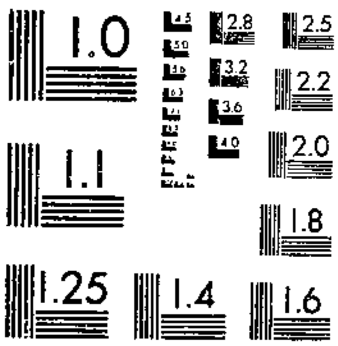
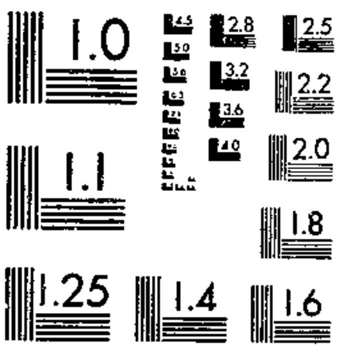
TB 773 (1939) USDA TECHNICAL BULLETINS UPDATA
KILN DESIGN AND DEVELOPMENT OF SCHEDULES FOR EXTRACTING SEED FROM CONES
RIETZ, R C 1 OF 1

START



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Technical Bulletin No. 773 · May 1939

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

Kiln Design and Development of Schedules for Extracting Seed from Cones

By RAYMOND C. RIETZ,[1] *Engineer, Forest Products Laboratory,[2] Division of Research, Forest Service*

CONTENTS

	Page
Introduction	1
Kiln design	2
General principles of Forest Products Laboratory cone kiln	3
Kiln installation and operation	7
Ozark extractory	7
Cass Lake and Chittenden extractory installations	12
Development of schedules for kiln-drying cones	16
Species and source of cones studied	17
Procedure for cone-drying experiments	19
Seed testing	25
Laboratory testing	25
Field testing	25
Cone opening	30
Eastern white pine	30
Jack pine	31
Red pine	32
Seed yield	32
Cone moisture reduction	34
Eastern white pine	35
Jack pine	35
Red pine	36
Longleaf pine	39
Seed moisture reduction	39
Eastern white pine	40
Jack pine	42
Red pine	42
Longleaf pine	42
Viability of seed obtained from kiln-dried cones	43
Eastern white pine	43
Jack pine	47
Red pine	49
Longleaf pine	50
Seed heating experiments	60
Species studied	60
Viability of heat-treated bare seed	61
Comparative influence of cone drying and seed heating	67
Conclusion	67
Eastern white pine	68
Jack pine	68
Red pine	68
Longleaf pine	69

INTRODUCTION

Since the advent of the Civilian Conservation Corps the total area planted to trees on national forests has increased substantially (fig. 1). To provide the seedlings for this expanded reforestation program has necessitated the establishment of additional nurseries throughout the United States as well as the enlargement of many of the existing nurseries. These nurseries require tremendous quantities of seed compared with former demands, particularly of conifer seed. To meet the demand for conifer seed, increased volumes of cones were purchased from private collectors, and C. C. C. enrollees were assigned to the collection of cones.

[1] The author wishes to acknowledge the suggestions of Rolf Thelen and W. K. Loughborough, Forest Products Laboratory, concerning the design of the cone kiln here described. Further acknowledgment is made to O. W. Torgeson, Forest Products Laboratory, and I. I. Davies and K. E. Kimball, former CCC appointees, for their assistance in the research studies; to H. L. Shirley and R. H. Blythe, Jr., Lake States Forest Experiment Station, and P. C. Wakeley, Southern Forest Experiment Station, for suggestions in planning the experimental studies; to R. O. Sowash, Lydick Nursery, and J. T. May, W. W. Ashe Nursery, for assistance in operating the extractories and collecting the field data on the seed studies; and to the supervisors of the Chippewa National Forest and the Mississippi National Forests for providing the cones used in the studies.

[2] Maintained by the U. S. Department of Agriculture at Madison, Wis., in cooperation with the University of Wisconsin.

Experience in handling this large volume of cones indicated that modifications in cone-drying methods were essential if seed was to be obtained soon after cone harvest. Solar drying was entirely too slow and uncertain as a cone-opening process. Air-drying in cone storage sheds, a reasonably satisfactory process for some species if seed is not immediately required, was too slow a process for most species. In addition, general experience at extracting plants had indicated that the cones of some species, particularly jack pine, cannot be opened effectively at atmospheric temperatures.

The cone-drying equipment then available was generally of the convection type. These driers depend upon the natural rise of heated air through cones spread on trays placed directly over the source of heat. Apparatus of this type is relatively cheap, easy to install by ordinary labor, and requires no especial technical ability to operate. The fire risk is, however, extremely high and adequate temperature control is not generally obtainable. Although the capacity of some of these convection driers was fairly large, the production of seed in pounds per day was comparatively small.

Because the Forest Products Laboratory has pioneered in the design of kilns for drying lumber, it was entrusted with the job of designing an efficient cone kiln. The dual problem was to design a more efficient kiln and to determine how this kiln should be operated to obtain high yields of uninjured seed in the most economical manner. The purpose of this bulletin is to describe the cone kiln designed by the Laboratory, together with results of experiments conducted in cooperation with the Lake States and Southern Forest Experiment Stations to increase the efficiency of cone-kiln operation.

KILN DESIGN

The opening of conifer cones to permit the release of seed is in most cases primarily a matter of reducing the moisture content of the matured cones. The cones of loblolly, slash, shortleaf, longleaf, and eastern white pine readily open as the cone moisture content is reduced. Certain species, like jack pine and lodgepole pine, however, require drying at elevated temperatures to obtain good cone opening.

To reduce cone moisture quickly and efficiently necessitates the use of as high a temperature and as low an atmospheric humidity as the seed can withstand without injury. In designing cone-drying equipment three essentials must therefore be provided—heat for evaporating moisture; air circulation to conduct the heat; and control of both temperature and atmospheric humidity to prevent injury to seed.

The rate of cone drying is also dependent upon a fourth factor, the cone itself. This, of course, varies with species and, within species, with degree of cone ripeness; also with the manner in which the cone was precured and the time the cone has been exposed since collection.

An internal-fan kiln provided with trays and operated on the same general principles as have been successfully applied in lumber drying meets the foregoing requisites of an efficient cone kiln. The fan provides forced circulation of warm air through the trays containing the moist cones. Positive circulation of air, conditioned and controlled as to temperature and relative humidity, across layers of moist cones provides the three necessary external requirements of the drying process. Various arrangements of air-moving equipment, whether

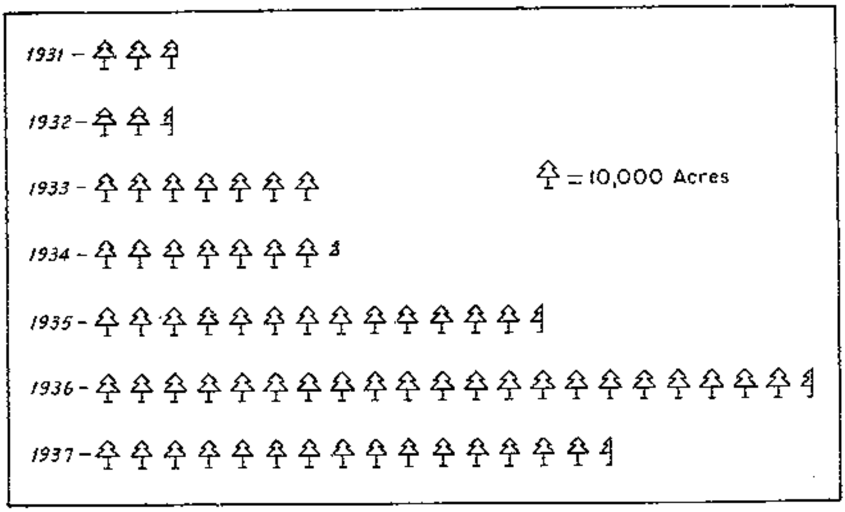


FIGURE 1.—Total national-forest area planted during the calendar years 1931–37. (Each symbol represents 10,000 acres.)

they be disk fans or centrifugal blowers, however, can be utilized to conform to limitations imposed by cone handling methods, building restrictions, or kiln capacity.

General Principles of Forest Products Laboratory Cone Kiln

The cone kiln designed by the Forest Products Laboratory is of the internal-fan type and is provided with trays. This kiln provides for the automatic control of temperature and relative humidity of the drying atmosphere and permits large volumes of air to be circulated at uniform and fairly high velocities throughout the trays of cones. Steam is used for heating and humidification. Steam heating is advocated because of the ease with which temperature control can be gained through the use of reliable and commercially available control instruments. The maintenance of low relative humidities in the kiln is accomplished by ventilation.

The general layout of the kiln is shown in figure 2. The kiln walls and ceiling, in the form of panels, are attached to a supporting steel frame. This frame also supports the overhead fan equipment and heating coils. Two 24-inch disk fans are used, operating at 550 r. p. m. and driven through V belts by means of two ½-hp. electric motors. The steam-heating coils are located to give efficient heat transfer. They are subdivided in order that the radiation can be varied to suit the heating demands and thus provide better temperature control. A small blower mounted on top of the kiln exhausts air under positive control. Fresh air is admitted into the kiln at the floor level.

The temperature and relative humidity of the kiln are controlled with an electrically operated recorder-controller. The same instrument automatically controls the amount of air vented by the exhaust blower.

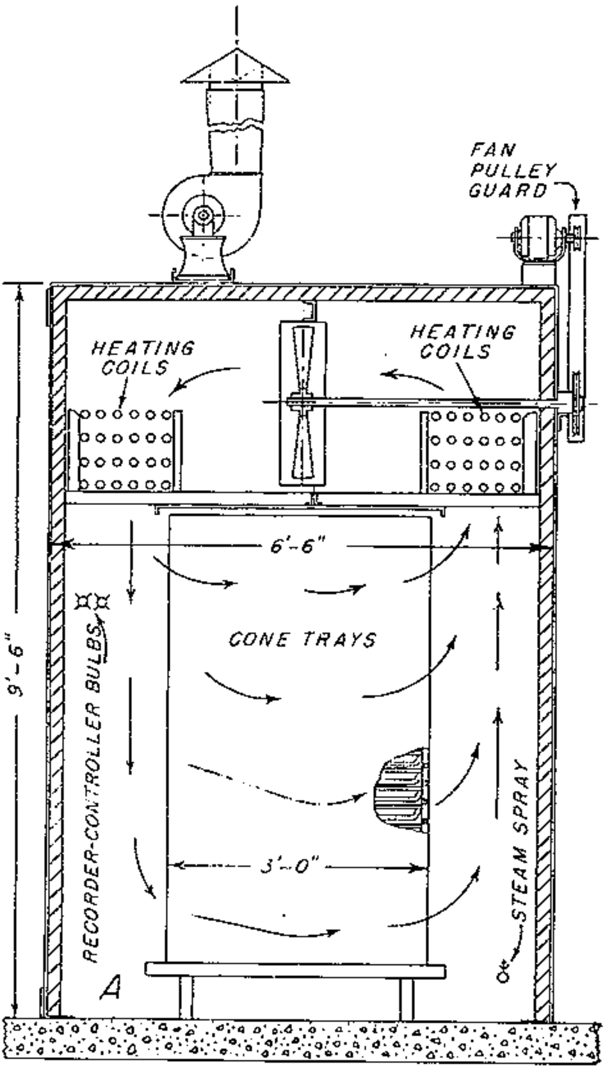
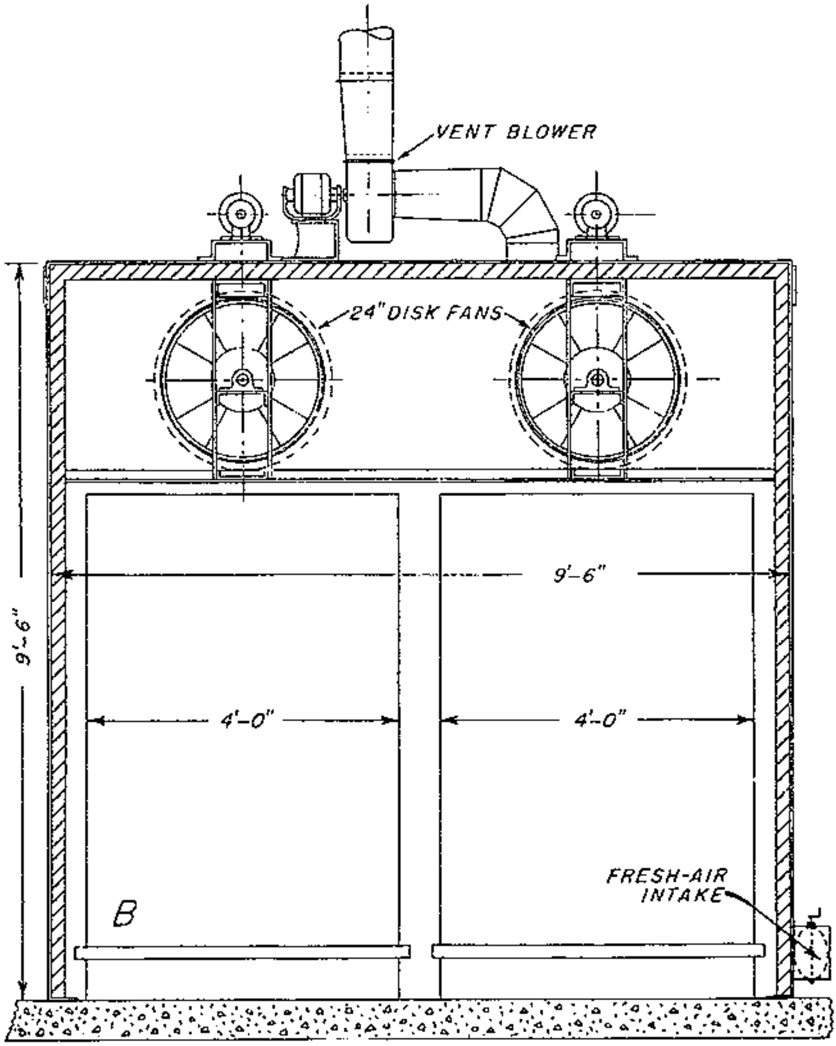


FIGURE 2.- -Layout of Forest Products Laboratory

The wall and ceiling panels can be made of many different kinds of building materials including wood. Preferably they should be moistureproof, fireproof, and should possess a fair amount of insulation. The panels are bolted to the structural steel framework and a plastic cement makes all joints vaportight.

The cones to be dried are spread on wire-mesh trays that are placed on top of one another and are piled on a skid that is moved in and out of the kiln by means of a lift truck. The spacing between the trays (fig. 3) can be varied to suit the size of the cones; 2-inch spacing lugs are provided for small cones like jack pine or white and black



internal cone kiln: *A*, Cross section; *B*, longitudinal section.

spruce; 3-inch lugs for red or shortleaf pine; and 4-inch lugs for white pine. Each skid carries 33 trays on a 2-inch spacing, 22 trays on a 3-inch spacing, and 16 trays on a 4-inch spacing. The cone trays are 3 by 4 feet in size and are easily handled by two men. The kiln is long enough to accommodate two skid loads of trays.

