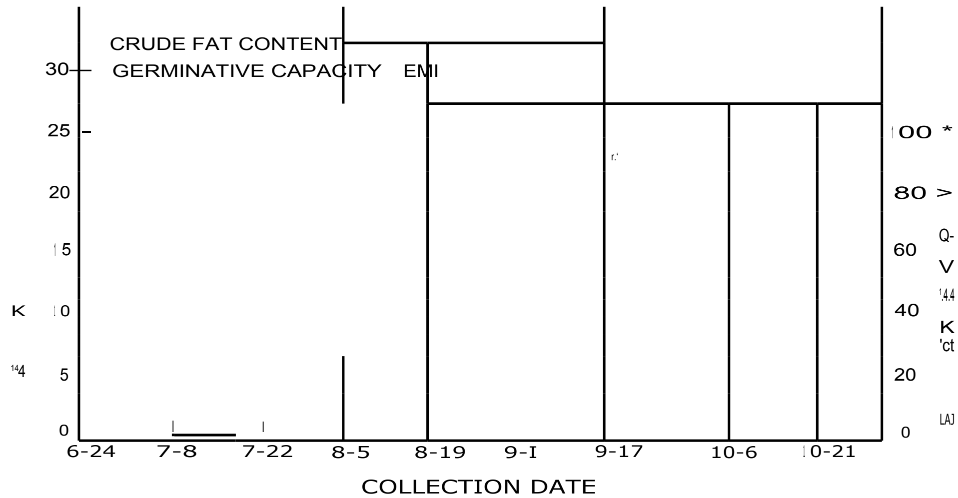


Figure 24. — *The relationship of crude fat content and germination in maturing seeds of* Liquidambar styraciflua *(Bonner 1972a) [no equivalent figure in Student Outline].*

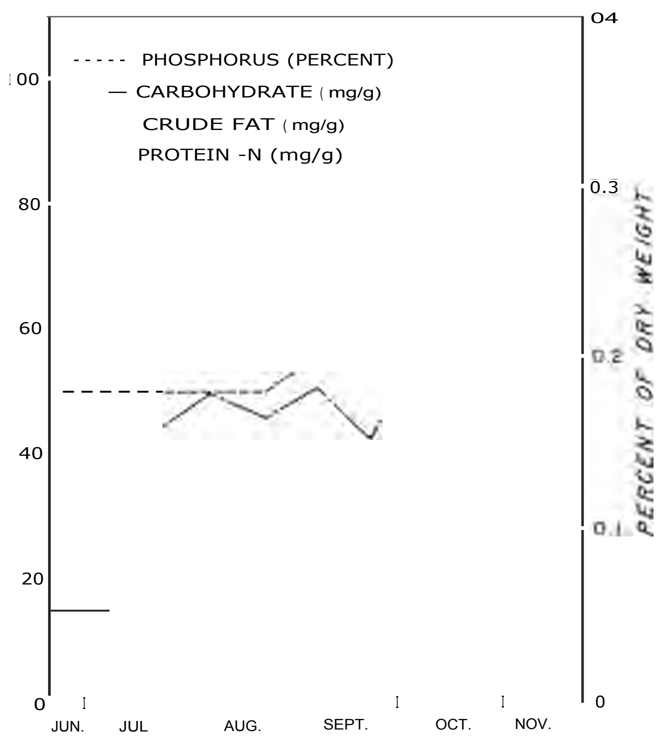


Figure 25. —*Seasonal changes in phosphorus, soluble carbohydrates, protein-nitrogen, and crude fat in samaras of* Fraxinus pennsylvanica *(adapted from Bonner 1973) [no equivalent figure in Student Outline].*

