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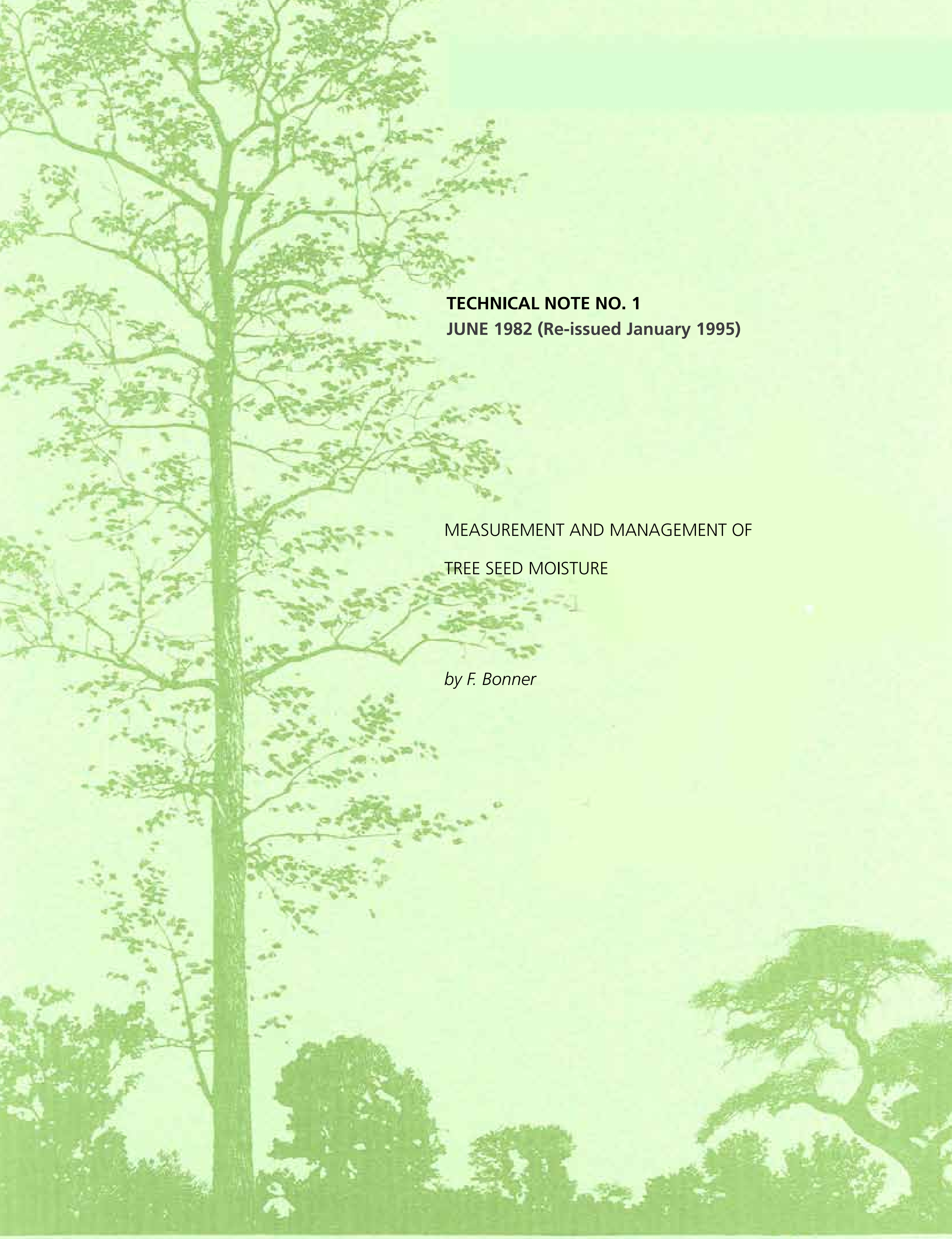