The cone kiln can be located on the ground floor or on the second floor of an extractory building, depending on how the cone trays are loaded and how the extractory building is arranged.

If steam is not available a domestic boiler generating low-pressure steam should be installed.

If electrical power is not available, either a small gas engine generator can be installed or the fans can be operated directly by a gas engine, the same engine operating a small air compressor supplying pressure for an air-operated recorder-controller.

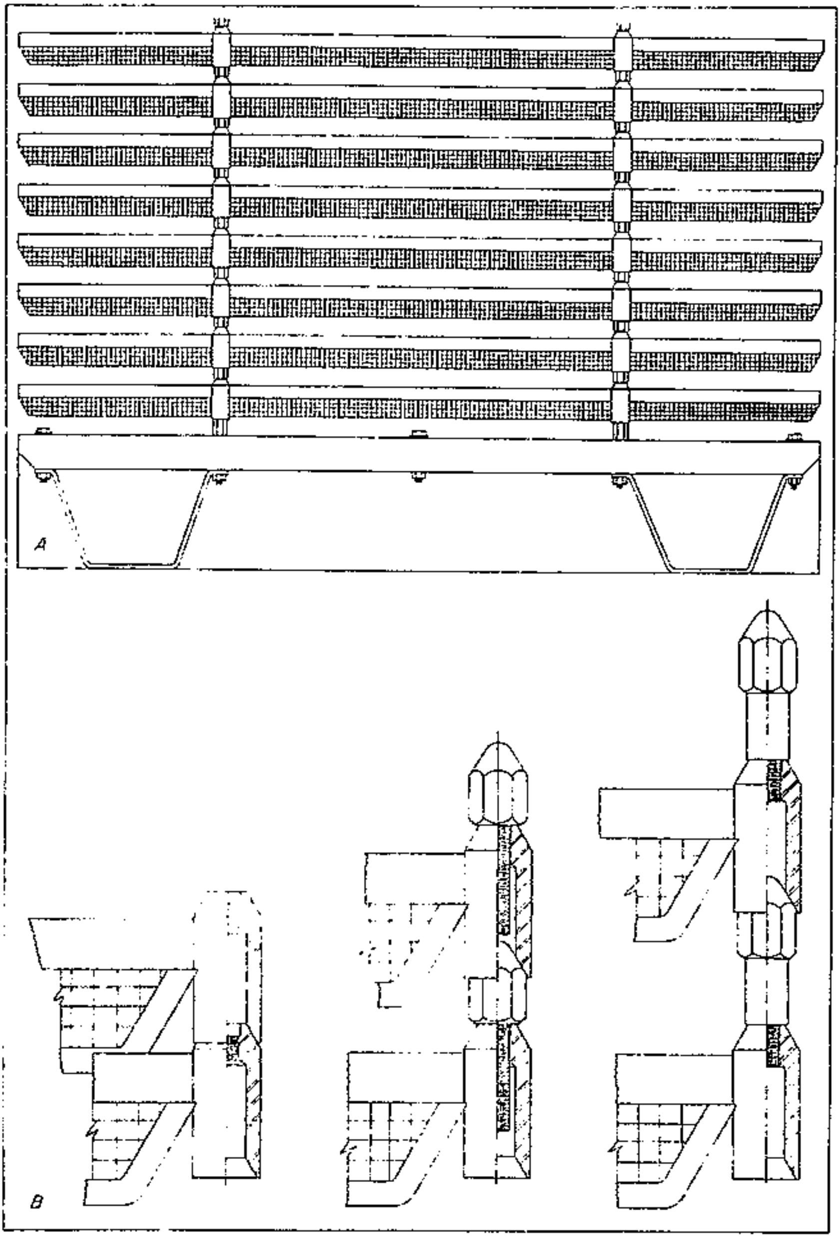


FIGURE 3. *A*, Metal cone trays designed for adjustable spacing; *B*, adjustable-spacing device produces a rigid stack of trays that can be efficiently handled.

KILN INSTALLATION AND OPERATION

The best means of explaining the functioning of the Forest Products Laboratory cone kiln is to describe actual installations at representative extractories. A new cone kiln is seldom erected from scratch; instead it must frequently be adapted to existing extractory facilities, which, of course, vary greatly depending on the species of cones and volume of seed required. A general specification that will apply to each individual installation is therefore unattainable.

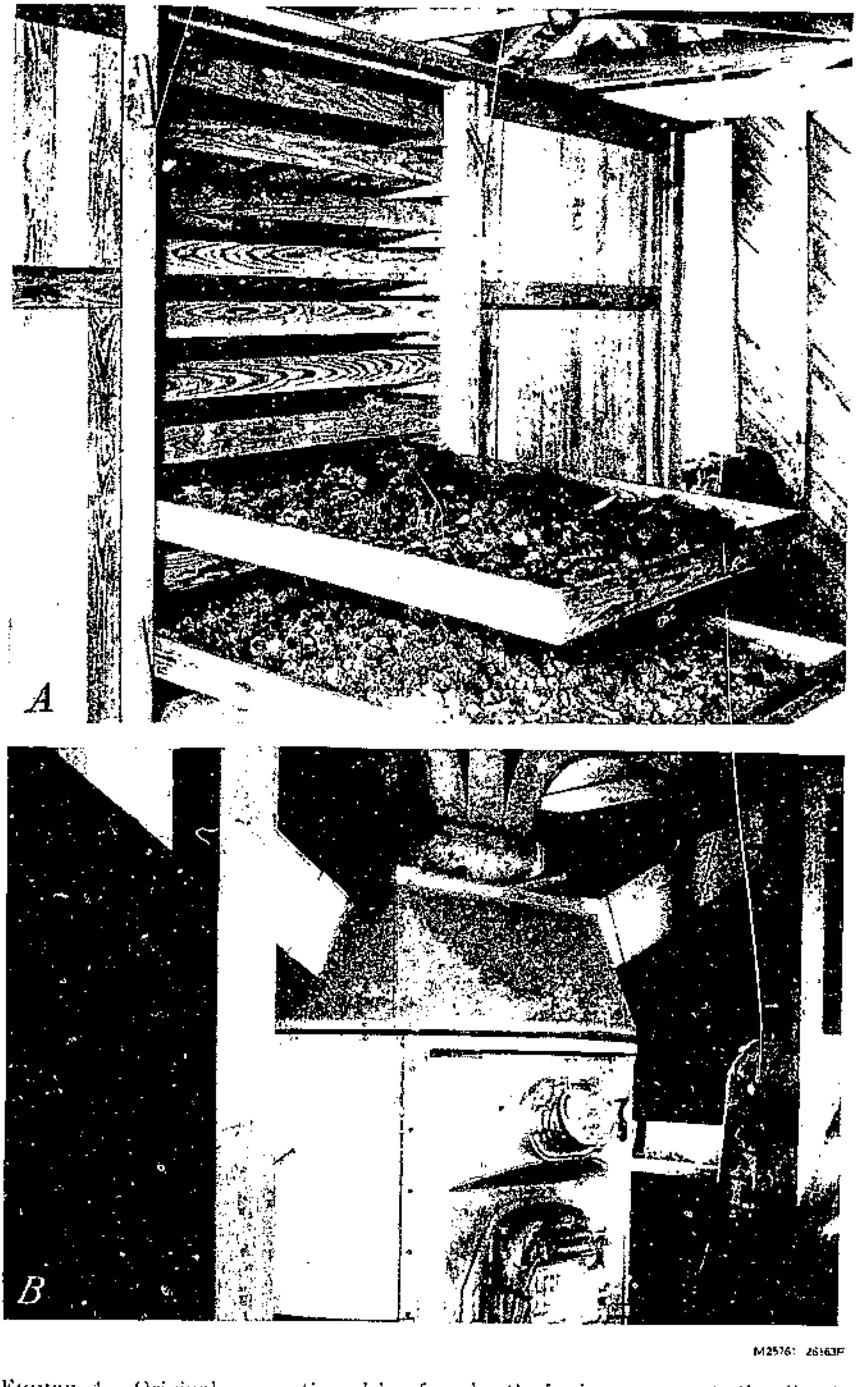
Ozark Extractory

The Ozark Extractory, Russellville, Ark., is representative of the installation of a Forest Products Laboratory cone kiln in an existing extractory. The extractory, which is under the supervision of officers of the Ozark National Forest, was originally built in 1933 to dry shortleaf pine cones. The original drier was of the convection type employing a hot-air furnace and wooden trays (fig. 4). The furnace was located on the ground floor and the drying compartment on the second floor in the central part of a two-story building. Two wings of the building provided shelves for the storage of cones. The precured, or air-dried, cones were carried in sacks to the second floor where they were spread on trays and loaded into the drying compartment. Considerable rehandling of the trays was necessary to obtain seed production, since only the lower trays of cones opened in a reasonable period of time. The dried, open cones were returned by chute to the ground floor for shaking. Seed-cleaning equipment was also located on the ground floor.

High fire hazard and general lack of control of temperature led to the abandonment of this equipment after only one season. It was replaced in 1935 with a Forest Products Laboratory cone kiln. The new kiln was set up to dry an average volume of 6,000 bushels of cones per year with the cost of the equipment amortized over a 10-year period, although the expected useful life is at least 20 years. The bill of material was as follows:

Steel (structural items and sheet metal), 1,800 pounds
Asbestos cement panels, 340 square feet
Low-pressure steam boiler—approximately 850 square feet of radiation—with required accessories including 1 water-level controller and safety feeder for boiler
Steam-fitting requirements (pipe in approximate lengths):
- 4-inch steel pipe, 8 feet
- 3-inch steel pipe, 30 feet
- 2-inch steel pipe, 45 feet
- 1-inch steel pipe, 410 feet
- Nipples, T, elbows, etc., for 1-, 2-, 3-, and 4-inch pipe
- Pipe covering for all but about 385 feet of 1-inch pipe
- 1 2-inch motor-operated valve
- 1 1-inch motor-operated valve
- 15 hand valves (globe)
- 3 air valves
- 4 check valves

Screws, bolts, etc.:
- 340 ¼-inch lead head bolts
- 160 ¼-inch machine screws and bolts
- 30 5/16-inch machine screws and bolts
- 250 ⅜-inch machine screws and bolts
- 20 ½-inch machine screws and bolts
- 72 butt-head rivets



M25761 26963F

FIGURE 4. Original convection drier for shortleaf pine cones at the Ozark Extractory: *A*, The drying compartment; *B*, the hot-air furnace.

Fan equipment:
- 2 24-inch disk fans
- 4 ball-bearing pillow blocks
- 2 V belts
- 2 ⅓-hp. electric motors
- 2 1-inch by 44⅝-inch ground shafts
- 2 sets of fittings for greasing bearings

Electric equipment:
- 1 ⅛-hp. blower, 700 (CFM)
- 1 electric recorder-controller 2-pen
- 1 master switch
- 3 motor-starting switches
- 2 motor-reversing switches
- 1 toggle-light switch
- 2 vaporproof lights
- Approximately 40 feet of ½-inch rigid conduit

Door equipment:
- 1 flush roller-strike door lock, capable of being opened from within or without
- 3 12-inch ball-bearing door hinges
- 4 feet of soft wool
- 18 feet of extruded rubber heat-resistant gasket

Accessories:
- 1 water-box fixture
- Sheet packing
- Twisted packing
- 3 gallons of kiln paint
- 100 cone trays
- 4 skids
- 1 lift truck

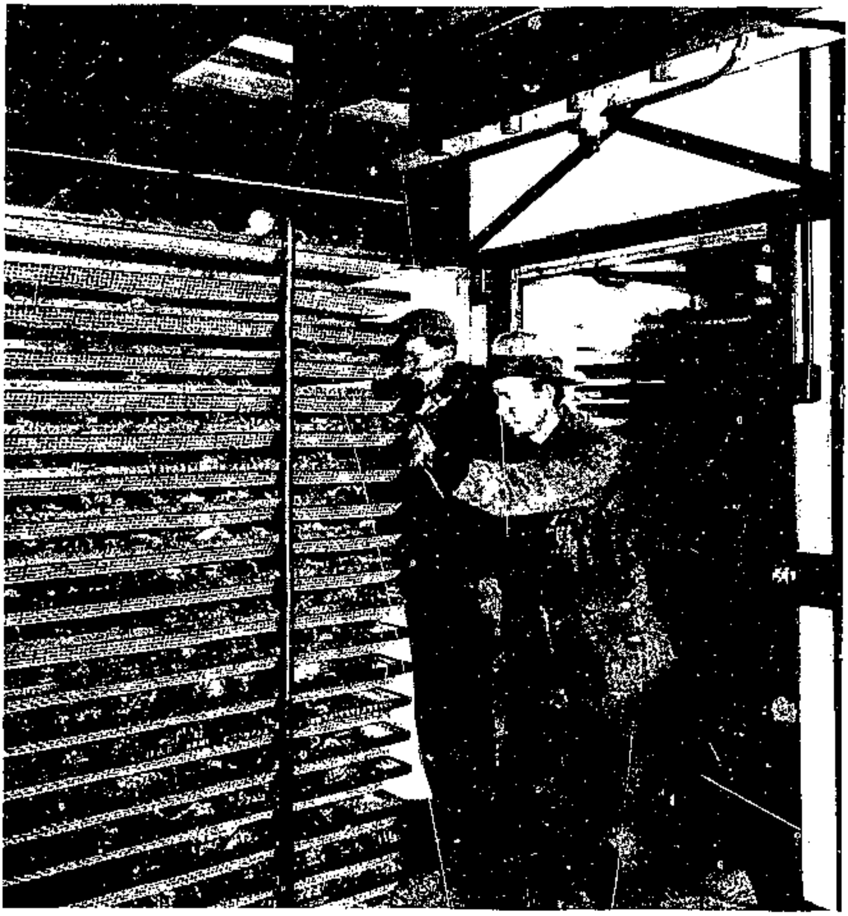
The new kiln is located on the ground floor in the central area of the original extractory building. The wall and ceiling panels of the kiln are made of asbestos cement of high resistance to fire. The door is constructed of the same material, is easy-swinging, and is provided with a latch that can be operated from the inside of the kiln as well as the outside. Gaskets of heat-resisting rubber are used around the doorcasing to prevent leakage of air. The skid loads of dry cones (fig. 5) are hoisted by elevator to the second floor where the cone shaker and seedcleaning equipment are located. Two skids of cones are placed in the compartment as shown in the sketches of figure 2, *B*.

The heating system in the kiln is subdivided into three separate units so that the radiation can be adjusted to meet the heating requirements with better temperature control. The steam connections and valves to the three heating units are shown in figure 6, *A*, with automatic motor-operated valve (*a*) placed in a bypass around the hand valves. Steam can be delivered to the coils without going through the control valve. The opening and closing of the motor-operated valve is controlled by the electric recorder-controller. This also controls operation of the blower on top of the kiln which provides positive ventilation. One of the two fan motors and the drive arrangement are shown in figure 6, *A*.