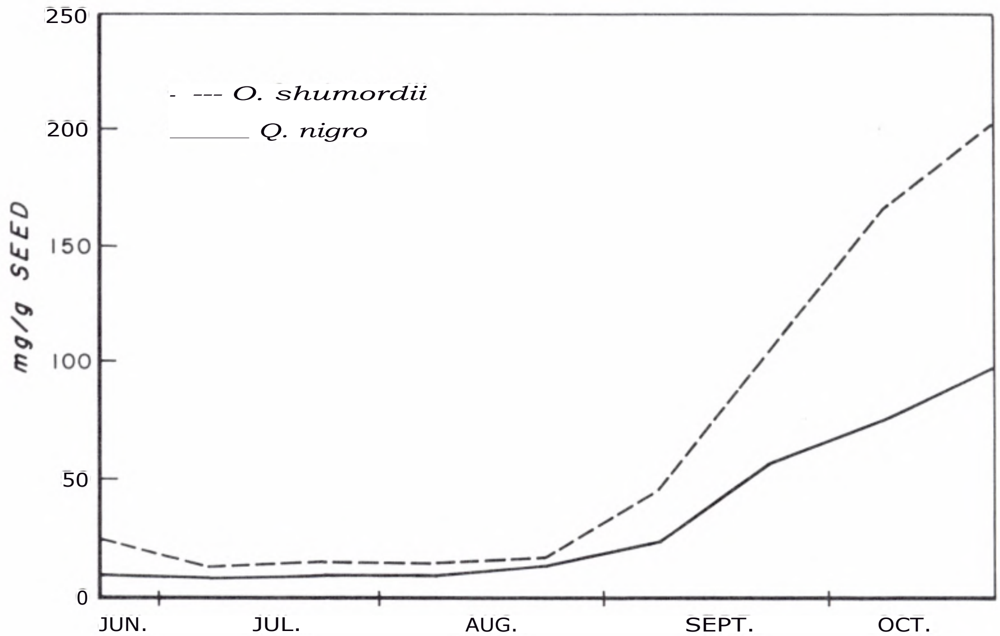


Figure *26.— Seasonal changes in crude fat content of fruits of* Quercus nigra *and* Q. shumardii *(adapted from Bonner 1974b, 1976) [no equivalent figure in Student Outline].*

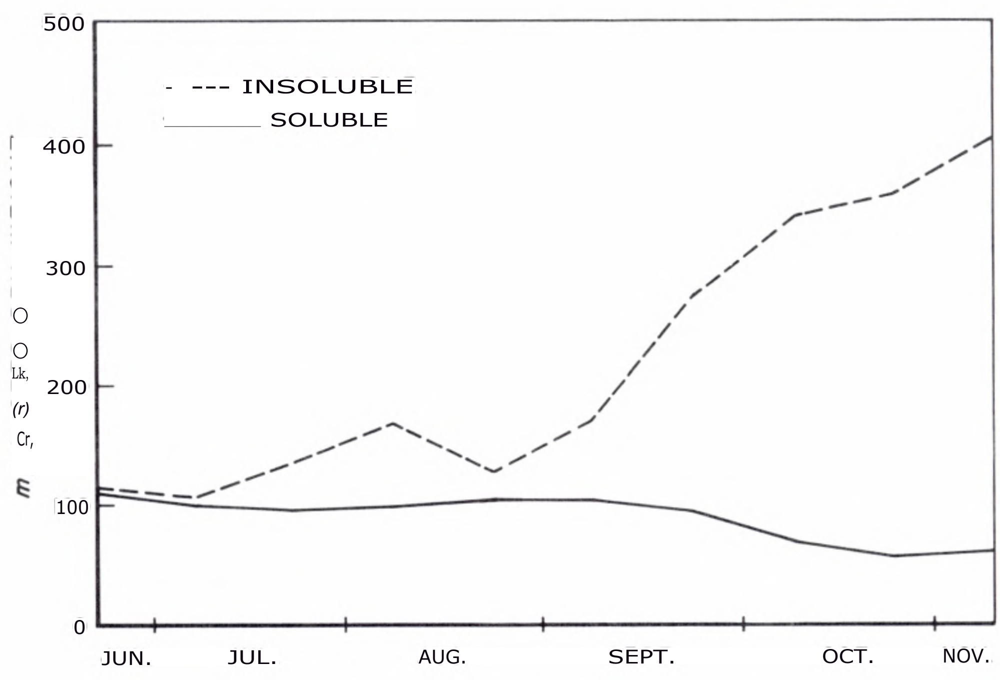


Figure 27. *— Seasonal changes in insoluble and soluble carbohydrates in fruits of* Quercus alba *(Bonner 1976) [no equivalent figure in Student Outline].*

