VIABILITY OF CONIFER SEED AS AFFECTED BY SEED MOISTURE CONTENT AND KILN TEMPERATURE

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INTRODUCTION

In collecting conifer seed to use in reforestation, the cones must be harvested before the scales open or the seed will drop out and be lost. After they are harvested, the green cones must be thoroughly air-dried before the scales will open sufficiently to release all of the seed. In some regions weather conditions may interfere with drying operations. This condition and the development of the forest-seed industry have brought into use the dry kiln with its wide range of temperatures as a more controllable means of opening freshly gathered, moist cones. Kiln operation in the drying of cones cannot, however, be governed by the sole aim of completing the run in the shortest possible time. Many organic compounds are more liable to be disorganized by heat when they have a high moisture content than when they are dry, and seeds may be expected to react in this way. That in some seeds disorganization from the application of heat is greatest when moisture content is high is well known, even from the rather meager specific data on the subject. Obviously, the kiln operator must know what temperatures he can apply without injuring the moist seed. Also, he should know whether he may not apply much higher temperatures after part of the cone and seed moisture has been driven off by moderate heat. The object of the study discussed here was to determine, for certain conifer seeds, what effect a gradual increase in heat may have on moist seed, and the relation of such effects to increase in the moisture content of the seed. Furthermore, it was desired to determine the critical combinations of heat, moisture, and duration of heating. Tests were made with seed already extracted by air-drying. Results from such tests, although not exactly comparable with those in actual practice, were regarded as clearly indicative of results to be expected in seed extraction.

REVIEW OF LITERATURE

The fact that certain dry seeds withstand higher temperatures than moist seed was reported by Eduard Heiden in 1859, Julius Sachs in 1865, and L. Just in 1875, according to citations by Atanasoff and Johnson (1). Waggoner (14) later heated radish seed under a large number of different moisture content and temperature conditions and found also that the ability of the seeds to withstand heating varied inversely with their moisture content. For example, when seed of the Icicle radish, having a moisture content of more than 38

1 Received for publication Nov. 20, 1935, issued July 1936.
2 The experimental work for this report was done at the University of California, Division of Forestry. The writer received many helpful suggestions from F. S. Baker, A. W. Sampson, and A. R. Davis.
3 Reference is made by number (italic) to Literature Cited, p. 864.
percent, was heated at 55° C. for one-half hour, the germination was
subnormal, but when the seed-moisture content was only 0.4 percent,
the germination was normal even after the seed was heated at 105° C.
At 100° and more, the germination became less with each step of
moisture increase above 0.4 percent.

Hottes and Wilson (8) obtained a moisture series similar to Wag-
goner's by placing wheat on trays in the upper part of jars which
had various concentrations of sulphuric acid in the bottom. Despite
the molding of samples with high moisture content, the investigators
found that samples having 10 percent moisture, after being heated
for 1 hour at 90° C. in a closed container, failed to germinate, but
when heated at 80°, germinated 100 percent. Samples with 12
percent moisture gave no germination after heating at 80°, but
76-percent germination after heating at 70°. Germinating methods
and sampling were not described.

Somewhat similar though less conclusive results were obtained by
Harrington and Crocker (6), Kienholz (10), and Hofmann (7).

A number of investigators have studied the lethal temperatures for
seed having a moisture content in equilibrium with ordinary storage
conditions, but for the purposes of this study their work is of little
value, since they made no record of either the air- or seed-moisture
content. These include Atanasoff and Johnson (1), Burgess (2),
Ewart (3), Gaine (5), Jodin (9), Robertson (11), Spafford (12), Staker
(15), and Wright. From these investigations dealing with lethal
temperatures for seed of no stated moisture content, one can only
conclude that with alfalfa, barley, wheat, oats, and acacia there is
likely to be a decrease in germination after the seed has been subjected
to about 90° C. for several hours, but seed from Douglas fir, ponderosa
pine, peas, and cress evidently is injured at a lower temperature.