The returns from the heating coils are shown on the extreme right of figure 6, *B*. Each return line is provided with an air vent. The motor-operated valve in the center is on the steam-spray line that provides vapor when the relative humidity in the kiln is lower than that set on the recorder-controller. As this valve is also in a bypass line, steam can be introduced into the kiln without actuating the controls.

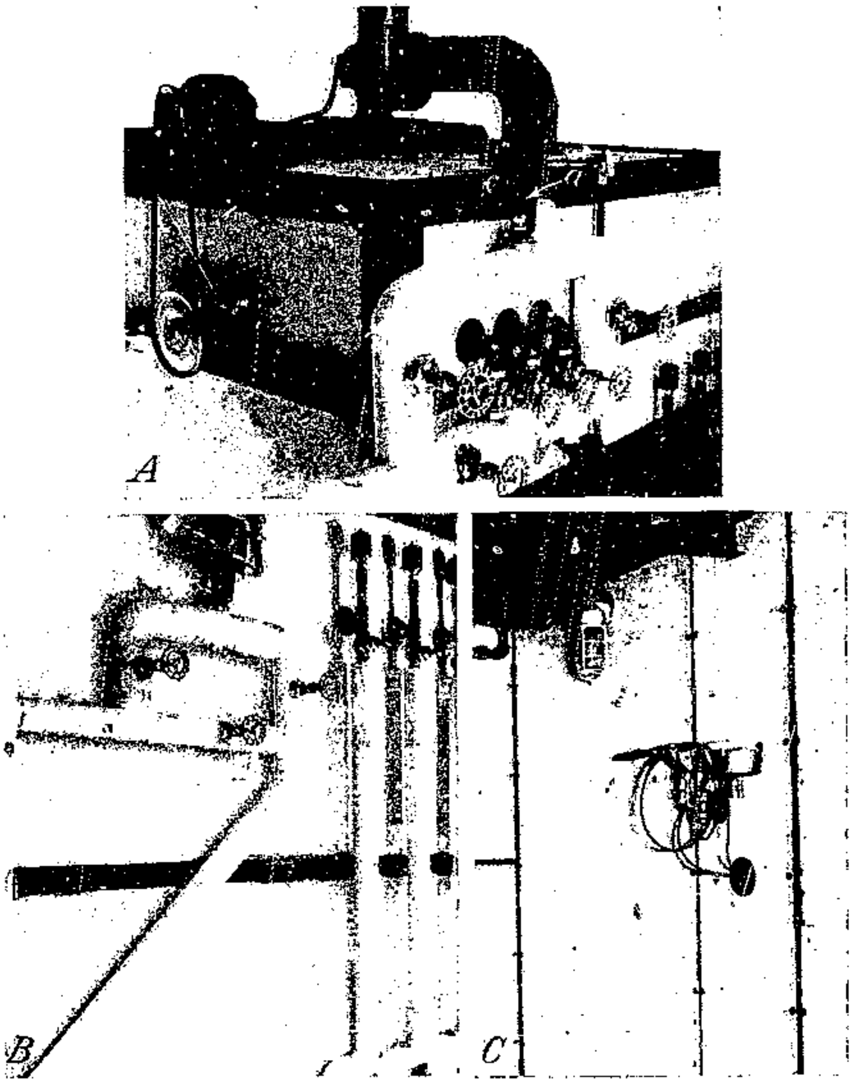
Lights in vapor-tight mountings are provided within the kiln (fig. 6, *C*). The two thermal elements of the recorder-controller, with a constant water-level fixture, are shown mounted in the center of the wall. One of the elements measures the dry-bulb temperature of the kiln atmosphere and the other, covered with a wet wick, measures the wet-bulb temperature. The depression of the wet bulb affords a measure of the relative humidity of the kiln atmosphere. The instrument to which these elements are connected not only records the temperatures of the elements but controls the dry-bulb and wet-bulb temperature of the kiln atmosphere over a range of 50° to 200° F.

During the 1935–36 season more than 19,000 bushels of cones were dried in this new kiln. The trays were each loaded with three-fourths of a bushel of shortleaf pine cones, making a kiln charge of 37 bushels. A kiln temperature of 140° F. was used at as great a wet-bulb depression as could be maintained. Shortleaf pine cones precured about 1



M27604F

FIGURE 5.—Skid load of cones in wire trays leaving the kiln at the Ozark Extractory.



M26699–26701–29430F

FIGURE 6.—Construction details of Ozark cone kiln: *A*, Top, end, and side of kiln; *B*, rear view of kiln; *C*, interior wall of kiln.

month required 8 hours of heating to produce satisfactory seed yields; cones precured for more than a month required 6 hours; and well air-dried cones required only 4 hours of heating.

The modern automatic instruments with which the cone kiln is equipped made it possible to reduce the number of men required for operating the kiln to a minimum and to simplify their tasks greatly. In operation the kiln yielded more viable seeds per bushel of cones in less time and at a lower cost per pound of seed than the method originally employed at the Ozark Extractory.

Cass Lake and Chittenden Extractory Installations

The Forest Service extractory buildings at Cass Lake, Minn., and Wellston, Mich., are similar in design (fig. 7). The kiln installations are identical, each consisting of two Forest Products Laboratory cone kilns operated independent of each other. Otherwise the construction is the same as that of the Ozark Extractory. The two kilns are built as a single structure separated by a partition wall (fig. 8).

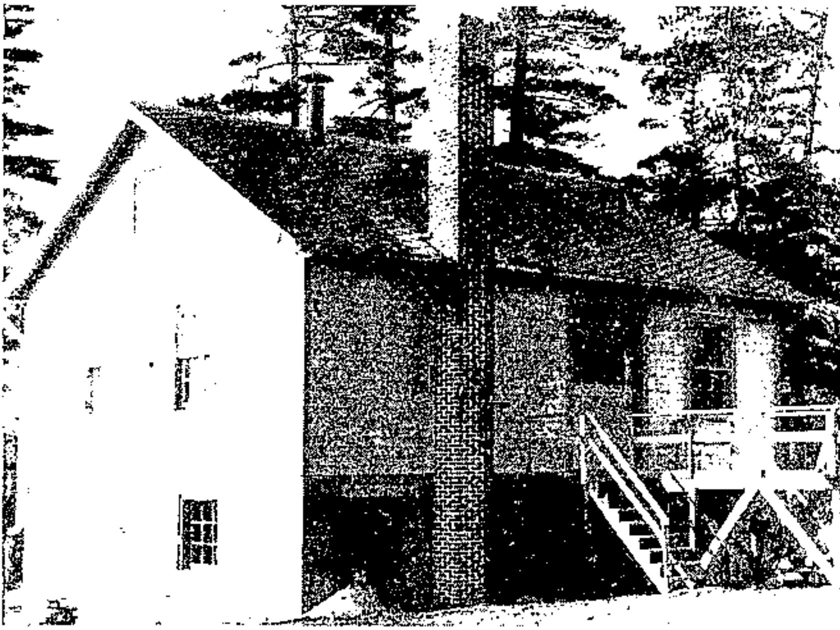
The cones are spread on the kiln trays in the cone-storage sheds (fig. 9) after the volume of cones per tray has been roughly measured. The entire operation is rapid—one man loading the measure, the other spreading the cones, and both handling the trays. A lift truck is run in under the skid to transport the loaded trays to the extractory building. A wood ramp connects the various cone-storage sheds with the extractory building at the Cass Lake extractory (fig. 10). At the Chittenden extractory, by utilizing a hillside location, only a small fill was necessary to obtain a fairly level concrete ramp from the cone-storage shed to the second floor of the extractory building where the kilns are located (fig. 11).

An adequate number of cone trays and skids are available so that two or more kiln charges are ready for the kilns at all times. The skids of loaded cone trays are held in the extractory building long enough to allow the cones to become heated to the room temperature before they are put into the kiln.

Loading and unloading of the kilns are easily and quickly accomplished by means of skids and lift trucks (fig. 12). The fan and heating equipment are located overhead, thus leaving a flat concrete floor and unobstructed wall space for the movement of the lift trucks in and out of the kiln.

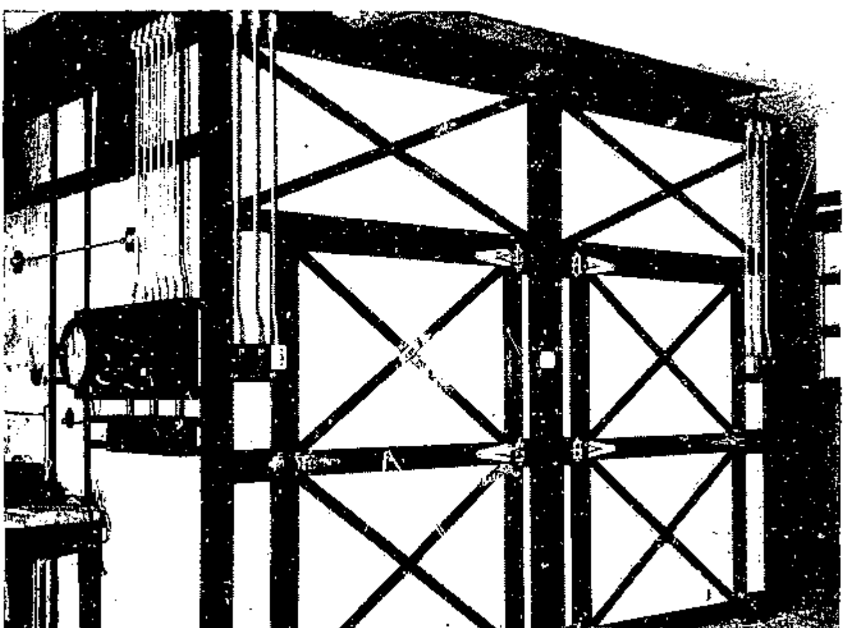
The kilns are heated by means of steam generated at 15 pounds or less pressure in domestic type boilers (fig. 13). Dried seed-extracted cones are used for fuel at both extractories; less than one-third of those available are needed. As steam is used for humidification it was necessary to provide for automatic water-level control in the boiler. The condensate from the steam coils in the kilns is returned by gravity to the boiler. Water pressure at the boiler water-level controller is maintained by an electric pump.

The supervision of these kilns may seem rather technical to the operator not familiar with the equipment, but with experience he will find less technical supervision required than for the ordinary convection drier. The dry-bulb and wet-bulb temperatures are set on the recorder-controller to correspond with whatever temperature and relative humidity are required for a specific species of cones. The drying conditions of the kiln atmosphere are thereafter etsablished and controlled by the automatic recorder-controller instrument. The kiln charge is pushed in, the fans are turned on, and the steam valves opened to obtain rapid heating of the kiln charge. As the cones dry, less heat is required so that the operator reduces the amount of radiation in the kiln in order to prevent exceeding the control setting. Experienced operators soon learn, from observing the movement of the recording dry-bulb temperature pen, when and which steam coils to shut off.



M33145F

FIGURE 7.—The Cass Lake Extractory. The extractory building at the Chittenden Extractory is of the same design.

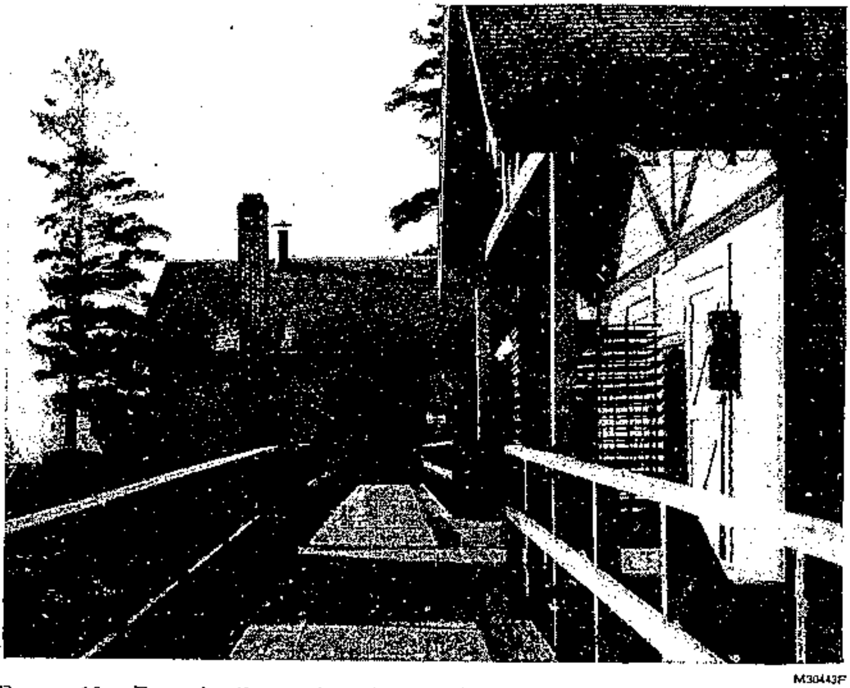


M29452F

FIGURE 8.—Forest Products Laboratory cone kiln installed at the Chittenden Extractory, identical with that at Cass Lake. In operation the loading and unloading of the two units are staggered so that the labor required for cone shaking and seed cleaning is efficiently employed.

M30756F

FIGURE 9.—Loading kiln trays with jack pine cones.



M30443F

FIGURE 10.—Ramp leading to the extractory building at the Cass Lake Extractory. A skid of empty cone trays stands in front of the cone storage shed on the right.

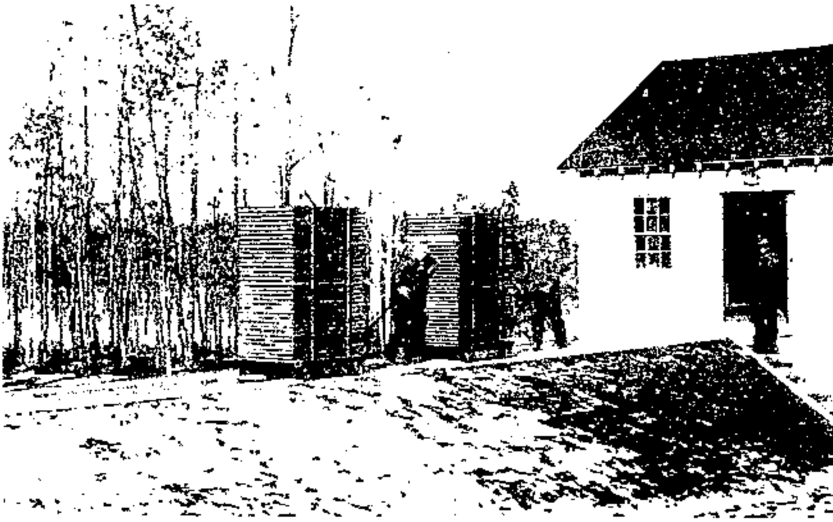


FIGURE 11.—Trucking loaded kiln trays to the extractory building at the Chittenden Extractory.