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MEASUREMENT AND MANAGEMENT OF TREE SEED MOISTURE

by F. Bonner

DANIDA FOREST SEED CENTRE

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Contents

SUMMARY

There are two kinds of tests for routine measurements of tree seed moisture, (1) accurate measurement (such as official International Seed Testing Association tests) and (2) rapid estimates. For small seeds (more than 30,0O0/kg) such as pine, fir, spruce, sweetgum, birch, or cherry, the suggested accurate test consists of weighing 4- to 5-g samples, oven-drying them at 103 ± 2°C for 17 ± 1 hr weighing again, and calculating the difference as percentage of moisture. For non-destructive, rapid estimates with small seeds, use an electric meter for measuring 80- to 200-g samples (depending on the make of meter). Large seeds (less than 30,000/kg) such as oaks, walnut, beech, or hickories must first be ground, cut, or broken and sample weights should be equivalent to the weight of five seeds. Then accurate measurement can be made by the same oven-drying techniques as for small seeds and rapid estimates can be made by weighing, microwave oven-drying, and weighing again.

This note was originally sent out as Research Paper SO-177 in November 1981 by USDA Forest Service, Southern Forest Experiment Station, New Orleans, Louisiana.

1. INTRODUCTION

All those who handle tree seeds (nurserymen, seed orchard managers, commercial seed dealers, or others) should be vitally interested in the moisture conditions of the seed stocks that they manage. The levels of seed moisture can influence or indicate (1) seed maturity, (2) longevity in storage, or (3) the amount of pretreatment needed. Seed moisture is the most important factor affecting the retention of viability in storage.

For »orthodox« seeds (seeds that can be stored at low moisture content, such as pines or sweetgum) experience has provided some general guidelines for potential damage in storage (table 1).

These guidelines do not apply to seeds that must be stored at high moisture levels to retain viability, commonly called "recalcitrant" seeds. The most common recalcitrant seeds in the United States are oaks.

Seed moisture should be measured (1) when seeds are cleaned and ready for storage, (2) 2 or 3 months after the start of storage, (3) every 1 or 2 years of storage (at most), and (4) before and after seed lots are shipped. The three general types of seed moisture measurement are (1) oven-drying/ gravimetric measurement, (2) rapid measurements with dielectric meters or similar devices, and (3) laboratory procedures, such as toluene distillation or Karl Fisher titration (which are used in research only and will not be discussed further).

2. SAMPLING

As in germination testing, the proper drawing of a sample for moisture testing is very important. Accurate measure of a sample's moisture is of little help if the sample is not representative of the seedlot.

2.1 Sampling Equipment

Free-flowing seeds (such as pine or sweetgum) in containers should be sampled with seed triers which are long enough to reach all areas of the containers. The best triers are those with a hollow, slotted brass tube on the inside of a slotted outer shell or sleeve (fig. 1). Several sizes are available, and one must choose a trier large enough in diameter to admit the seeds freely.

Large seeds (such as oak or hickory) and seeds that are not free-flowing should be sampled by thrusting the hand into the seeds and removing small portions. The hand should be inserted flat with fingers extended together, and closed as it is withdrawn. It is difficult to sample deeper than 40 cm with this method, and containers may have to be partially emptied to facilitate sampling.

Table 1. Potential damage at various moisture contents in stored seeds

Seed moisture content	Potential case of damage
Below 5%	lipid autoxidation
5-6%	very little damage-ideal for storage
10-18%	active fungal grown
18% and above	heat from respiration
30% and above	non-dormant seeds germinate

Source: Harrington 1973

2.2 Number of Samples

Ideally, the sample should be made up of equal portions taken from evenly distributed volumes of the lot. The number of samples should be proportional to the size of the container; if part of a lot is in 40 liter containers and part in 80 liter containers, twice as many portions should be taken from the 80 liter containers as from the 40 liter ones.

The Association of Official Seed Analysts has suggested these sampling guidelines (Association of Official Seed Analysts, 1975).