**EXPERIMENTAL METHODS**

**MATERIAL USED AND NATURE OF TESTS**

The seed used in this experiment was that of Douglas fir (*Pseudotsuga
taxifolia* (LaMarck) Brit.) and ponderosa pine (*Pinus ponderosa*,
Dougl.). It was purchased from a dealer in forest seed at Longview
Wash., and was accompanied by declarations of origin. The fir seed
came from an altitude of 700 feet in Cowlitz County, Wash. The pine
seed was from Antelope Creek watershed, Siskiyou County, Calif.,
elevation 4,800 feet. Both kinds of seed were harvested in the fall of
1930 and had been extracted from air-dried cones.

The heating experiments were made in February 1931. The seeds
were heated under 36 different combinations of conditions, including
3 known degrees of moisture, a long and a short period of heating, and
6 temperatures ranging by 5-degree intervals from 45° to 70° C.
The percentage of germination from 5 samples, each containing 100
seeds, was used as the criterion of the result of each different treatment.
Thus, a total of 180 germination tests was made. To obtain a basis
for the choice of procedure, the effect of small changes in conditions
and the reliability of the germination percentage were measured in
preliminary experiments.

*Wright, E. THE VIABILITY OF NATIVE AND EXOTIC SEED AT HIGH TEMPERATURES. Berkeley, Calif.
1923. (Thesis, Univ. Calif.)*
ADJUSTING THE MOISTURE CONTENT

Three moisture conditions were chosen with the intention of having a maximum and minimum that are commonly encountered and an intermediate point to help determine any graduation of effects due to the moisture.

The driest sample came from seed stored in crocks under laboratory conditions, averaging $7 \pm 0.5$ percent moisture. The intermediate moisture condition was set at 30 percent, which represents that of seed in cones that have been stored for some time previous to extraction. The maximum moisture condition was set at 60 percent for the fir and 50 percent for the pine, because moisture of these percents approaches the greatest amount of water which these seeds will absorb and approximates the moisture content of freshly gathered cones.

A moisture content of 30 percent was obtained by soaking the Douglas fir seed in water for 35 minutes and the ponderosa pine seed for 3 hours. The moisture contents of 60 percent for Douglas fir seed and 50 percent for the pine were obtained by soaking the fir seed for 10 hours and the pine seed for 15 hours.

After the water was drained from the seeds, they were spread on a paper towel for approximately 5 minutes to allow the superficial water to dry. The seed was mixed and respread several times during the drying period, so that it would have a uniform exposure. When the coats appeared free from a water film, the seed was put in stoppered heating bottles and a 6-g sample set aside for a moisture determination (based on the constant weight after drying the sample at 90° C.). These checks showed that the seed classed as having 30 percent moisture actually had a range of ±2 percent, and that classed at 50 or 60 percent actually had a range of ±3 percent.

HEATING

The seed was heated at temperatures of 45°, 50°, 55°, 60°, 65°, and 70° C. in the upper part of a thermostatically controlled electric oven. By means of a small motor-driven fan, the desired temperature was maintained in all parts of the upper half of the oven with a variation of only ±1°.

The seed containers were glass bottles, the cork stoppers of which had a fine groove cut in the side to allow a balance with atmospheric pressure. The bottles containing the pine seed were 2 inches square and 4 inches tall, and those containing the Douglas fir seed were 1%-inch round bottles, 3 inches tall.

It was desired to prevent any significant drying in the seeds during heating. Trial samples showed no appreciable loss in moisture content during a preliminary 10-hour heating period at 50° C., and moisture-content samples taken in the regular heating periods indicated that 2 percent was the maximum loss to be expected, this occurring in the samples which had 30 percent or more moisture at the beginning.