The Chittenden and Cass Lake extractories have been successfully manned with two shifts of two men and one shift of three men. The three-man shift is ordinarily used during the daytime to catch up on seed-cleaning and seed-weighing routine. Two men are able to load and unload the kiln trays, shake the cones, dewing and clean seed, and maintain steam, although they have very little free time.

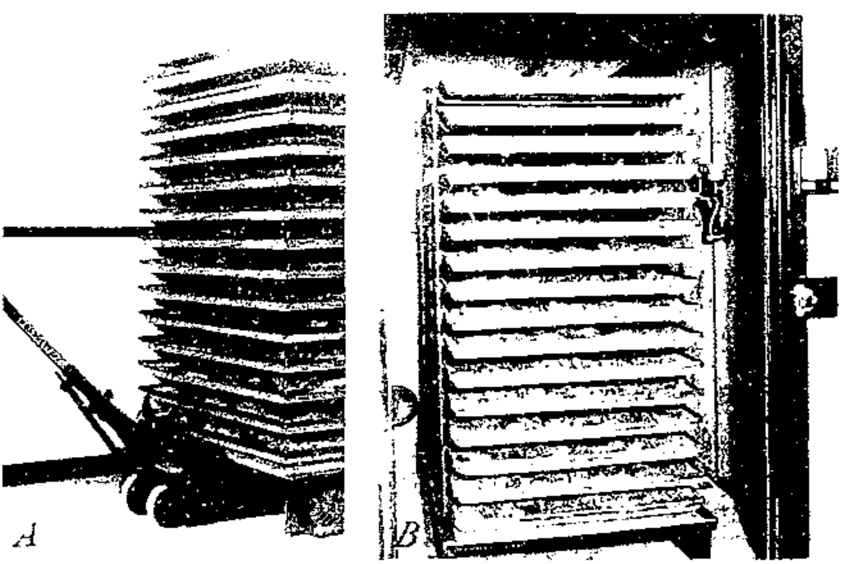


FIGURE 12.—A, The skid load of cone trays can be easily pulled or pushed with a lift truck; B, a charge of eastern white pine cones in the kiln at Cass Lake. Note that the light switches and fan switches are accessible to the operator near the door latch.

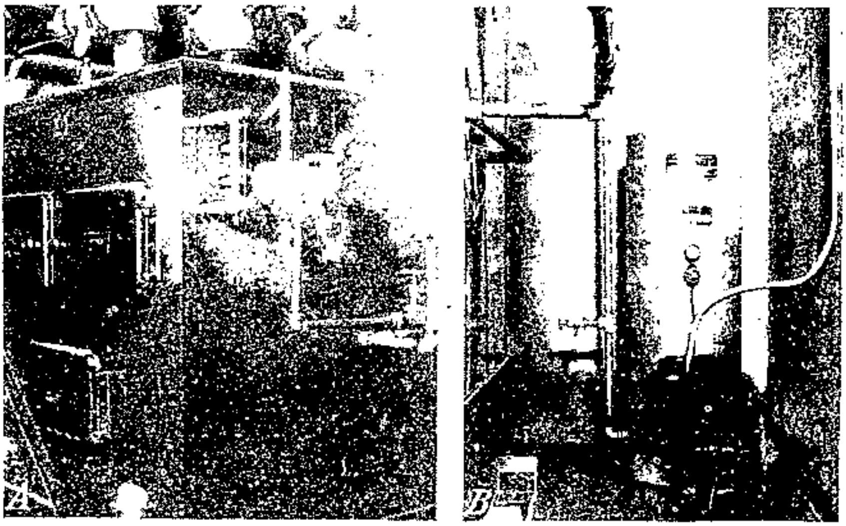


FIGURE 13.—Steam boiler (*A*), and water-pump (*B*) installation at the Chittenden Extractory.

DEVELOPMENT OF SCHEDULES FOR KILN-DRYING CONES

The optimum drying schedule is that combination of temperature, relative humidity, rate of circulation, and time in the kiln which will produce high yields of viable seed at low cost. Rapid drying of cones, as has been discussed, results from maintenance of high dry-bulb temperatures, low wet-bulb temperatures, and high rates of air circulation. The internal factors of moisture movement in the cones may influence the degree or extent to which advantage can be taken of the drying conditions. In drying cones, however, the governing factor is seed viability—seed quality must be maintained. Cones are relatively expensive compared with the cost of seed extraction and it is therefore essential that none of the contained seed be injured.

Working out of the schedules given here entailed not only operation of the kiln, but also a close watch on many additional factors that may have a bearing on seed vitality, such as the handling and storage of the cones before and after kiln drying, and finally the actual sowing and germination of the seed.

The evaporation of cone moisture reduces or depresses the temperature of the cones to less than that of the dry-bulb temperature of the kiln. Theoretically, the initial kiln temperatures can be very high as the evaporation of the moisture from the cones keeps them cool, provided sufficient moisture is available for free evaporation. The action is similar to that of the wick on the wet-bulb thermometer. As the rate of evaporation of moisture slows up, the temperature of the cones will rise and the kiln temperature must be lowered to prevent seed injury. A schedule of decreasing temperatures, although theoretically sound while low wet-bulb temperatures are maintained in the kiln, is dangerous in that the seed is likely to be injured.[3] With a schedule of decreasing temperatures, the operator of the kiln is never certain that all the cones have sufficient moisture to keep the cone temperature depressed and therefore he does not know just when to drop the kiln temperature. The constant-temperature schedule has therefore been adopted by most American operators as the most expedient and is the type dealt with in this bulletin.

The most convincing experimental procedure and the one used for determining the kiln schedules described here is to heat the cones at various temperatures, obtain the released seed after different durations of heating, and test for seed viability. Cone treatments made in the kiln that is to be used subsequently to dry the same species of cone eliminates any experimental consideration of the influence of different rates of air circulation. The findings, however, are strictly limited to the kiln in which the cones were heated; recommendations as to schedules for other kiln types cannot be made.

Species and Source of Cones Studied

Cone-drying experiments designed to determine drying conditions that would result in high yields of viable seed were made on eastern white pine (*Pinus strobus*), jack pine (*P. banksiana*), and red pine (*P. resinosa*) cones at the Cass Lake Extractory, Cass Lake, Minn., and on longleaf pine (*P. palustris*) cones at the W. W. Ashe Extractory, Brooklyn, Miss.

Cones of most species open and release their seed during the autumn. Cone opening is particularly rapid if warm, dry winds prevail. To obtain seed in quantities it is necessary to collect the cones after the seed is mature but before the cones have started to open. Provision for aeration in the storage of the moist green cones prevents heating and molding and at the same time allows those cones to precure that have not ripened naturally on the trees.

EASTERN WHITE PINE

Although eastern white pine cones are often air-dried to complete opening, the operation requires a rather long time. After some preliminary air-drying, however, they can be kiln-dried in a comparatively short time without damage to the contained seed.

About 660 bushels of eastern white pine cones of the 1936 crop, collected on the Chippewa National Forest from trees of 9 to 12 inches in diameter, between August 24 and September 12, 1936, were immediately sent to the extractory, spread on precuring trays, and placed in the cone storage shed. The experimental kiln runs were made between October 10 and 22. The average moisture condition of the precured cones for the duration of the experiments was 36 percent.

A quantity of seed released during the handling of these partially air-dried cones was saved as normally air-dried seed. A sample was sealed in a glass jar and stored in a room at 40° F. Other samples

[3] Toumey, James W. Seeding and planting in the practice of forestry; a manual for the guidance of forestry students, foresters, nurserymen, forest owners, and farmers. Ed. 2, rev. and enl. by Clarence F. Korstian. 507 pp., illus. New York and London. 1931.

were later heat-treated in the laboratory so that results of the cone heat-treating method might be compared with a seed heat-treating procedure.

JACK PINE

Jack pine retains a high percent of its cones on the tree unopened. The picked ripe cones must, therefore, be kiln dried to effect seed release.

Cones needed for each experimental kiln run were taken from a supply of 257 bushels of jack pine cones picked from mature trees 9 to 18 inches in diameter felled in the Bena District of the Chippewa National Forest between September 3 and 17, 1936. Jack pine cones can be bulk-piled without damage, unlike eastern white pine, black spruce, or white spruce cones, which must be spread on precuring trays for storage. The cones were therefore stored in sacks, which were piled in one corner of a cone-storage shed until needed. The experimental kiln runs were made in October 1936, after the cones had been stored for about 5 weeks. The average moisture content of these cones was 22 percent.

Seed heating-treating studies were not made because air-extracted jack pine seed was not available.

RED PINE

Red pine cones are sometimes stored in sacks, but it is believed that this method of cone storage is injurious. The cones are known to "case-harden" in the sacks, requiring submersion of the cones in water prior to kiln drying in order to obtain good opening. On the other hand, the traying of cones for storage requires additional equipment and entails rehandling. A comparison of the merits of the storage of cones in sacks and in trays was therefore an essential additional part of this study.

After an adequate volume of cones of the second and third week of the 1937 collection on the Chippewa National Forest had accumulated at the Cass Lake Extractory, they were randomly sorted into three equal piles. One was immediately heat-treated, but the other two were set aside to be used for the storage phase of the study. The average moisture content of the fresh cones was 60 percent; that of the cones stored in sacks for 4 months, 42 percent; and that of the cones stored in trays for 4 months, 27 percent.

Some of the green cones were dried at room temperatures (80° F. or less) to produce seed that could be considered as being normally air dried. A sample of this seed was then stored in a glass jar in a room at 40° and subsequently heat-treated in the laboratory.

LONGLEAF PINE

The Forest Service operates four extractories having forced-air circulation cone driers to produce the slash, longleaf, shortleaf, and loblolly seed required by its southern nurseries. The principal species extracted is longleaf pine and a temperature of 120° F. is used in the cone driers. If higher temperatures could be used without reducing the viability of the obtained seed, the drying rate of the cones would, of course, be speeded up and seed production thereby increased. An experiment in the drying of longleaf pine cones to determine the influence of increased cone temperatures on the germinative capacity of longleaf pine seed was accordingly made at the W. W. Ashe Extractory in the fall of 1937.

The longleaf pine cones were collected on the Leaf River unit of the Desoto National Forest in the fall of 1937. The source of trees was almost entirely second growth, of an age class between 30 and 60 years, growing in open stands at an elevation of 75 to 150 feet above sea level. The cones were stored in a cone-storage shed for about 2 weeks. The average moisture content of the cones at the time of kiln-drying was 35 percent.

Air-dried longleaf pine seed for a seed heat-treating study was obtained from cones collected on the Kisatchie National Forest during the fall of 1936. The comparison of seed-heating studies with the foregoing cone-drying studies of this species was made with cone crops differing in both year and locality.

Procedure for Cone-Drying Experiments

The cone-drying experiments were designed so that the temperature and duration variables were tried in all combinations, except that in the jack-pine experiments the durations of heating were not the same for all temperatures. The design of the experiments made it possible to analyze the germinative-capacity data according to the methods of analysis of variance as systematized by Fisher.[4] The principal variables of the studies were temperature and duration of heating.

In order to compare the various cone treatments it was necessary to adjust the relative humidity of the kilns so that the cones being dried at the various constant temperatures would all dry to about the same moisture content if left in the kiln long enough. Since information to indicate the moisture content which either cones or seed would attain under various conditions of temperature and relative humidity is lacking, the equilibrium moisture-content values for wood, as shown in figure 14, were used. Equilibrium moisture content is defined as the moisture content at which a hygroscopic material neither gains nor loses moisture when surrounded by air at a given relative humidity and temperature. At 120° F., for example, a wood equilibrium moisture content of 6 percent is maintained with a 30-percent relative humidity; at 160° a relative humidity of 45 percent is required.

EASTERN WHITE PINE

Air-dried cones of eastern white pine were kiln-dried at 100°, 120°, 140°, and 160° F. for 2, 4, 8, and 12 hours. All the experimental kiln runs were made at a wood equilibrium moisture content of 6 percent. As four durations of cone drying were made at each of the four different temperatures and two replications of the entire experiment were made, the experiment all together comprised 32 kiln runs. Each run was a random selection from the total available supply of cones.

[4] Fisher, R. A. The design of experiments. Ed. 2, 260 pp., illus. Edinburgh and London. 1937.

Each experimental kiln run consisted of a full kiln charge of 16 bushels of what originally were green closed cones. The 16 kiln trays on each skid were spaced 4 inches apart. When the load of one-half bushel of green cones had fully opened, each tray would be adequately filled.

After kiln-drying, the two skids of kiln trays making up the charge were sorted into two rearranged groups by piling the trays from each alternately on two empty skids. Thus each of the new skids carried groups of trays representing the entire kiln run. These two groups of cones were handled separately through the cone-shaking, seed-dewinging, and seed-cleaning processes and the cleaned seed from each was kept in separate containers, resulting in two lots of seed representing each run. Variations in the drying as the result of location in the kiln itself were randomized out by the foregoing process of shuffling the kiln trays.

The dried cones were tumbled in a hand-operated drum-type shaker in order to shake out the seed. Dewinging of the seed was accomplished by tramping the seed in grain sacks. The seed was cleaned in a hand-operated cleaner and placed in cans having small screw tops. The cans were stored in an unheated building at the extractory until all the runs were completed. They were then stored in a room maintained at 40° F.

Four laboratory germination tests were made on each seed lot obtained in the cone-drying experiment. A preliminary analysis of the germination data indicated that no differences in germinative capacity existed between the two lots of seed representing each kiln run. In the final analysis of the laboratory germinative capacity data each kiln run is represented by eight tests. The degrees of freedom of the variates of the experiment are shown in table 1.

TABLE 1.—*Proportioning of the degrees of freedom associated with the variables of the eastern white pine cone-drying experiment*

Source of variation	Degrees of freedom
Total (32×8)−1	255
Between temperatures (4−1)	3
Between durations (4−1)	3
Between runs (2−1)	1
Interaction:	
Temperature×duration	9
Temperature×runs	3
Duration×runs	3
Temperature×duration×runs	9
Within classes (error) [32×(8−1)]	224

JACK PINE

Jack pine cones from the available supply were kiln-dried at a temperature of 140° F. for 3, 6, and 15½ hours; at 170° for 2, 4, 6, and 22½ hours; at 195° for 2, 3, and 4 hours; and at 200° for 2 hours. All kiln runs were made at 4-percent wood equilibrium moisture content, since a trial run conducted at 170° and at 6-percent wood equilibrium moisture content gave very unsatisfactory cone opening even after 17 hours of treatment.