(1) For lots of one to six containers, sample each container and take a total of at least five cores or hand fulls.
(2) For lots of more than six containers, sample five containers plus at least 10 percent of the number of containers in the lot.

For seeds that have not been mixed recently (such as stored seed stocks), sub-samples should be taken from the top, center, and bottom thirds of the containers and combined. As containers are handled, empty seeds and wings have a tendency to work to the top, and they usually exhibit different moisture characteristics from filled, dewinged seeds.

Figure 1. Sampling seed with a slotted trier.

2.3 Care of Sample

Samples taken from seed in cold storage should be drawn and packaged under storage conditions. Packaged samples can be opened when they reach room temperature (usually around 2 hr). When cold seeds come into contact with warm, moist air, moisture will condense on the seeds, and seed moisture content will increase. The humidity is usually low in air-conditioned offices and laboratories and seed exposure for short periods is less critical there unless the sample moisture content is high.

3. MEASURING SEED MOISTURE

3.1 Oven-drying Techniques

Oven-drying techniques are now the standard techniques for official determinations of seed moisture in seed laboratories. Seeds are heated at prescribed temperatures for prescribed times, and all weight loss is considered to be moisture. Weighing samples before and after drying provides the data for calculation of moisture content.

Pretreatment of Samples: Small seeds (such as pines, sweetgum, or green ash) can be dried intact. Larger seeds (such as acorns, or nuts) must be broken into smaller pieces, so that all internal moisture can be driven off in the oven. A good rule of thumb is that any seeds that average over 10 mm in diameter or length should be broken.

Official international rules (International Seed Testing Association 1976) require the grinding of large seeds so that 50 percent of the ground material can pass a sieve with a mesh size of 4.O mm. But with seeds of high oil content (such as walnut, hickories, or beech) or seeds with high moisture content (such as oaks) grinding is difficult. A satisfactory alternative to grinding is to rapidly cut or break the seeds into small pieces. Acorns can be cut with hand pruning shears (fig. 2). Nuts of hickory and walnut can be put in cloth bags (to prevent the pieces from scattering) and broken with hammers.

Grinding, breaking, or cutting should always be done on a larger sample from which the actual measurement sample (commonly called the »working sample«) can be drawn. For example, a sample of 5 to 10 seeds should be rapidly mixed prior to drawing the working sample, which should equal the weight of 5 seeds. Working samples for small, intact seeds should be 4-5 g.

Spoons or spatulas should be used to handle moisture samples whether intact seeds or cut pieces; handling seeds with fingers can sometimes leave a residue of skin moisture on the seed surface.

Figure 2. Acorns cut into quarters with hand pruning shears.

Drying Equipment: Seeds should be dried in containers of non-corrosive metal or glass that have a flat bottom, rounded sides at the base, and a snug-fitting cover. The sample should be spread evenly on the bottom of the container to allow good air circulation (fig. 3). There should be no more than 0.3 g of seeds per cm2.

Either gravity-convection or mechanical-convection ovens may be used, but preferably the latter. Good insulation and good thermostatic controls are also needed. Most laboratory ovens distributed by scientific supply houses in the United States are sufficient.

Drying Schedules: Seeds of all tree species can be dried at 103 ± 2°C for 17 ± 1 hr. Accurate moisture determinations can be made on some species by drying at 130°C for 4 hr (Bonner 1972), but this has no advantage over the lower temperature unless time is critical. The lower-temperature schedule is normally preferred, because the drying period of 17 ± 1 hr fits an overnight schedule very well; samples put into the oven at the close of a work day will be ready to cool and weigh the following morning. Timing the 17-hr period should not be started until the oven temperature reaches 103°C with the containers inside.