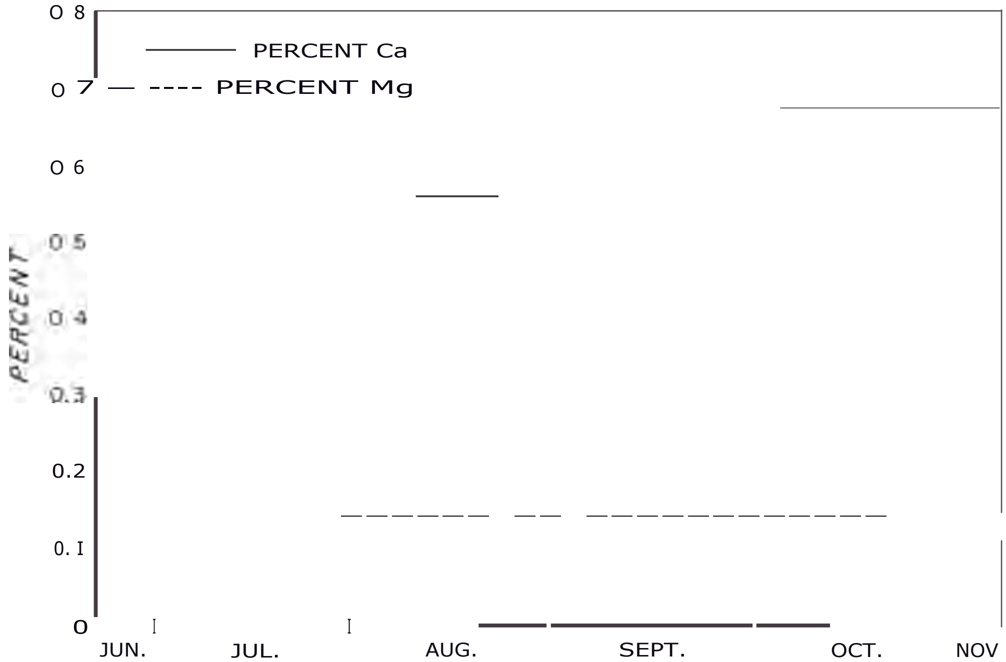


Figure 28.— Seasonal changes in calcium and magnesium in samaras of Fraxinus pennsylvanica *(adapted from Bonner 1973) [no equivalent figure in Student Outline].*

can obtain some nutrition or growth factors from cone or fruit tissues to complete maturation.

2. **Avoiding dormancy**
   a. *Tilia americana* —This species can be picked before full maturity when the seedcoat is not completely dried.
   b. *Acacia* spp. — Early collections were reported by Doran and others (1983).
   c. *Gleditsia triacanthos — Early* collection also works with this legume; the pod is picked while it still shows some yellow. Hard-seeded dormancy is not so strong, but resistance to disease is low.
3. **Usefulness—** Artificial maturation is useful when collecting on remote or expensive sites. However, seed yield and quality usually suffer. In one case, *Liquidambar styraciflua* yield was 20 percent lower than with natural maturation; germination was equal to that of seeds from later collections.

I. Delayed Collections

For certain species, there is no rush to collect the fruits; they do not disperse their seeds right away (orthodox seeds only).

1. **Serotinous cones *(Pinus* and *Picea)* —** Resins prevent cones from opening until they melt in wildfires. In cool climates, seeds can remain viable for several years in the cones.
2. **Delay in abscission** —*Platanus* spp. are good examples of a fruit that stays intact on the tree for several months past maturity without decreasing seed quality.

J. Sources

For additional information, see Bonner 1972a, 1972c, 1976; Nautiyal and Purohit 1985; Rediske 1961; Willan 1985, p. 33-38.

V. Postharvest Care

A. Introduction

The time between collection and extraction is often overlooked as a crucial segment of seed acquisition. Fruits and seeds, often high in moisture content, must be stored and/or transported for extraction and cleaning. Special care must be taken during this period to avoid loss of seed quality, especially in tropical and subtropical areas where transportation systems do not allow immediate delivery to extraction centers.

B. Objectives

1. Recognize the crucial times when seed quality may be lost.
2. Plan storage and transportation systems to minimize the danger to seed quality.