Before the experimental kiln runs were begun, the supply of cones was built into a conical pile in a large cone-storage shed. This pile

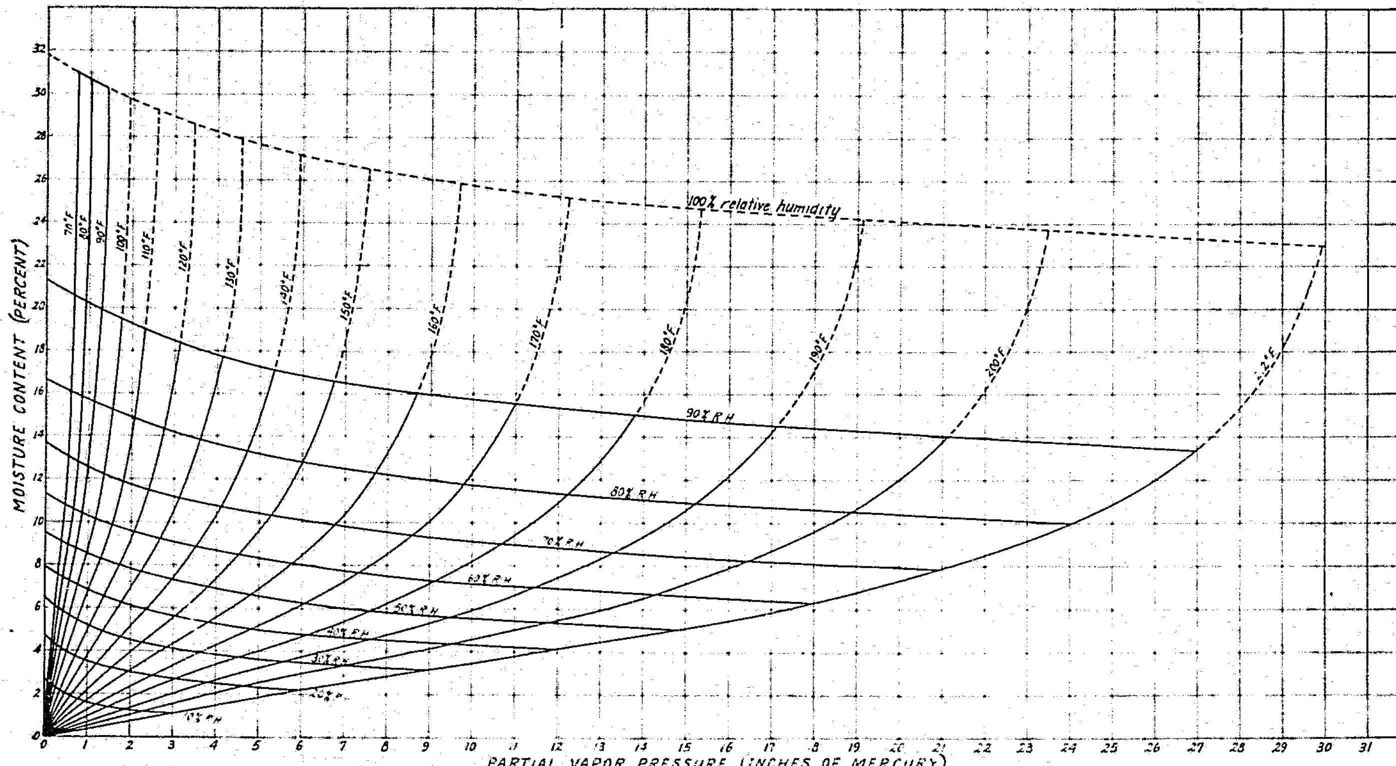


FIGURE 14.—The moisture-content values of Sitka spruce at equilibrium with various temperatures, partial vapor pressures, and relative humidities (R. H.). Other species of wood might show some slight variations, but the general shape of the curves would be the same for all species.

of cones was turned over several times with shovels in somewhat the same manner that concrete is mixed by hand. The kiln trays were filled from this mixed supply of cones, being taken from the pile at random.

Each experimental kiln run was a full kiln charge consisting of 2 skid loads of trays. Each skid held 33 trays on a 2-inch tray spacing and each tray held one-third bushel of jack-pine cones, making a total of 22 bushels of cones for each kiln charge.

After each run, the 2 skid loads of kiln trays making up the charge were sorted into 3 groups of 22 cone trays each. From each skid load of trays the 3 top trays were placed on an empty skid, the next 3 trays on a second empty skid, the next 3 on a third empty skid, the fourth group on the first skid, and so on until the 3 groups of 22 trays were complete. The bottom tray of each of the groups of 3 kiln trays was provided with fly wire to prevent seed falling through to the trays below.

The cones of each of the 3 skid loads were handled separately through the cone-shaking, seed-dewinging, and seed-cleaning processes, which were the same as those described for eastern white pine cones. The three cleaned lots of seed resulting were kept in separate containers. Thus 3 lots of seed were obtained representing each kiln run and subsequent treatment. The storage of the seed was the same as for eastern white pine.

The laboratory germinative capacity data indicated that kiln drying at 170° F. for 22½ hours; at 195° for 2, 3, and 4 hours; and at 200° for 2 hours was injurious to the seed. The statistical analysis was confined to the germinative capacity data obtained on seed from cones kiln-dried at 140° for 3, 6, and 15½ hours and at 170° for 2, 4, and 6 hours. The degrees of freedom of the variates are shown in table 2. Each kiln run provided 3 seed samples and each seed sample was tested four times.

TABLE 2.—*Proportioning of the degrees of freedom associated with the variables of the jack pine cone-drying experiment*

Source of variation	Degrees of freedom
Total $(6\times3\times4-1)$	71
Between treatments $(6-1)$	5
Between means of lots within treatments $[6\times(3-1)]$	12
Within lots $[6\times3\times(4-1)]$	54

RED PINE

The experiments on red pine cones were undertaken to determine the merits of (1) kiln-drying fresh cones, (2) storage of cones in sacks and then kiln-drying, and (3) storage of cones in trays and then kiln-drying.

The cones to be dired in the green condition were dumped in a large pile and mixed by turning the pile over two or three times with shovels. Cones were then taken from the pile at random to fill the trays making up the experimental kiln charges. The average moisture content of these green cones was 60 percent. The cones were next dried at 120°, 130°, 140°, 150°, and 160° F. for 3, 5, 7, and 9 hours at both 3 and 6 percent wood equilibrium moisture content.

Full-tray loadings were not made; instead, each experimental kiln run consisted of 5½ bushels of cones on a single skid of 22 trays with ¼ bushel of cones per tray. As the kiln holds 2 skids of trays, 2 runs were started in each kiln, the front skid being pulled out after the shorter duration of treatment and a dummy load of trays put in its place.

The handling of the cones stored in sacks was as follows: The sacked cones were piled in a long row in a cone-storage shed that had an open screened floor. Each sack held approximately 1½ bushels of cones. The sacks were piled six layers high, adjacent layers were separated by two 3- by 3-inch wood spacing strips.

The handling of the cones stored in precuring trays consisted of placing the trays in a shed having a solid floor. The trays were piled one on top of another with spacing bars between them.

Both the sacked and trayed cones were put in the storage sheds in October 1937. The kiln runs were made in February 1938 after the cones had been stored approximately 4 months. These stored cones were dried at 120°, 130°, 140°, 150°, 160°, and 170° F. for 3, 5, 7, and 9 hours at a 3 percent wood equilibrium moisture content. The same kind of tray loading that was used for the green cones was employed. Each kiln run consisted of drying a sack-stored and a tray-stored skid load of trays at the same time. The experimental kiln runs were randomized and the cones used for each of the sack-stored and tray-stored runs were also randomized.

The dewinging, cleaning, and storage of the seed after kiln drying was the same as described for eastern white pine (p. 20).

Each seed sample representing a kiln-drying run was sampled for four laboratory germinative capacity tests. The degree of freedom of the variates for the green cones are shown in table 3 and the stored cones in table 4.

TABLE 3.—*Proportioning of the degrees of freedom associated with the variables of the red pine drying experiment with green cones*

Source of variation	Degrees of freedom
Total (5×4×2×4−1)	159
Between temperatures (5−1)	4
Between durations (4−1)	3
Between equilibrium moisture contents (2−1)	1
Interaction:	
Temperature × duration	12
Temperature × equilibrium moisture content	4
Duration × equilibrium moisture content	3
Temperature × duration × equilibrium moisture content	12
Within classes (error) [5×4×2 (4−1)]	120

TABLE 4.—*Proportioning of the degrees of freedom associated with the variables of the red pine drying experiment with stored cones*

Source of variation	Degrees of freedom
Total (6×4×2×4−1)	191
Between temperatures (6−1)	5
Between durations (4−1)	3
Between storage (2−1)	1
Interaction:	
Temperature × duration	15
Temperature × storage	5
Duration × storage	3
Temperature × duration × storage	15
Within classes (error) [6×4×2 (4−1)]	144

LONGLEAF PINE

Drying treatments were made in the kiln at the W. W. Ashe Extractory. The kiln is much larger than the Ozark, Chittenden, or Cass Lake Extractory kilns although it is a steam-heated, temperature-controlled, and forced-air circulation kiln. The frame building housing the kiln (fig. 15) is a two-story structure and the kiln, also built of wood, is located on the upper floor. The kiln has a capacity of 150 bushels of longleaf pine cones.

M3658CF

FIGURE 15. Extractory building at the W. W. Ashe Nursery, Brooklyn, Miss.

Drying treatments were made at 115°, 120°, 125°, 130°, and 135° F. for durations of 8, 12, and 16 hours, making 15 experimental runs in all. The relative humidity of the kiln atmosphere was adjusted so that all the kiln runs were made at 4 percent wood equilibrium moisture content. The dry-bulb temperature of the kiln was automatically controlled with a thermostat. The wet-bulb temperature was manually controlled by the adjustment of the intake of fresh air.

Each experimental kiln run consisted of one skid load of 10 fully loaded cone trays. The usual tray loading was about 3 bushels of cones, making a test load of about 30 bushels of cones. Immediately after removing the skid of cones from the kiln, the cones were shaken and the seed obtained was cleaned without dewinging. The seed was sampled by halving and quartering the supply. The seed samples were placed in cloth bags, which allowed the seed to dry, and were stored in a cool room. A few days after the runs were completed the seed was transferred to glass jars having screw tops and stored in a room maintained at 40° F.

Each seed sample was tested in the laboratory on four different sublots. The degrees of freedom of the variables of the germinative capacity data are shown in table 5.

TABLE 5.—*Proportioning of the degrees of freedom associated with the variables of the longleaf pine cone-drying experiment*

Source of variation	Degrees of freedom
Total (5×3×4−1)	59
Between temperatures (5−1)	4
Between durations (3−1)	2
Interaction:	
Temperature×duration	8
Within classes (error) [5×3 (4−1)]	45

SEED TESTING

LABORATORY TESTING

A uniform germination technic was used in the laboratory to test the viability of the many seed samples studied. The germination sample consisted of 1,000 randomly selected seed from the supply representing each treatment. The eastern white pine, red pine, and jack pine samples were obtained by splitting the supply with a seed sampler until the approximate sample size was obtained, from which the 1,000 seeds were selected at random. The longleaf pine samples were obtained by quartering a pyramidal pile of seed to a small sample.

Each seed sample was divided into 4 sublot samples of 250 seeds and each sublot was sown in a different flat containing washed and sterilized plaster sand.

The longleaf, eastern white, and red pine seed flats were stored in a room maintained at about 40° F. The after-ripening period for these three species was 30 days. The jack pine seed samples were germinated without stratification.

The germination room was operated at 60° F. for 16 hours and 80° for 8 hours of the day. Electric lamps about 2 feet above the sand flats were turned on when the room was operated at 80°. The eastern white pine and the jack pine seed samples were germinated in the seed laboratory at the Lake States Forest Experiment Station (fig. 16, *A*). The longleaf pine and the red pine seed samples were germinated in a temperature-controlled room at the Forest Products Laboratory (fig. 16, *B*). The flats for all species were shifted around in order to expose them to the varied conditions of light, temperature, and circulation of air.

As the seeds sprouted they were lifted and the count recorded. Except for the jack pine, the ungerminated seed were lifted after germination was complete and cut to determine the number of blind seeds sown in each sublot. Very little difficulty was encountered with damping-off fungus.

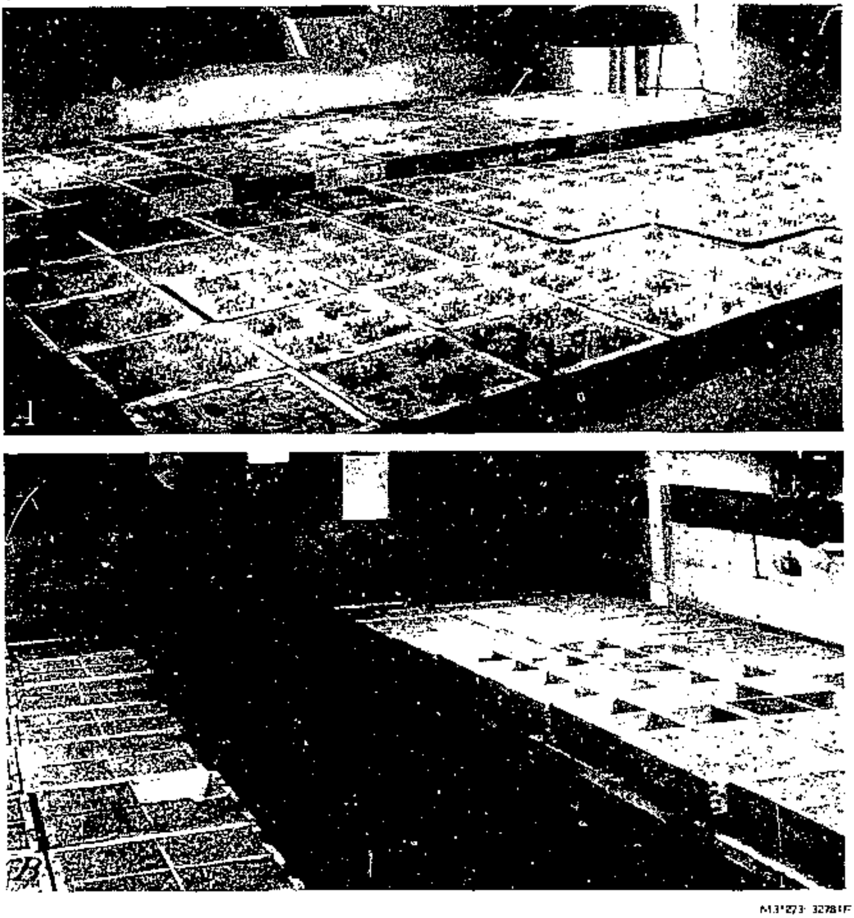
FIELD TESTING

In the laboratory it is possible to control the conditions to which the germinating seed is subjected both as to the germinating medium and the surrounding atmospheric conditions. Such control is not possible in field experiment, owing principally to the heterogeneity of the soil. The design of the field experiment must, therefore, be such that the heterogeneity of soil will not mask the results of different treatments.