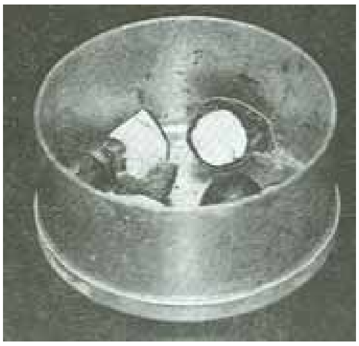

Figure 3. Metal can for drying samples by the oven method.

One potential problem is overcrowding the oven with containers to the point that air movement (and thus moisture removal) is impeded. Space approximately equal to the diameter of the containers should be left open between containers during drying (fig.4).

Cooling: For accurate weighing, the containers and their seed material should be cooled in desiccators for 30-45 min before dry weights are recorded. With rapid-weigh electronic balances in air-conditioned, low-humidity laboratories, this cooling step can be skipped, if necessary, since it takes about 30 s. for hot (103°C) samples to absorb a measurable amount of moisture from the air.

Weighing and Calculations: All weights should be measured to three decimal places. Modern electronic balances are ideal for rapid sample weighing (fig. 5).

Moisture contents should always be expressed as a percentage of the wet weight of the sample. Gravimetric determinations in oven-drying procedures are calculated to one decimal place:

$$\text{percent moisture} = \frac{\text{wet weight - dry weight x 100}}{\text{wet weight}}$$

Tolerance: Duplicate determinations should be made for each seed unit. The arithmetic mean of the duplicate measurements is taken as the moisture content. In official tests (International Seed Testing Association 1976), if the difference between these measurements exceeds 0.2 percent both must be repeated. But for many tree seeds, this tolerance limit is not reasonable; experience has shown that as seed size increases and as seed moisture content increases, natural variability of the test material will make it increasingly difficult to meet the tolerance limit of 0.2 percent. In large seeds (such as hickory or walnut) or in high moisture seeds (such as oaks) the 0.2 percent tolerance may be met only 10 percent of the time. Only with small seeds, such as many pine species or sweetgum, with moisture contents below 10 percent is the 0.2 percent tolerance reasonable. More realistic tolerances for moisture tests are given in table 2.

A step-by-step procedure for oven-drying technique is given in Appendix I.

Table 2. Suggested tolerances for variability in seed moisture tests

Sample condition	**Tolerance (%)**
Small seedsa, moisture < 12%	0.3
Large seedsb, moisture < 12%	0.4
Small seeds, moisture > 12%	0.5
Large seeds, moisture > 12%	0.8
Large seeds, moisture > 25%	2.5

a For example: pines, firs, sweetgum.
b For example: hickories.