About 1 hour was required for the temperature at the center of a bottle of dry seeds to equal an oven temperature of 50° C.; therefore it was necessary to preheat the seed in a quick way. To do this, the glass containers were warmed, then the seed was introduced, and, with thermometers thrust through the stoppers, the bottles of seeds
were warmed in a small hot oven. The samples were constantly watched and shaken by hand so that uniform heating from the outside to the center would be obtained. The desired temperature generally was reached in 5 to 10 minutes, and the bottles were then quickly transferred to the main oven.

The thermometers in the bottles were allowed to project through the two ventilator holes in the top of the main oven and were checked frequently to avoid any accidental fall or rise in temperature. The temperatures within the bottles did not vary more than 1° C. Six bottles of seed usually were put in the oven at the same time so that seed representing three different moisture conditions and two different durations of heating were subjected to the same temperature.

To determine the effects of two different durations of heating, some of the bottles were removed from the oven at the end of half an hour, the rest remaining 3 hours. Upon removal, the seed was spread on paper towels to dry and cool for 24 hours, whereupon it was stored in unsealed envelopes for 1 week before the germination tests were made.

**GERMINATION**

Since it would be very difficult to measure the separate physiological changes within seed which had been heated, the ultimate effect of high temperature was judged by the percentage of germination after heating. To obtain a standard for comparison of effects, eight random samples of unheated seed taken from the same crock were germinated. To have these under representative sprouting conditions, four samples were placed in each of the two germinating chambers.

By means of a graduated test tube of small diameter, the seeds were measured into lots containing approximately 100 seeds each, and no accurate count was made until the end of the germination period. Each lot was put in a separate test tube to be soaked in water 24 hours, after which time the water was drained off and the sample was placed on an individual plate in the germination chamber. The germination plates were rough-surface, 4- by 3-inch paper ice-cream plates that had been soaked in water for 3 weeks to make them thoroughly saturated when first put in the germinator.

The germinating equipment consisted of two automatically controlled, water-jacketed germinators, with eight wire shelves in a chamber 18 by 20 by 20 inches and a water-pan humidifier under the bottom shelf. Temperatures were maintained at 27° C. The atmosphere was saturated at all times to prevent excessive drying of the plates.

The samples were inspected at 5-day intervals by removing one shelf at a time and recording for each numbered plate the number of seeds having protruding sprouts. The recorded seeds were then discarded. If molds or midge fly larvae appeared on the plate, or if some of the radicles had started to wilt as a result of damping-off fungi, the observation was included in the notes, in order that any correlation between the presence of these associates and the seed viability might be discovered. If any of the plates needed moistening, they were sprayed with a fine jet of water.

The tests were continued for 60 days, whereupon it was estimated from cumulative germination curves that sprouting of viable seeds
was complete. Previous cutting tests had shown the original stock of pine seed to have from 7- to 30-percent culls. To determine accurately the germination percentage, it was necessary to know the number of fully developed seeds in each sample. This was done in the case of the ponderosa pine samples by cutting open the ungerminated seeds and eliminating the undeveloped specimens. Germination percentages were based upon the number of sprouted ponderosa pine seed plus the developed but unsprouted seed. From previous cutting examinations it was found that the original Douglas fir seed was 98-percent sound, and since most of the ungerminated Douglas fir seed in the sprouting tests had disintegrated before the end of 60 days, no careful cutting tests were made on them after germination, the original number in each sample being used as the basis for germination computations.

As the plates were inspected, the area of each plate covered by the black mold *Chaetomium elatum* was estimated in tenths; the ratio of seeds attacked by the white mold *Verticillium* sp. and the presence of midge larvae were recorded on a scale of 10; and the presence of crystals, as yet unidentified, noticed on some of the pine-seed coats, was indicated in the notes. Since the presence and amount of damping-off fungi, molds, fly larvae, and crystals later proved to have no correlation with the germination results, they will not be discussed further.

**RESULTS AND DISCUSSION**

**ANALYSIS OF THE DATA**

The first step in handling the data was to determine the final germination percentage of each of 360 samples, and, for each species, to average these percentages for the five samples which had the same moisture content and were heated at the same temperature for the same length of time. The standard deviation of the five samples for each treatment was computed and compared with the deviations of individual samples which occurred farthest from the average. None of the samples showed sufficient deviation from the mean to be rejected. The standard error (standard deviation of a mean) was also computed. The final germination percent and the standard error of each are given in table 1.