C. Key Points

The following points are essential to postharvest care:

1. High moisture contents and high temperatures are dangerous for orthodox species.
2. High moisture levels must be maintained in recalcitrant seeds, but excessive heat is a problem with these seeds.
3. Fruit storage can be advantageous for some species because of the afterripening processes that occur in the seeds.

D. Storage Before Extraction

1. **Operation schedules** — Time does not permit seeds from all trees or families to be collected at peak maturity; therefore, some must be picked and stored. Extractories could not handle them all at once, anyway, at least for pines in the United States.
2. **Predrying—** When artificial heat can be used, drying during storage can remove much of the moisture and thus lower drying costs. In pines of the Southern United States, two-thirds of the moisture removal required for cone opening can be done in predrying storage. Moisture should decrease from about 70 to 30 percent.
3. **Completion of maturation—Completion** of maturation is an often overlooked benefit, but it is just as important as predrying.
   a. *Abies is* a well-known example; 5 or 6 months in cool, moist conditions complete maturation. In natural habitats, seeds mature as cones disintegrate. *Picea glauca* in Canada needs 6 weeks of storage in the cone to achieve the best germination.
   b. New data show similar benefits to seed quality from storage before extraction for some pines of the Southern United States.
   c. Premature collection is suitable for some multiseed angiosperms; e.g., *Liquidambar styraciflua, Liriodendron tulipifera,* and *Platanus occidentalis.* This is done to lengthen collection season or, in northern climates (Scandinavia and Russia), to complete ripening in conifers in short growing seasons. It is usually not recommended in the United States because yield per cone and seed quality generally suffer.

E. Southern Pines

1. **Storage** is usually related to operation schedules.
2. **Outdoor storage** is better than indoor storage because:
   a. Drying is faster outdoors.
   b. Cones open better when wet/dry/wet/dry cycles occur.
3. **Containers**
   a. Containers must provide air circulation.
   b. Loose-weave burlap bags (about one-third hectoliter) and 7-hectoliter, wooden crates are effective.
      (1) Burlap bags of *Pinus taeda* cones left in the seed orchard in the shade did well in one study, providing an extra 5 weeks of collection time. Shaded concentration points were no better than sunny ones.
      (2) Temperature profiles of the 7-hectoliter crate show no overheating in the middle.
   c. Plastic bags or sacks should not be used.
   d. Paper sacks are effective for small lots if their tops are left open.
4. **Time**
   a. Cone storage can improve germination rate.
   b. Maximum length of storage depends on the species:
      (1) 4 weeks for *Pinus elliottii*
      (2) 5 to 7 weeks for *P. taeda*
      (3) 3 weeks for *P. palustris*
      (4) 5 to 7 days for *P. strobus* in the Southern United States
      (5) 7 to 9 weeks for *P. strobus* in Ontario
5. **Other factors**
   a. Original maturity—More mature cones may have shorter optimum storage periods (very important), although this cannot be quantified as yet.
   b. Local conditions (weather, equipment, etc.) are also important; warm, rainy conditions increase the risk of cone molds.
6. **Immaturity/Dormancy**
   a. Seed ripening in cones increases germination rate and thus decreases dormancy.
   b. Past a certain point, cone storage will decrease germination — first, germination rate, then total germination. This point cannot be accurately defined as yet.
7. **Heat and Molds**
   a. Green cones can generate enough heat to char cones black.
   b. External molds are common in 7-hectoliter crates, but studies have found no evidence of damage to seed quality. *Pinus echinata* data from Pollock, Louisiana, and *Abies alba* from Yugoslavia demonstrated better germination in seeds from moldy cones.

c. Good aeration is essential to prevent mold growth on cones during drying.

F. Serotinous Cones

1. Storage is not a major problem for *Pinus glauca, P. contorta,* or *R patula.*
2. **Maturity —** Some pine seeds need to stay in the cone because 3 years may be needed to reach maturity *(Pinus torreyana* in the Western United States).
3. **Viability—Seeds** can retain viability for several years in cones, but seed quality may be reduced. However, Canadian workers found that seeds from 10-year-old *P contorta* cones in Canada can be very good.