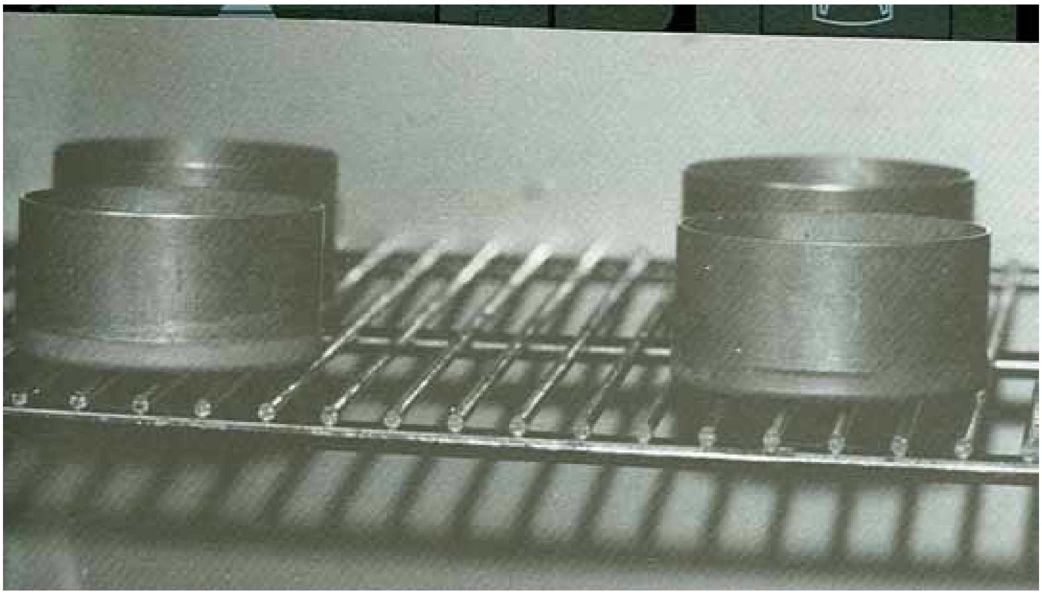

Figure 4. To allow optimum air movement within the oven, leave spaces between containers equal to their diameter.

Figure 5. Modern electronic balances are ideal for rapid sample weighing

3.2 Electric Moisture Meters

In many instances very rapid measurements of seed moisture content are valuable. Electric moisture meters that work on the principle of electrical resistance or capacitance offer such a possibility for non -destructive testing. Meters available in the U.S. were designed for cereal grains, and they will work only on small tree seeds that flow easily and settle uniformly into the narrow measurement chambers (fig. 6). Dewinged pine seeds, sweetgum, sycamore, and depulped black cherry are some of the seeds suited to measurement in electric meters. Acorns are too large, and winged seeds, such as ash or maple, will not settle uniformly.

Most meters will determine moisture contents within 1.0 percent or less of the "true" moisture content determined by oven-drying. This is not accurate enough to be accepted for official testing, but it is certainly good enough for decisions on seed handling.

One drawback is that most meters will not measure moisture above 15-20 percent. Decisions on such matters as suitability of a lot for storage could still be made, but in the case of some moist seed lots, the inability to measure moisture of this level could be damaging. Seed quantity could also be a problem for researchers or tree improvement workers who deal with small lots. Most electric meters require 90-200 g of seeds for a test.

Figure 6. One type of electric seed moisture meter that can be used on some tree seeds

Operation: Electric meters are built to indicate the total amount of moisture in the measurement chamber, so conversion of meter readings to percentages of moisture requires that a constant sample weight be used every time. Samples should be transferred to rapid-weigh balances by spoon or spatula (not with hands), and quickly dumped into the measurement chamber. As in the oven-drying technique, the seeds should be at room temperature.

As soon as the sample is in the measurement chamber, the meter reading should be recorded. This reading is then related to seed moisture content by means of a calibration chart for each species and each make of meter. A step-by-step procedure is outlined in Appendix II.

Calibration Charts: Calibration charts for one meter currently in wide use for tree seeds in the U.S. are found in Appendices III and IV. Charts for other species can be easily prepared from paired measurements of electric meters and oven-drying.

At least 10 lots of the seeds should be used. These lots should weigh at least 0.5 kg each, and they should have different moisture contents. If moisture levels of some samples must be changed by adding moisture, then they should be allowed to equilibrate for 2 wk before measurements are made.

Meter readings are taken on samples of each lot, and subsamples (5-10 g) are drawn from these samples for moisture determination by oven-drying. Sample weight will depend on the make of meter and type of seed, but it must be the same for all samples. The measurement chambers should be full if possible, and always more than half full.

Meter readings can then be plotted against oven-drying data for construction of a curve. More accurate determinations can be made by calculating regression equations.

3.3 Microwave Drying

Large seeds (such as acorns or hickory nuts) will not fit the measurement chambers of electric meters. It is possible, however, to make rapid moisture content estimates for these seeds by drying them in home microwave ovens. The seeds must be cut or broken (just as in oven-drying techniques), weighed, dried, and reweighed (fig.7). Moisture content is calculated just as in oven-drying.