After computing the final germination percentages, the cumulative germination percentage for each sample and the mean of the five duplicate samples was computed for the end of each 5-day period. These cumulative mean values are plotted in figures 1 and 2 to illustrate the progress of sprouting. The standard deviation of the five samples around the moving average formed by the cumulative mean values was computed for each curve and is shown in the figures.

To those who are accustomed to germinating agricultural crop seeds, the variations in the following tests may seem unusually large. However, it has been the experience of investigators using forest seed that tree seeds are more liable to give low germination percentages and highly variable results.

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*By the formula, standard error = \( \frac{\sigma}{\sqrt{N-1}} \).*
### TABLE 1.—Average germination\(^1\) of Douglas fir and ponderosa pine seed of given moisture content heated at various temperatures for 0.5 and 3 hours

#### DOUGLAS FIR

<table>
<thead>
<tr>
<th>Heating temperature (°C.) and period</th>
<th>7 percent moisture content</th>
<th>30 percent moisture content</th>
<th>50 percent and 60 percent moisture content</th>
<th>Heating temperature (°C.) and period</th>
<th>7 percent moisture content</th>
<th>30 percent moisture content</th>
<th>50 percent and 60 percent moisture content</th>
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<tbody>
<tr>
<td>45°:</td>
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<td></td>
<td></td>
<td>60°:</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>0.5 hour</td>
<td>62±3.2</td>
<td>68±1.8</td>
<td>58±3.0</td>
<td>0.5 hour</td>
<td>61±1.7</td>
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<tr>
<td>3 hours</td>
<td>65±2.2</td>
<td>55±3.8</td>
<td>38±3.6</td>
<td>3 hours</td>
<td>64±4.3</td>
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<td></td>
<td></td>
<td>65°:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5 hour</td>
<td>62±3.0</td>
<td>60±2.8</td>
<td>37±1.2</td>
<td>0.5 hour</td>
<td>43±1.9</td>
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<td></td>
</tr>
<tr>
<td>3 hours</td>
<td>57±4.5</td>
<td>25±3.1</td>
<td>1±0.6</td>
<td>3 hours</td>
<td>53±2.0</td>
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</tr>
<tr>
<td>55°:</td>
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<td></td>
<td></td>
<td>70°:</td>
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<tr>
<td>0.5 hour</td>
<td>66±1.5</td>
<td>30±3.9</td>
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<td>0.5 hour</td>
<td>11±2.8</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3 hours</td>
<td>52±3.6</td>
<td>1±0.2</td>
<td>0</td>
<td>3 hours</td>
<td>18±2.3</td>
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</tbody>
</table>

#### PONDEROSA PINE

<table>
<thead>
<tr>
<th>Heating temperature (°C.) and period</th>
<th>7 percent moisture content</th>
<th>30 percent moisture content</th>
<th>50 percent and 60 percent moisture content</th>
<th>Heating temperature (°C.) and period</th>
<th>7 percent moisture content</th>
<th>30 percent moisture content</th>
<th>50 percent and 60 percent moisture content</th>
</tr>
</thead>
<tbody>
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<td>45°:</td>
<td></td>
<td></td>
<td></td>
<td>60°:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5 hour</td>
<td>24±1.8</td>
<td>23±2.8</td>
<td>17±2.7</td>
<td>0.5 hour</td>
<td>18±1.5</td>
<td>2±0.5</td>
<td>4±0.8</td>
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<tr>
<td>3 hours</td>
<td>21±3.0</td>
<td>21±2.8</td>
<td>23±3.3</td>
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<td>21±1.8</td>
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<tr>
<td>50°:</td>
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<td></td>
<td></td>
<td>65°:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5 hour</td>
<td>21±1.3</td>
<td>25±1.8</td>
<td>18±2.4</td>
<td>0.5 hour</td>
<td>13±2.0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3 hours</td>
<td>22±2.2</td>
<td>19±2.8</td>
<td>9±1.4</td>
<td>3 hours</td>
<td>11±9</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>55°:</td>
<td></td>
<td></td>
<td></td>
<td>70°:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5 hour</td>
<td>19±2.2</td>
<td>16±3.5</td>
<td>17±1.9</td>
<td>0.5 hour</td>
<td>9±2.1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3 hours</td>
<td>17±2.1</td>
<td>3±0.6</td>
<td>0</td>
<td>3 hours</td>
<td>7±7</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) The significance of the mean is given in terms of the standard error of the mean. A range of 3 times the standard error above and below the mean of 5 observations includes, according to normal probability, 96 percent of all other means which might be obtained from additional samples of the same material (4).