280135°—41——4

The Latin square and the randomized block system of field planting were accordingly selected for this experiment. They provide valid estimates of error because of the effective randomization.[5]

The seed obtained from the kiln-drying of the eastern white pine cones was sown in the spring of 1937 in the Lydick Nursery, Cass Lake, Minn., after stratification in wet sand at 40° F. for 30 days. All 16 seed lots were sown in a single 16 by 16 Latin square having 256 plots.



M-31273 32781F

FIGURE 16. *A*, Germination room at the Lake States Forest Experiment Station; *B*, germination room at the Forest Products Laboratory.

Each plot was 4 by 4 feet in size. Adjacent plots in each bed were separated by a bed board. Each bed was 4 feet wide and about 70 feet long. Adjacent beds were separated by a 14-inch path. No special preparation of the soil was made other than discing and working in peat moss.

A sufficient quantity of seed was sown in each plot to produce approximately 1,000 seedlings based upon the laboratory germinative capacity values. The seed in each plot was sown by hand (fig. 17)

[5] See footnote 4, p. 19.

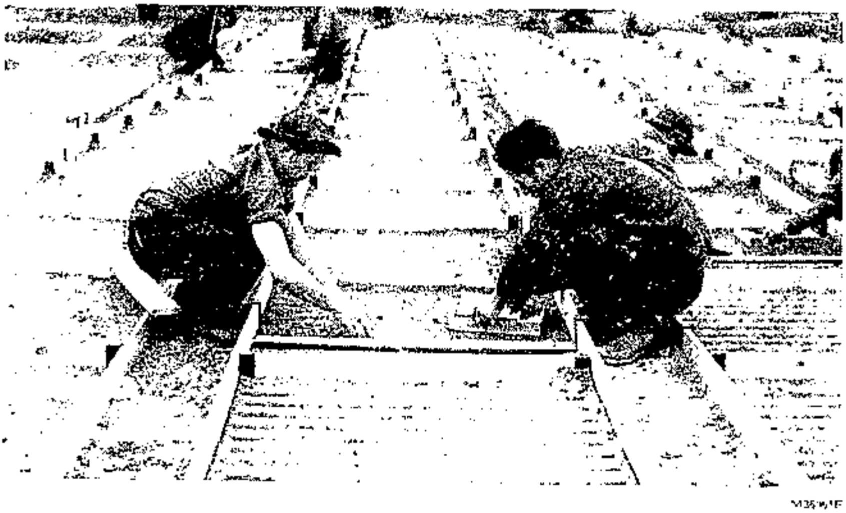


FIGURE 17. Sowing eastern white pine seed in prepared plots in the nursery. The 256 plots in the 16 by 16 Latin square were sown by hand.

in 10 rows spaced 4 inches apart. A sowing trough was used to maintain uniform spread of the seed and depth of coverage. Ten percent of the seed in each plot was sown in each of the 10 rows within the plot (fig. 18).

The count of the seedlings was started 20 days after the seed was sown. Complete seedling counts were taken 24, 31, 38, 45, and 52 days after sowing. A count of the surviving seedlings at the end of the first growing season was made in November 1937.

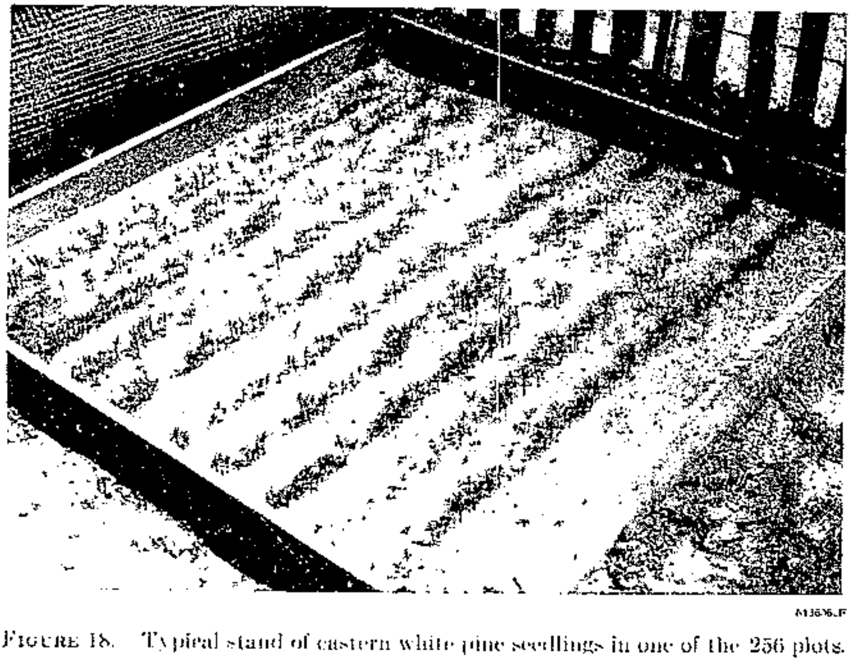


FIGURE 18. Typical stand of eastern white pine seedlings in one of the 256 plots.

M32052F

FIGURE 19.—Covering plots with sand and sprinkling with acid to control damping-off.

Nine of the eleven seed lots from the jack pine cone-treating experiment were sown in a 9 by 9 Latin square in the Lydick nursery. The area was adjacent to the eastern white pine sowing and the same plot size, 4 by 4 feet, was used. The seed was sown in May 1937 by broadcasting and then covering with sand (figs. 19 & 20). The amount of seed, by weight, sown in each plot was based on the laboratory germinative capacity values and seed counts per unit weight. Sufficient seed was sown in each plot to obtain a seedling density of about 1,000 seedlings per plot. A complete count of the seedlings in all the plots was made 67 days after sowing (fig. 21) and a count of the surviving 1-0 plants was made in the spring of 1938 before new growth had started.

Seed from the 15 seed lots of longleaf pine was

M32051F

FIGURE 20.—Covering seedbeds with wire mesh to keep out birds and rodents.

FIGURE 21. — [illegible]

FIGURE 22. — Preparing [illegible]

sown at the W. W. Ashe Nursery, Brooklyn, Miss. The seed had been sealed in cans and stored for 4 months at 40° F. Prior to sowing, the seed was stratified in wet peat moss for 30 days at 40° F. The 15 seed lots were sown in 10 randomized blocks, in contrast to the Latin square sowing of the eastern white and jack pine seed. A sample of 100 seed representing each treatment was sown across a 4-foot bed in each block (fig. 22), in April, 1938, and was covered with burlap for 11 days. Complete counts were taken 21 days after sowing. The number of utilizable 1-0 seedlings, representing plant percent, were counted in December 1938.

The red pine cone drying experiment provided 88 seed lots of which 16 were selected to test in the field. A randomized block system of field sowing similar to the longleaf pine field study was used. The field sowing was made in the Lydick Nursery, in the spring of 1938. A sufficient quantity of seed was sown in each row representing a treatment, in each of the 10 blocks, to produce a density of 100 seedlings per row. A complete count of established seedlings was made 41 days after sowing. A count of the surviving number of 1-0 seedlings was made in November 1938.

CONE OPENING

A reduction in the moisture content of seed cones is expected to cause their opening—the amount of seed released increasing with greater cone opening. Immature or wormy cones, however, are very difficult to open and usually any unopened cones in a kiln charge can be traced to these causes.

Eastern White Pine

Freshly picked, mature eastern white pine cones will not readily open if immediately kiln-dried. The resinous coating seems to prevent the movement of the scales and unfortunately kiln-drying does not greatly change this coating material. A preliminary air-drying period, often called the precuring period, is therefore necessary.

Cone opening in eastern white pine, after a preliminary precuring period sufficiently long to set the resin coating, is proportionate to moisture-content reduction, as shown in figure 23. The degree of cone opening was based on a visual and arbitrary standard. The cones of several trays of each experimental kiln run were inspected and each cone in the tray graded as to whether it was completely open, three-quarters open, one-half open, one-quarter open, or closed. The degree or extent of cone openness was based on what the grader thought the release of seed would be if the cones were well shaken. Other graders using such a system probably would get different results on inspecting the same cones but it is expected that the slope of the cone-opening and moisture-content relationship would be the same. The relation indicates that eastern white pine cones are expected to release all of the contained seed when dried to a cone moisture content of 6 percent.

The relation shown in figure 23 is independent of the kiln temperature at which the cones were dried. The line of regression was calculated by the method of least squares.

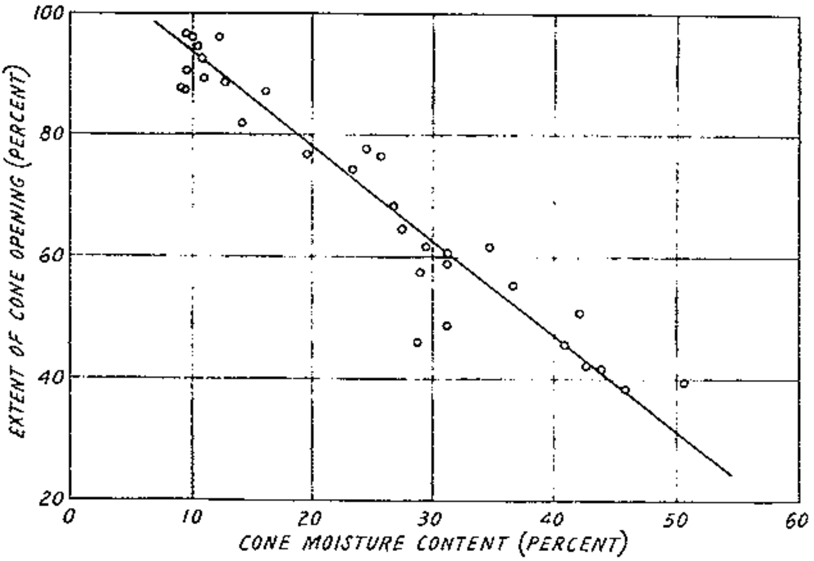


FIGURE 23.—Relation of extent of cone opening and moisture content for eastern white pine cones.

JACK PINE

Jack pine cones will not open appreciably at normal atmospheric temperatures. The cementing material between the scales seems to require heating before cone-opening stresses can react. Since air-drying offers no stimulation to subsequent kiln-drying, mature cones can be kiln-dried immediately after collection.

Jack pine cones open as the contained moisture is evaporated, provided that the drying atmosphere is at a temperature high enough to soften the cementing film between the scales. Cone-opening and moisture-content relationship for jack pine cones dried at different temperatures is shown in figure 24. The percentage of opening is based on a cone-inspection system similar to that used for eastern white pine and also on a system of measuring the volumetric expansion of the dried cones. Careful measurement of original closed and

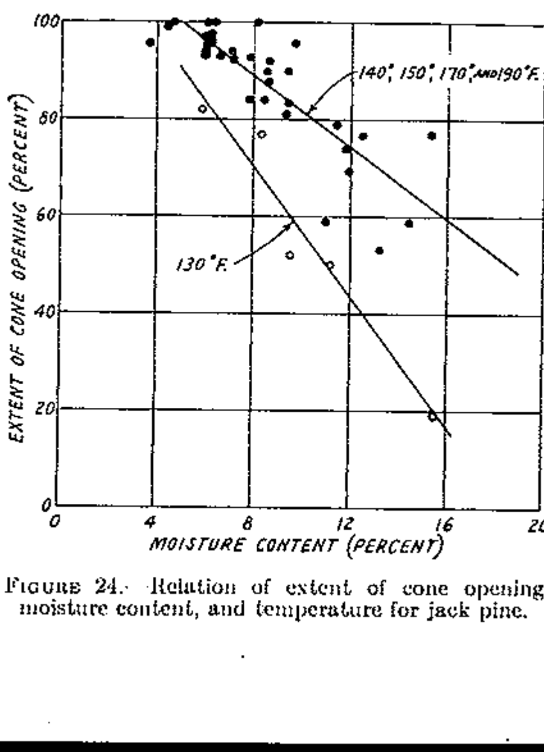


FIGURE 24.—Relation of extent of cone opening, moisture content, and temperature for jack pine.

subsequent cone volume indicates that the maximum expansion is 2.8; that is to say that 1 bushel of closed jack pine cones will expand to 2.8 bushels when completely opened. The moisture content of jack pine cones prior to kiln-drying was found to be about 22 percent. Cones of older crops as distinguished by their color, freshly picked cones, and cones that had been stored for some time had moisture values not deviating very far from this average value.

To obtain good cone opening in jack pine the kiln temperatures must be at 140° F. or higher. The regression of cone opening on moisture content at 130° F. is significantly lower than the regressions at 140°, 150°, 170°, and 190°, which were pooled in figure 24. Lower moisture values have to be attained when the cones are dried at 130° to obtain the same degree of cone opening as at the higher temperatures. Complete cone opening was obtained at an average moisture content of about 5 percent when kiln-dried at 140° or higher (fig. 24). This means that high kiln temperatures should be used in the kiln-drying of jack pine cones in order to facilitate their opening, concomitant with seed quality.

Red Pine

The relation of cone opening of red pine cones to moisture reduction is shown in figure 25, as measured by the volumetric expansion of the kiln-dried green cones. Maximum expansion was found to be 2.25 times the original closed volume. This 100-percent opening was attained at a moisture content of 12 percent; a higher value than that for either eastern white pine or jack pine. The relation (fig. 25) is linear and therefore cone opening is proportionate to cone moisture content. The line of regression was calculated according to the method of least squares. The influence of temperature was pooled to calculate this regression, since different temperatures did not produce significant differences in cone opening as measured.

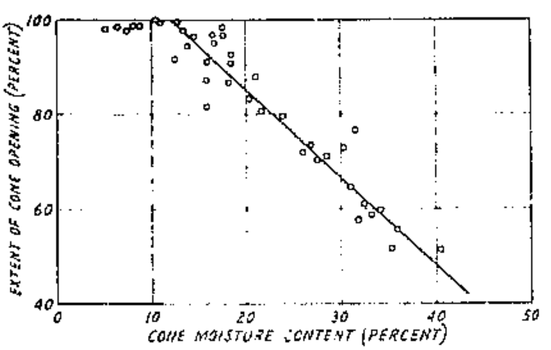


FIGURE 25.—Relation of cone opening to moisture content for red pine cones. Data obtained by kiln-drying green cones at 10° intervals from 120° to 160° F.