One moisture determination can be made in about 5 or 6 min with a microwave oven. Limited experience with this method has shown large error limits for acorns (6-7 percent) but smaller errors for shagbark hickory (1 percent) and green and white ash (2 percent) (Bonner and Turner 1980). These error limits reflect the variability of the sample material more than inherent errors in the procedure. Without alternatives for the large tree seeds, this method has promise. A step-by-step procedure for the microwave method is found in Appendix V and typical drying times for some species with a particular microwave oven are given in Appendix VI.

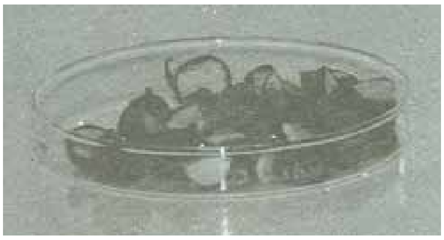

Figure 7: An acorn sample ready for drying in a microwave oven. Note that the dish is in the center of the oven floor.

3.4 Gravimetric Testers

There are a dozen or more automatic or semi-automatic gravimetric testers available commercially. All have a small oven with attached or built-in weighing devices. Heat from electric heating elements or infrared bulbs dries the samples in a few minutes and the weight loss is assumed to be seed moisture only. Some models have direct moisture read-outs, and others just supply the data for the operator to use.

This type of moisture tester was also developed primarily for rapid deter-mination in grains, but they are used for tree seeds in some countries. A list of several laboratories that use such meters on tree seeds can be found in Bonner (1977).

4. MANAGING SEED MOISTURE

Knowing the moisture content of your seed does no good, unless this knowledge is used to maintain seeds at the proper moisture. In the case of orthodox seeds, this usually means monitoring the moisture in cleaned seeds to know when they are dry enough to be put into storage. It also means using the proper storage container for each type of seed and storage environment.

In the simplest refrigeration systems, no humidity controls are used, and relative humidity is always above 90 percent. Since orthodox seeds must be maintained at low moisture contents during storage, they must be stored in moisture-tight containers to avoid absorption of moisture from the atmosphere. Recalcitrant seeds, in contrast, may be stored in unsealed containers in humid atmospheres.

Humidity control in cold storage is possible, but expensive. It is common in storage facilities for agricultural seeds, where temperatures are lowered only to about 10-12°C. In these conditions, where relative humidity is kept in the 50-60 percent range, orthodox seeds may be stored in unsealed containers, but recalcitrant seeds must be kept in closed containers to avoid desiccation.

Seeds exposed to the ambient atmosphere will lose or gain moisture from the atmosphere depending on seed moisture content, seed chemical content and the ambient humidity; eventually the seed moisture will attain equilibrium with the storage environment. These equilibrium moisture contents are relatively constant for each species, which is useful information for managers of seed storage facilities. A summary of the known values for southern tree species (table 3) shows that orthodox seeds have similar values under the same conditions, while the recalcitrant acorns equilibrate at higher moisture contents. True equilibration for acorns is tenuous, because active respiration produces a slowly decreasing seed weight. Slight differences may also occur because of chemical content; starchy seeds will usually absorb more atmospheric moisture than seeds with high lipid content.

Table 3. Equilibrium moisture contents for somee tree seeds stored at 4-5°C.

		Equilibrium moisture content %	
Common name	**Species**	**Stored at 40-55% RH**	**Stored at 95% RH**
Black cherry	*Prunus serotina*	9	21
Black walnut	*Juglans nigra*	11	20
Green ash	*Fraxinus pennsylvanica*	8	23
Loblolly pine	*Pinus taeda*	10	17
Longleaf pine	*Pinus palustris*	10	...
Shagbark hickory	*Carya ovata*	10	15
Shumard oak	*Quercus shumardii*	13	32
Sweetgum	*Liquidambar styraciflua*	8	20
Sycamore	*Platanus occidentalis*	9	21
Water oak	*Quercus nigra*	17	29
White oak	*Quercus alba*	37	50
Yellow-poplar	*Liriodendron tulipifera*	10	19