\(^2\) For the indicated seed moisture content and duration of heating, this value represents the first significant deviation from normal that resulted from increase in the temperature applied. The normal values were 68±1.8 percent for Douglas fir and 29±2.4 percent for ponderosa pine.

According to some authors, not only the final germination percentage at the end of a long period but also the germination that takes place within a short time should be considered as an indicator of the physiological condition of seed. Harrington and Crocker (6) found, in testing heated Kentucky bluegrass seed, that the germination, although it later equaled the normal, was subnormal during the early part of the germination period. To study such relationships for Douglas fir and ponderosa pine, the writer plotted germination percentages for 5-day intervals. From inspection of figures 1 and 2, it is apparent that the condition which Crocker and Harrington observed does not exist in the present experiment. In fact, it is reversed. Germination of Douglas fir seed heated while in a moist condition was, for the first 20 days, equal to that of the unheated samples. After 20 days the heated seed did not germinate at the same rate as the unheated samples. This is shown by the fan shape of the curves in figures 1, B, and 2, A. However, the pine-germination progress curves begin to show differences in seed viability by the fifth day and remain nearly parallel after that (figs. 1, C, and 2, B).

### TOTAL GERMINATION RESULTS AND THEIR APPLICATION

In table 1 it is seen that dry (7-percent moisture content) Douglas fir seed was not injured by heating for 3 hours at 50° C., but if the moisture content was 30 percent, a great loss in germination occurred.
Also, dry seed heated at 60° germinated normally, but seed with 30 percent or more moisture content heated for one-half hour at the same temperature failed completely. A temperature of 50° is often used in seed-extraction kilns. If freshly gathered cones (which usually have a moisture content of much more than 30 percent) are put in a kiln at 50° and are not allowed free air circulation so that every cone with its seeds can dry out in less than 3 hours, probably the seed will be injured. If the moisture content is 60 percent when the cones are put in the kiln, the seed will probably be injured in less than one-half hour, unless it dries considerably within a few minutes.

![Figure 1: Cumulative germination of seed at different moisture contents under different degrees and periods of heating. A Douglas fir seed heated at 45° C., and B, at 50° for one-half hour and for 3 hours; C, ponderosa pine seed heated for the same periods at 50°, and D, at 55°.](image-url)
It is possible that the relatively low temperatures which injure wet seed may reduce the germination of seed sown naturally. Surface soil temperatures often reach 50° C. in the fall when the soil and seeds are wet.

Table 1 shows that a temperature increase of 5° C. when heating Douglas fir or ponderosa pine seed may decrease the germination more than 30 percent. An increase from 50° to 55° C. caused a great loss in germination of Douglas fir seed when moisture content was 30 percent and the heating period was one-half hour, and a further increase of 5° caused a complete loss of viability. This indicates that care must be taken to keep all cones in a kiln at the same safe temperature. Temperatures at various places inside a drying chamber often differ by 5°. A temperature record taken at one point may indicate a safe condition while seeds at some other point are being destroyed.