SEED YIELD

Cone opening in eastern white pine, jack pine, and red pine is linearly related to cone moisture content and it can be inferred that seed yield is also linearly related to cone moisture content for it is expected that seed release would be directly proportional to cone openness. This is the case with red pine. The relation of seed yield (cleaned and adjusted to a 5 percent moisture-content value) with cone moisture content for red pine is shown in figure 26. A temperature of 160° F. resulted in significantly lowered seed yields. Such was not expected as the cone openness-cone

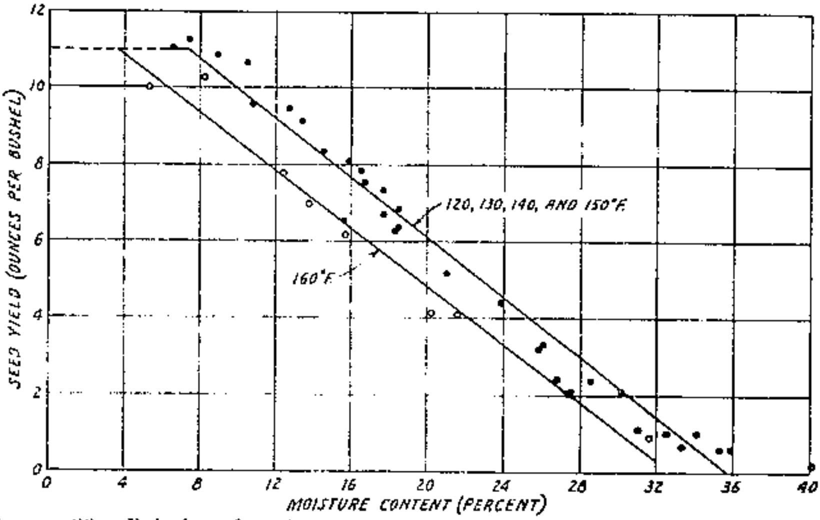


FIGURE 26. Relation of seed yield, cone moisture content, and temperature for red pine. Data obtained by kiln-drying green cones.

moisture content relation (fig. 25) was not influenced by temperature. At kiln temperatures of 150° or lower, the degree of release of seed is directly proportional to cone moisture reduction—seed release starting at about 36 percent when the cones are about half open (fig. 25).

The yield of seed from red pine cones that had been stored either in sacks or on trays for 4 months was not influenced by kiln temperature or the type of cone storage. The regression of seed yield on cone moisture content was not significantly different from that of figure 26 for temperatures of 150° F. or lower.

As indicated in figure 25, based on volume measurements of open cones, maximum cone opening is attained when the moisture content has been reduced to 12 percent. It might be expected that maximum seed yield would be obtained at the same degree of drying, but, as shown in figure 26, additional seed release takes place with drying below

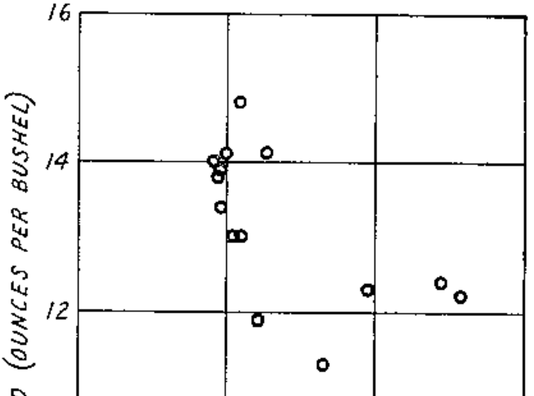


FIGURE 27.—Plot of seed yield and cone moisture content for eastern white pine.

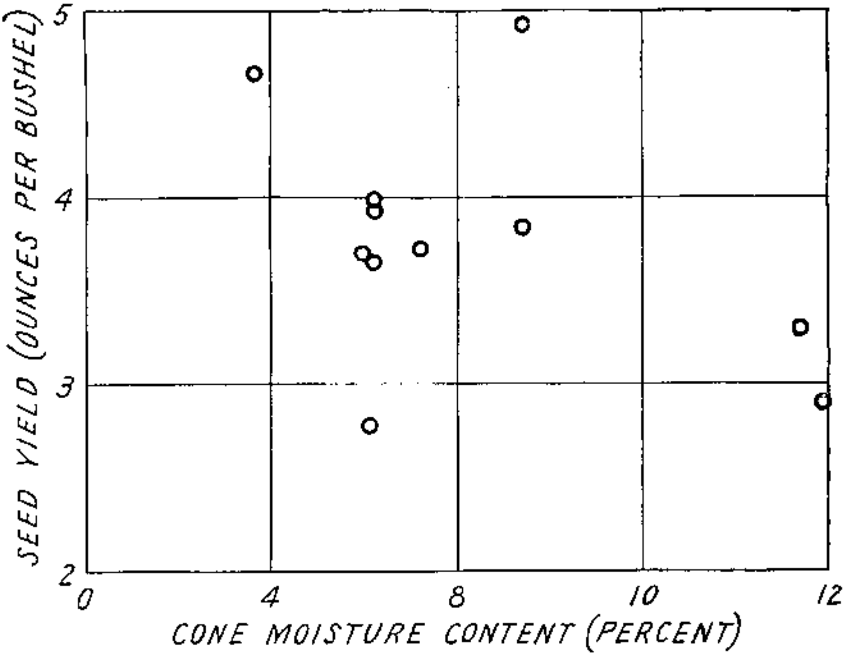


FIGURE 28. Plot of seed yield and cone moisture content for jack pine.

12 percent. Probably the cones actually open an additional amount not measureable by the volume method. A yield of 11 ounces of seed per bushel of cones was obtained at a cone moisture content of 6 percent.

Yield data were also obtained for eastern white pine and jack pine as a function of cone moisture content. The variation in yield, however, was so great that no attempt was made to correlate the plotted data of figures 27 and 28. In handling the partially air-dried eastern white pine cones prior to kiln-drying, some seed was shaken out of the cones. This loss of seed unquestionably influenced the yield data. The jack pine cones used in the study were well mixed and well measured, yet the yield data are particularly erratic.

CONE MOISTURE REDUCTION

As cone opening and seed release are directly proportional to the reduction in moisture content, the rate at which the cones are dried should be as fast as is consistent with the production of good seed. The drying rate is a function of the wet-bulb depression of the kiln atmosphere. In other words, the greater the wet-bulb depression, the faster the drying rate, provided an adequate volume of heated air is circulated through the cones. High temperatures and low wood equilibrium moisture content should therefore be used in the cone kiln. High temperature is not only influential in increasing the wet-bulb depression but at the same time effectively increases the diffusion of moisture in the cones to the evaporation surfaces.

Eastern White Pine

The relation of cone moisture content, kiln temperature, and duration of heating for air-dried eastern white pine cones is shown in figure 29. All the kiln runs from which the data for figure 29 were plotted were made at 6 percent wood equilibrium moisture content. The higher temperatures reduce the cone moisture content at a faster rate. The wet-bulb depression maintained in the kiln at the various dry-bulb temperatures to produce 6 percent wood equilibrium moisture content is as follows:

Kiln temperature (dry bulb) (° F.)	*Wet-bulb depression (° F.)*
100	21.5
120	27.5
140	28.5
160	28.5

The wet-bulb depression is the same at 140° and 160° F., yet the drying rate at the higher temperature is faster, owing to the increased diffusion of moisture in the cones.

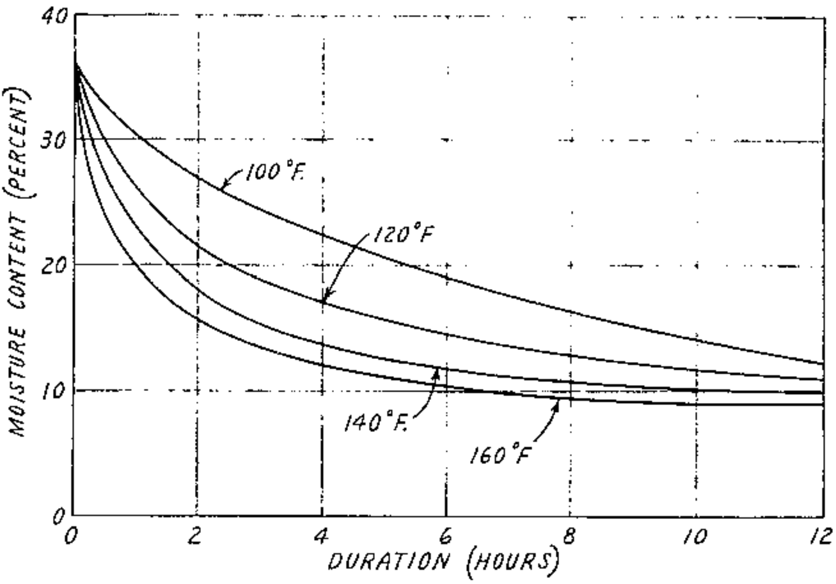


Figure 29. —Relation of cone moisture content, kiln temperature, and duration of heating for eastern white pine. Data from runs made at 6 percent wood equilibrium moisture content in a Forest Products Laboratory cone kiln at Cass Lake, Minn.

Eastern white pine cones must be dried to about 6-percent moisture content in order to produce maximum seed yields. From the curves of figure 29 this moisture condition was not attained in 12 hours of drying even at 160° F. Wood equilibrium moisture content lower than 6 percent should therefore be used in the kiln if the maximum yield of seed is to be attained in a reasonable time.

Jack Pine

The relation of cone moisture content, kiln temperature, and duration of heating for jack pine cones is shown in figure 30. All the kiln runs from which the data for figure 30 were plotted were made at 4 percent wood equilibrium moisture content. The wet-bulb depression associated with the different temperatures at which cone treatments were made is as follows:

Kiln temperature (dry bulb) (° F.)	*Wet-bulb depression (° F.)*
130	38.5
150	41.0
170	43.0
190	43.5

Greater wet-bulb depression, obtained by increased temperatures, increased the drying rate and reduced the time to reach a defintie moisture condition. At 170° F. a heating period of more than 7 hours was required to kiln dry the cones to the 5 percent at which maximum cone openness is expected.

Red Pine

The relation of cone moisture content, kiln temperature, and duration of heating for both green and stored red pine cones is shown in figure 31. The green cones were kiln-dried at both 3- and 6-percent wood equilibrium moisture content. Their initial moisture content was 60 percent. The 3-percent wood equilibrium moisture content speeds up the drying because of the increased wet-bulb depression.

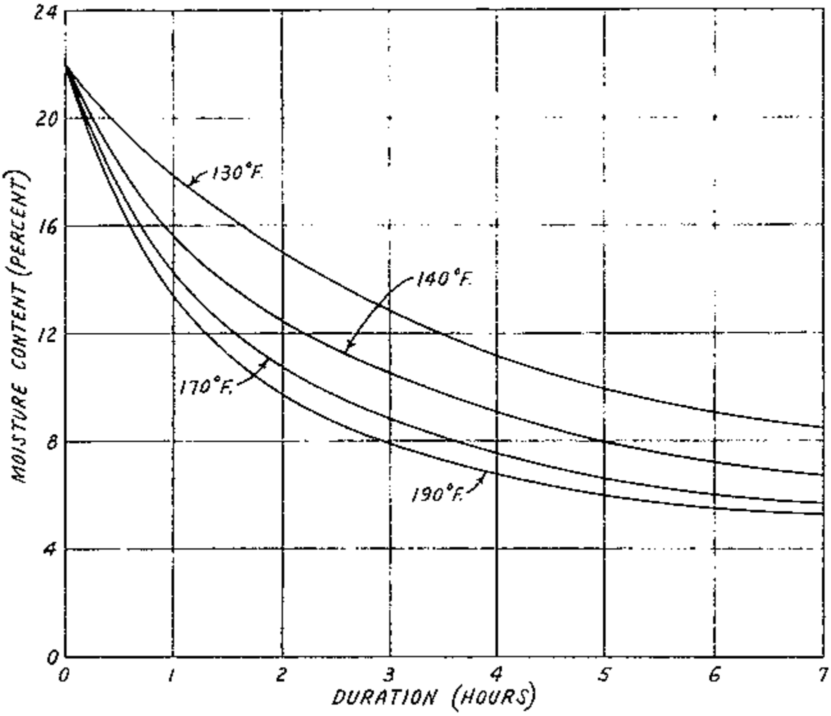


Figure 30. Relation of cone moisture content, kiln temperature, and duration of heating for jack pine. Data from runs made at 4 percent wood equilibrium moisture content in a Forest Products Laboratory cone kiln at Cass Lake, Minn.

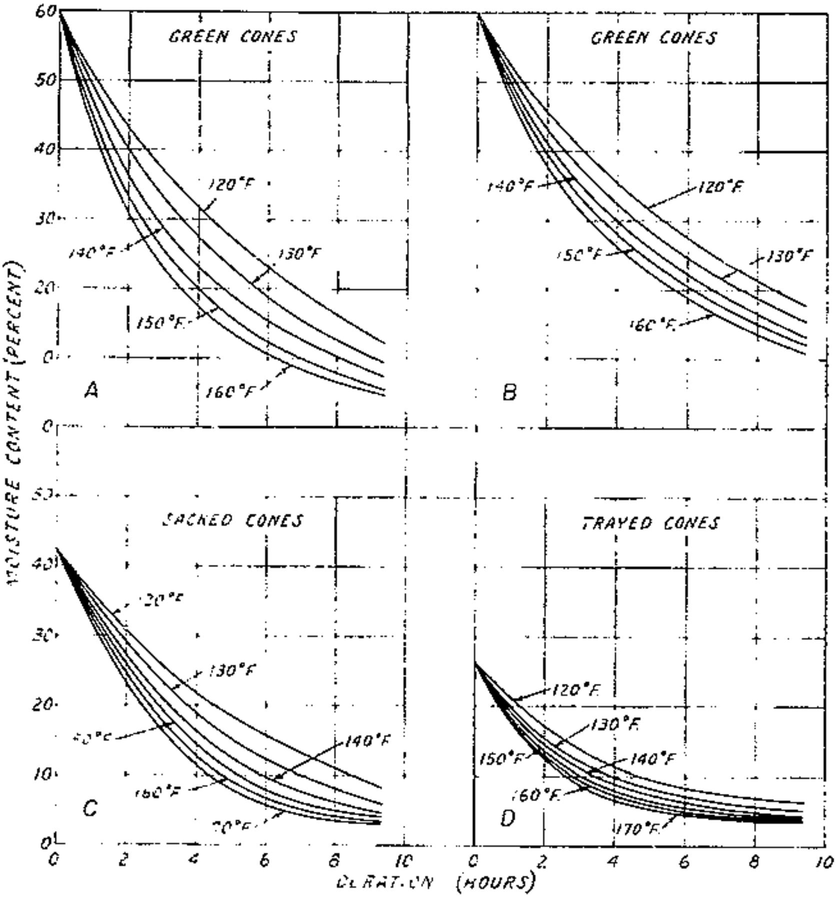


FIGURE 31.—Relation of cone moisture content, kiln temperature, and duration of heating for red pine, (A and B) green, (C) sacked, and (D) trayed cones. All treatments were at 3-percent wood-equilibrium moisture content except B, which was at 6 percent.