G. Other Conifers

1. ***Abies*** (true firs) — Seeds of true firs must complete ripening in the cones. They should be stored in burlap bags in sheds with plenty of aeration around the bags for weeks to 6 months, depending on the species.
2. ***Picea*** (spruce) — Seeds of most spruce species should be extracted as early after collections as possible. Winston and Haddon (1981) in Canada found that 4 weeks of cone storage at 5 °C of *P. glauca* were enough, but Wang' reported that 6 weeks were needed. These seeds had excellent germination and no dormancy; no stratification was needed. Immature *R rubens* cones can be stored for several weeks, then the seeds are "teased" out with wet/dry cycles.
3. ***Pseudotsuga — Extended*** storage of 3 to 4 months is possible in dry, well-ventilated conditions. Too much moisture leads to pathogen problems. Some artificial ripening is possible.
4. **Tropical pines**
   a. Treatment of tropical pines is similar to that for Southern United States pines, but the tropical environment is more stressful. Cones should be stored under a roof or cover with good ventilation, and temperature should be kept between 20 and 35 °C.
   b. Rodents and fungi can be big problems, so special efforts should be made to protect the seeds.
   c. In Honduras, *Pinus caribaea* is precured until all of the cone changes from green to brown.
   d. In New Zealand, immature cones of *R radiata* are stored for 10 weeks at 20 to 24 °C to complete ripening and to fit the planting schedule (Willan 1985).
   e. In Indonesia, green and green/brown cones of *P. merkusii* had improved opening, yield, and seed quality when stored for 2 to 4 weeks before extraction (Arisman and Powell 1986).

H. Hardwoods

1. **Artificial ripening—Many** hardwoods of the Southern United States respond to artificial ripening of immature fruits; *Liguidambar styraciflua* can be collected 4 weeks early; *Liriodendron tulipifera* can be collected 4 to 6 weeks early. However, seed yields and quality will suffer. This effort has not been as successful in pines.
2. **Regular storage—The** above species should be stored in loose-weave bags and for as short a period as possible. They should be spread one or two fruits deep for drying and stirred two or three times daily to avoid overheating. Other orthodox species include:
   a. *Eucalyptus — Tight-weave* cloth or plastic can be used, but overheating is a danger with plastic; use with caution.
   b. *Legumes* —Storage is not difficult, but overheating is possible if moisture is high; they should be spread to dry.
   c. *Drupes — Short* storage to complete ripening is possible for some species, but they should be spread in a single layer and shaded, preferably indoors. As soon as the color changes, they should be cleaned. For *Prunus* species drupes should be cleaned within 3 days of collection.

I. Summary

Seeds of most species fit into one of three groups:

1. **Harvest dry, keep dry—Usually** start fruits drying immediately and keep dry after extraction (e.g., *Pinus, Liquidambar, Liriodendron, Acacia,* and *Eucalyptus).*
   a. Dry slowly.
   b. Provide good aeration; do not use plastic bags.
   c. Use suitable containers, including:
      (1) Burlap bags
      (2) Racks
      (3) Wooden crates
      (4) Canvas or plastic sheets
2. **Harvest moist, then dry—Keep** moist when collecting and during extraction to avoid formation of tough, impermeable

---

'Wang, B.S.P. 1985. Personal communication with the author. On file with: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, Starkville, MS 39759.

covers (drupes); extract, then dry seeds for storage (e.g., *Nyssa* and *Prunus)*.

a. Spread to avoid heat and (in most cases) fermentation.
b. Use trays or bags; do not use plastic.
c. Avoid outer coat toughness.
d. Extract, wash, and dry for storage.

3. Moist forever — Recalcitrant seeds are kept moist forever because drying will decrease quality; seeds are not stored when collected, but are extracted immediately e.g., *Quercus, Aesculus, Shorea,* and *Hopea.*

a. Never dry.
b. Keep moisture 30 percent.
c. Refrigerate to a safe temperature:
   (1) 1 to 3 °C for temperate recalcitrants (e.g., *Quercus)*.
   (2) 15 to 20 °C for tropical recalcitrants.
d. Use polyethylene-lined containers or polyethylene bags 4 to 10 mil thick.

J. Sources

For additional information, see Bonner 1987a; Willan 1985, p. 78-86.