Figure 2.—Germination of seed which, at a moisture content of 30 percent, has been heated for one-half hour: A, Douglas fir; B, ponderosa pine.
The length of time that seeds are heated may have in some instances as great an effect on the viability as the seed-moisture content and heating temperature. When Douglas fir seed had a moisture content of 30 percent and was heated at 55° C., the germination after a ½-hour heating period was 30 percent, but after a 3-hour heating period was only 1 percent (table 1 and fig. 1, A and B). However, if the seed was dry, a 3-hour heating period had no appreciably greater effect than a ½-hour period. Apparently the heat resistance of dry seed is such that the initial damage is done in a short time, and no more injury is caused unless a very long heating period is used.

When dry Douglas fir or ponderosa pine seed (7-percent moisture content) is heated at 45° C. for one-half hour, the viability is not impaired. If the temperature, or seed moisture content, or time, or all three factors together, are increased unit by unit, there may be no evident effect on viability at first, but, ultimately, a combination of conditions is reached which causes a slight decrease in seed germination. This may be called a critical combination of conditions. Beyond that critical combination, any increase, either in heating temperature, seed-moisture content, or duration of heating, will cause a corresponding decrease in viability. It may be said that, in kiln-drying, a slight increase in any one of these three factors is not dangerous unless the factors are already near a critical combination. But if cones are being dried near the critical heat point, the greatest care must be taken to avoid any increase in one of the three drying factors without a corresponding safe decrease in another factor. It will be of prime importance to the kiln operator to know the critical combinations of heating conditions. Within the range of conditions tested in this experiment, the critical points exist at some combination of conditions slightly more moderate than those which caused the first significant losses, as shown in table 2.

**Table 2.—Summary of temperatures causing first significant injury of seed at different moisture contents**

<table>
<thead>
<tr>
<th>Seed-moisture content and duration of heating</th>
<th>Douglas fir</th>
<th>Ponderosa pine</th>
<th>Seed-moisture content and duration of heating</th>
<th>Douglas fir</th>
<th>Ponderosa pine</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 percent: 1½ hour</td>
<td>65° C.</td>
<td>55° C.</td>
<td>50 percent (ponderosa pine):</td>
<td>50° C.</td>
<td>45° C.</td>
</tr>
<tr>
<td>30 percent: 1½ hour</td>
<td>55° C.</td>
<td>55° C.</td>
<td>60 percent (Douglas fir):</td>
<td>45° C.</td>
<td></td>
</tr>
<tr>
<td>3 hours</td>
<td>45° C.</td>
<td>50-55° C.</td>
<td>1½ hour</td>
<td></td>
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</tr>
</tbody>
</table>

**SUMMARY**

From the results of this experiment on seed of ponderosa pine and Douglas fir a few general statements may be made concerning the practice of kiln-drying cones of these species before shaking out the seed. It seems imperative that there should be a thorough circulation of drying air around every cone. The cones should not be in piles, as this will keep the inside ones moist. There will be economy in spreading the cones in a thin layer so that they may dry more rapidly, for the sooner they dry, the less apt they are to be damaged by heat.

The drying should be begun with a relatively low temperature—40° C. for instance—which may be increased as the cones become drier. Near the end of the run the temperature probably can be
raised to 55° if the seed-moisture content has already been reduced to 20 percent or less. If the cones have been somewhat air-dried before they are put in the kiln, they may be started at a higher temperature than more moist cones. Moisture-content samples should be taken, and the sacks of cones should be graded according to moisture content, if the greatest efficiency of kiln operation is desired. When this is done, a batch of wet cones can be run at a low safe temperature and a charge of dry cones at a faster-drying but equally safe temperature. In that way it will not be necessary to extend the heating period of the dry cones in order to prevent injury to the seed of a few moist cones.

LITERATURE CITED


(2) BURGESS, J. L. 1919. RELATION OF VARYING DEGREES OF HEAT TO THE VIABILITY OF SEEDS. Jour. Amer. Soc. Agron. 11: 118–120.