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Appendix I

Measurement of seed moisture content by oven drying

1. Mix the seed lot well and draw the sample correctly.
2. Do not expose cold seeds to warm, moist air. Either draw sample in cold storage and place in airtight container, or allow seed lot to reach room temperature before sampling.
3. Do not touch seeds with your fingers; use spoons or spatulas.
4. Use covered containers of glass or non-corrosive metal with rounded sides at the base. Put no more than 0.3 g/cm2 of seeds on the dish surface. This rule can be relaxed when drying cut or broken pieces of large seeds because of larger air spaces between pieces.
5. Seeds larger than 10 mm in diameter or 10 mm in length must be ground or cut into pieces. Grind so that 50 percent of the material can pass through a 4 mm mesh sieve, unless the seed is oily or high in moisture (above around 15 percent). For these cases, cut or break seeds into pieces no larger than 5-6 mm in diameter.
6. Allow oven to regain the drying temperature (103°C) after inserting samples before starting the drying time.
7. Leave a space equal to the diameter of a sample container between containers during drying.
8. Allow container and sample to cool in a desiccator for 30-45 min. before taking dry weight. With rapid-weigh electronic balances in airconditioned (low-humidity) laboratories, the cooling step can be skipped if necessary. It takes about 30 s. for hot samples to absorb moisture from the air.
9. Take duplicate sample and treat exactly the same. For large seeds that are ground or cut, two samples must be prepared independently for the duplicates.

Appendix II

Measurement of seed moisture content with the Burrows (Dole, Radson) electric moisture meter[a]

1. Mix seed lot well and draw a sample of at least 1/2 lb.
2. Do not expose seeds to warm, moist air, as moisture will condense on them. Either draw sample in cold storage and place in air-tight container, or allow seed lot to reach room temperature before sampling.
3. Do not touch seeds with your fingers; use spoons or spatulas.
4. Weigh proper sample size (see calibration charts).
5. Turn Power Switch to »ON« position. Set the red line on the zero mark of "A" scale and balance the circuit with the Balance Knob (center the needle in the Balance Meter).
6. Pour sample into hopper.
7. Turn Power Switch to »ON« position again, and rebalance the circuit by turning the Main Dial.
8. Record »A« Scale reading and consult the proper calibration chart for the corresponding percentage of moisture.
9. Other procedures are as described in the manufacturer's manual.

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a Mention of trade names is solely to identify material used and does not constitute endorsement or recommendation by the U.S. Dep. of Agriculture over others not mentioned.

Appendix III

Calibration data for measuring seed moisture content of some southern and eastern tree species on a Burrows (Dole or Radson) meter[a]

Common name	**Sample size [b] (g)**	**Moisture content (%)**												
		6.0	**6.5**	**7.0**	**7.5**	**8.0**	**8.5**	**9.0**	**9.5**	**10.0**	**10.5**	**11.0**	**11.5**	**12.0**
		meter reading of 'A' scale												
Black cherry[c] (depulped)														
Eastern white pine	142	76	79	82	85	88	90	93	96	99	102	105	107	110
Loblolly pine	142	78	80	83	86	90	94	98	104	108	114	19	124	129
Longleaf pine (dewinged)	142	78	81	84	87	90	93	95	98	101	103	06	109	111
Longleaf pine (winged)	85	45	46	48	50	52	53	55	57	58	60	62	64	66
Pond pine	85	41	43	45	47	49	50	52	54	56	58	60	62	63
Shortleaf pine	142	76	78	80	81	84	86	89	92	96	100	105	110	114
Slash pine	142	76	80	82	85	88	92	95	99	103	107	112	116	120
Sweetgum[c]	142	70	74	77	81	84	87	91	94	97	100	101	105	108
Sycamore[c]	142	..	..	60	64	67	70	74	78	82	86	90	95	100
Virginia pine	85	..	..	34	38	43	47	52	56	61	65	70	74	79
Yellow-poplar[c] (dew-	142	74	77	79	82	86	88	92	96	100	105	110	114	119
inged)	85	42	44	46	49	51	54	57	60	63	66	70	73	77

a Mention of trade names is for information only and does not imply endorsement or recommendation by the U.S. Dep. of Agriculture over others not mentioned. Unless otherwise noted, data supplied by USDA Forest Service, National Tree Seed Laboratory, Macon, Ga., in cooperation with Eaton Corporation.

b If 85-g samples are weighed in hopper, a weight must be added (see manufacturer's instructions).

c Bonner (1978).

Appendix IV

Calibration data for measuring seed moisture content of some northern and western species on Burrows (Dole or Radson) meter[a]

Common name	**Sample size (g)**	**Moisture content (%)**												
		6.0	**6.5**	**7.0**	**7.5**	**8.0**	**8.5**	**9.0**	**9.5**	**10.0**	**10.5**	**11.0**	**11.5**	**12.0**
		meter reading of 'A' scale												
Alpine fir	142	40	45	50	55	60	66	71	77	83	88	94	100	106
Balsam fir	142	52	55	57	60	62	65	68	72	75	78	83	86	91
Colorado blue spruce	142	78	83	87	92	96	101	106	112	118	126	134	142	150
Douglas-fir	142	52	56	60	63	67	71	75	79	83	87	91	95	99
Englemann spruce	142	79	84	88	94	99	104	109	114	121	128	137	146	150
Grand fir	142	66	71	76	80	85	89	94	98	103	107	112	116	121
Limber pine	142	78	82	85	89	93	97	101	105	109	112	118	122	126
Lodgepole pine	142	73	76	80	84	88	92	96	100	104	108	113	118	122
Norway spruce	142	56	59	61	64	67	71	74	78	82	86	91	95	100
Ponderosa pine	142	79	82	85	88	92	96	100	104	108	113	118	123	128
Red pine	142	76	79	82	84	88	91	94	98	102	106	111	114	118
Scotch pine	142	75	79	83	87	91	96	100	104	108	113	118	122	126
Western larch	142	68	72	74	77	80	83	86	89	92	95	98	101	104
White fir	142	42	47	52	57	62	68	74	79	85	90	96	102	107
White spruce	142	44	47	49	53	56	60	65	70	76	83	92	101	111

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Appendix V

Moisture determination using home microwave ovens

Differences in ovens and settings make calibration of individual ovens necessary. Variation can be reduced by preheating ovens prior to measurement.

1. Draw a sample of at least 10 seeds or fruits.

2. Preheat oven with a dish of water at the center of the oven floor.

3. While oven is heating, quickly break or cut large seeds into fragments no larger than one-fourth the size of the intact seeds. Mix and place an amount equal to five intact seeds in a tared glass container. Metal containers cannot be used in microwave ovens.

4. Record fresh weight to three decimal places.

5. When oven floor temperature reaches 60°C, remove water dish and place container and sample in center of oven.

6. Dry sample for selected time period. While the first sample is drying, draw, prepare and weigh a duplicate sample in the same manner. Check floor temperature before drying second sample(it should be 60°C).

7. Remove sample and weigh immediately on electric pan balance. If a rapid-weigh balance is not available, samples should be cooled in a desiccator for 30-4O min before weighing.

Appendix VI

Typical drying times using General Electric JET 85, OT 1[a] Microwave oven at low setting (floor temperature, 6O°C)

Common name	Species	Sample weight(g)	Sample condition	Drying time (min)
Green ash	*Fraxinus pennsylvanica*	3	intact	5
Shagbark hickory	*Carya ovata*	20	broken	4.5
Shumard oak	*Quercus shumardii*	25	cut	4.5
Water oak	*Quercus nigra*	10	cut	4.5
White ash	*Fraxinus americana*	3	intact	5

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