The wet-bulb depression at the various temperatures for the 3- and the 6-percent wood equilibrium moisture content are as follows:

Kiln temperatures (dry bulb) (° F.)	Wet-bulb depression at 3-percent equilibrium moisture content (° F.)	Wet-bulb depression at 6-percent equilibrium moisture content (° F.)
120	41.5	27.0
130	45.0	28.0
140	47.0	28.5
150	49.5	28.5
160	51.0	28.5

At the 6-percent wood equilibrium moisture content, the wet-bulb depression is the same for 140°, 150°, and 160° F., yet figure 31 shows that the increasingly higher temperature has reduced the time to reach any given cone moisture. This is due to the increased rate of moisture diffusion in the cones at the increased temperature, as in eastern white pine. The cones do not attain the 6-percent moisture content required for maximum seed release within 9 hours of drying.

At 3-percent wood equilibrium moisture content, however, the cones attain a 6-percent moisture content in less than 9 hours when temperatures of 150° or higher are used.

The advantage of allowing the cones to air-dry before kiln-drying is exemplified in figure 31. The trayed cones were at a moisture content of about 27 percent when placed in the kiln; the time required to lower their moisture content to 6 percent was appreciably less than that required to dry either the sacked cones (42-percent moisture content) or the green cones (60-percent moisture content) to a 6-percent moisture content.

The time required for the cones to attain a 6-percent moisture content when dried at different temperatures and at 3-percent wood equilibrium moisture content is given in figure 32. Green cones kiln-dried at 150° F. and 3-percent wood equilibrium moisture content required about 9 hours, sacked cones about 7 hours, and trayed cones 6 hours to dry to 6 percent. The reduction in kiln time when the cones are well air-dried will, in the long run, pay for the additional costs of the tray storing method.

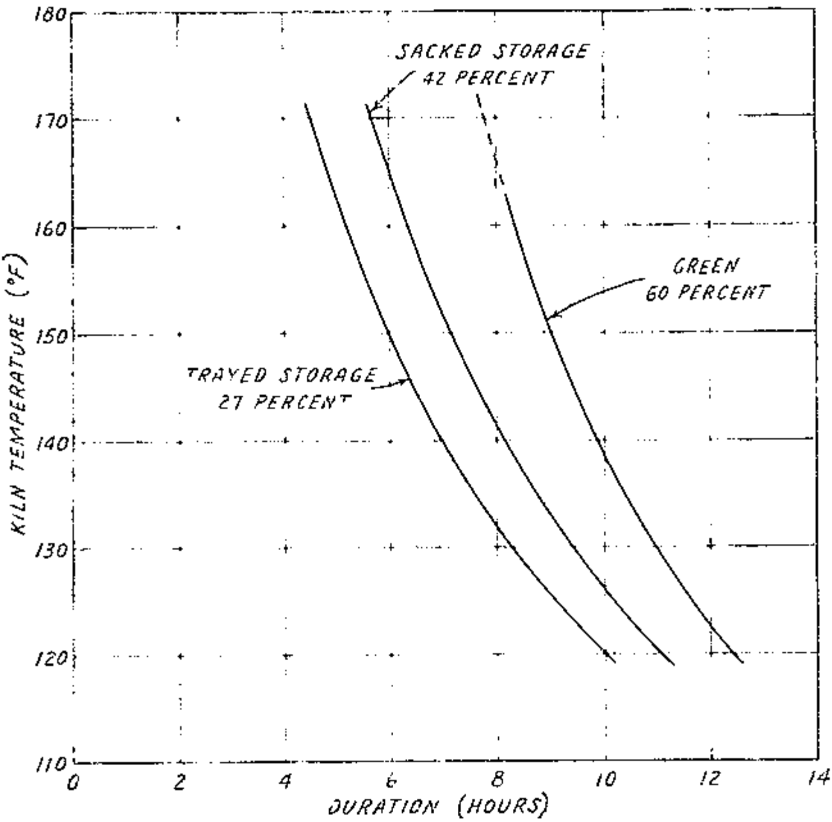


FIGURE 32.—Time required for red pine cones to attain a 6-percent moisture content when dried at different temperatures and 3-percent wood equilibrium moisture content.

Longleaf Pine

The relation of cone moisture content, kiln temperature, and duration of heating for longleaf pine is shown in figure 33. All the kiln runs from which the data for figure 33 were plotted were made at 4 percent wood equilibrium moisture content. The higher temperatures are particularly effective in increasing the rate at which the cone moisture content is lowered.

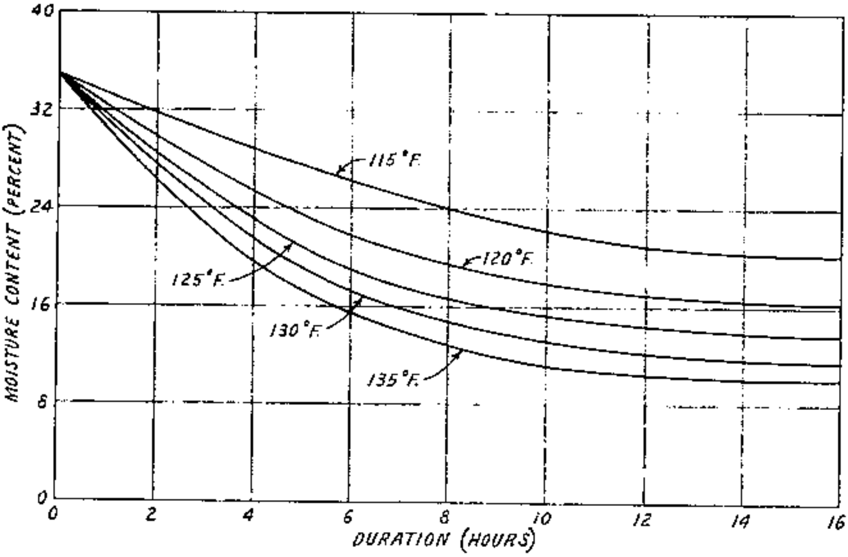


Figure 33.—The relation of cone moisture content, temperatures, and duration of heating for longleaf pine. Data from air-dried cones (35 percent) heat-treated in a forced-air circulation cone kiln at the W. W. Ashe Extractory.

SEED MOISTURE REDUCTION

The reduction in the moisture content of the seed is an important factor in the kiln-drying of cones. Usually the obtained seed must be stored and if it is to be held for any appreciable time, especially in the case of conifer tree seed, it must be dry. Ordinarily the cone-drying process must at the same time desiccate the seed to a moisture condition suitable for prolonged storage. The degree or extent of seed desiccation must not in itself reduce the viability of the seed.

The relationships of seed moisture content to the duration of cone drying for the various species studied were obtained by sampling the seed after cleaning. Since the variation introduced by the seed-cleaning process was not determined, the correlation given here may not be strictly true. The chances are good that wet seed lost and very dry seed regained moisture in the cleaning process. Assuming, however, that the kiln-drying process was accountable for the greater amount of seed desiccation, the correlations do show the general influence of different kiln conditions on seed moisture reduction.

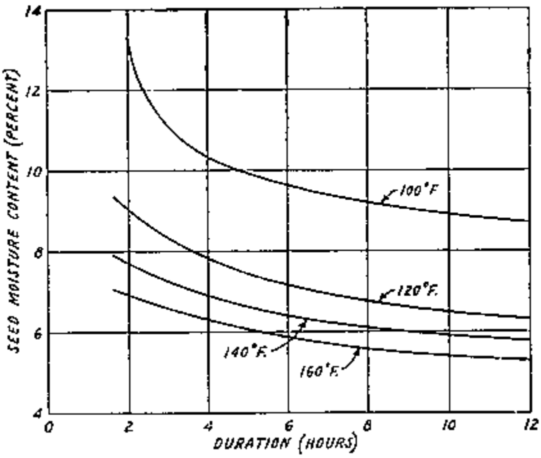


FIGURE 34.—Relation of seed moisture content to duration of cone drying at various temperatures for eastern white pine. Data from partially air-dried cones that were kiln dried at 6 percent wood equilibrium moisture content.

Eastern White Pine

The relation of seed moisture content to duration of cone drying for eastern white pine at various kiln temperatures, all at 6 percent wood equilibrium moisture content, are shown in figure 34. The curves show the influence of the higher temperatures in reducing seed moisture. The 6 percent wood equilibrium moisture content was used to prevent overdrying of the seed, since for this species a 6 percent seed moisture content is considered suitable for prolonged storage. At the higher temperatures the seed attained moisture-content values of less than 6 percent. This means that the wood equilibrium moisture-content values for the seed of eastern white pine are probably less than that for wood at the corresponding temperatures. A comparison of figure 34 with figure 29 shows that the moisture content of the seed at

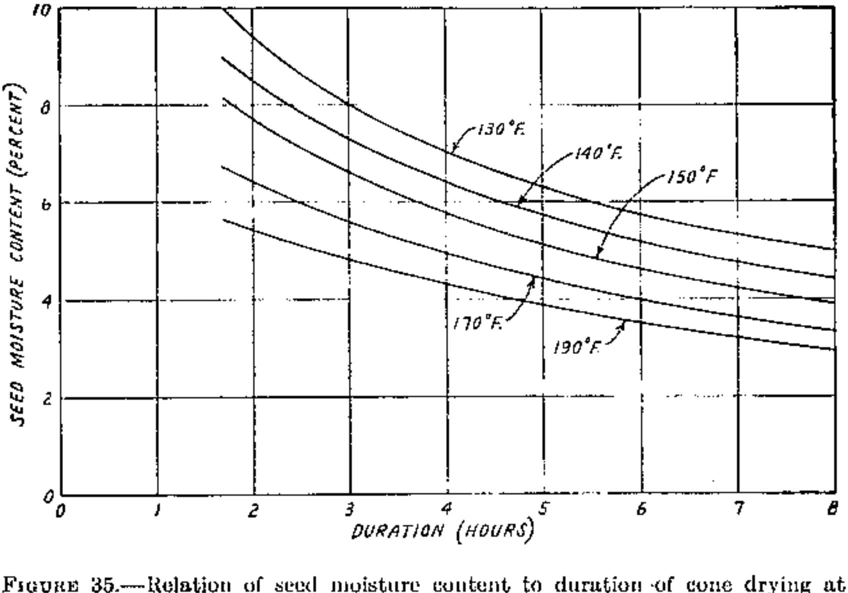


FIGURE 35.—Relation of seed moisture content to duration of cone drying at various temperatures for jack pine. Cones were kiln dried at 4 percent wood equilibrium moisture content.

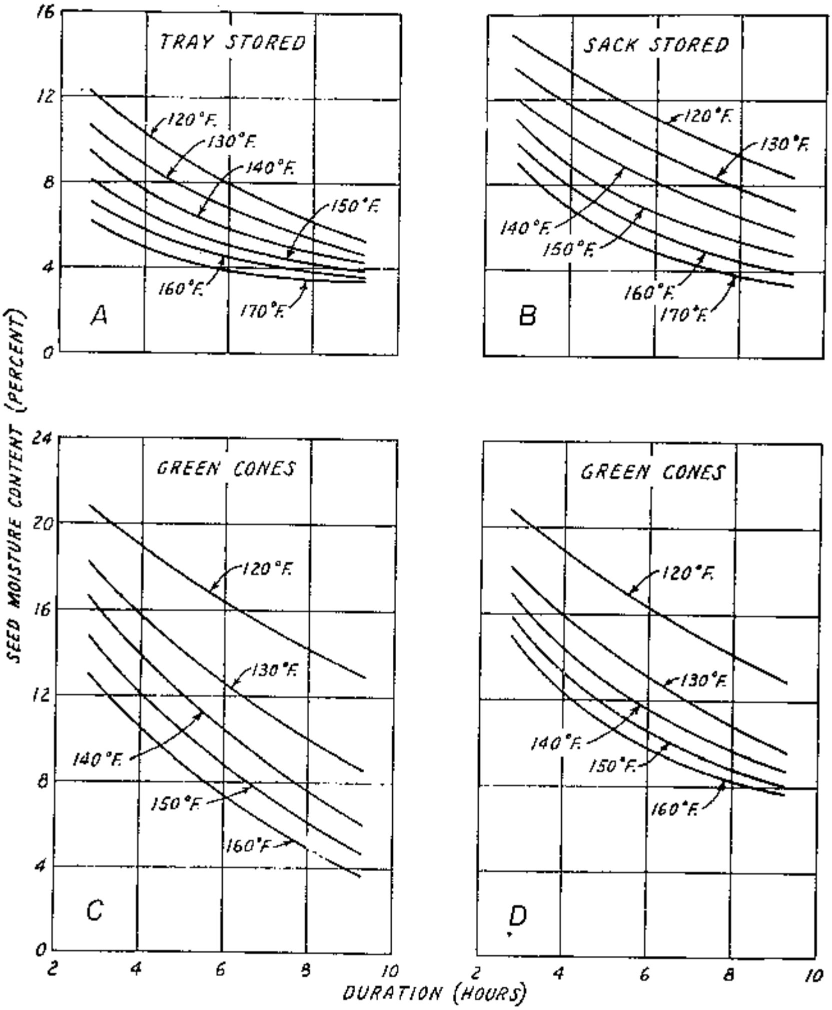


FIGURE 36.—Relation of seed moisture content to duration of cone drying at various temperatures for red pine. Data from stored cones (*A*) trayed and (*B*) sacked kiln-dried at 3 percent wood equilibrium moisture content and green cones kiln-dried at (*C*) 3 and (*D*) 6 percent.

any time and for any of the temperatures studied is considerably less than the moisture content of the cones. In other words, in drying partially air-dried eastern white pine cones, which have opened to a certain extent, the contained seed reaches a lower moisture condition in a shorter time than do the cones. The moisture in the seed is evaporated independently of that in the cones. This difference in dryness of seeds and cones cannot be completely accounted for by seed cleaning. Seed at moisture-content values of less than 8 percent was obtained in the kiln but not in the cleaning room.

Jack Pine

The relation of seed moisture content to duration of cone drying for jack pine at various kiln temperatures, at 4 percent wood equilibrium moisture content, is shown in figure 35. The higher the kiln temperature the quicker the seed is desiccated. The higher kiln temperatures produced seed at moisture-content values of less than 4 percent indicating that the seed probably has a lower equilibrium moisture content value at these conditions than does wood. Comparing figures 35 and 30, the reduction of moisture in the seed is faster than it is in the cones; the seed and cones dry independent of each other, especially after some cone opening has taken place.

Red Pine

The relation of seed moisture content to duration of cone drying for red pine cones in the green condition when dried at both 3 and 6 percent wood equilibrium moisture content are given in figure 36. Similar relationships are also given for stored cones dried at 3 percent wood equilibrium moisture content. A comparison of the various sets of curves shows the superiority of 3 percent wood equilibrium moisture content in reducing the moisture content of the seed at a faster rate. Storage conditions that allow the cones to dry, as in tray storage, enable rapid moisture-content reduction of the seed to a low value when subsequently dried in the kiln. None of the various conditions produced seed with a moisture content under the wood equilibrium moisture content at which they were dried.

As was true for the eastern white pine and jack pine, the red pine seed attains a lower moisture condition than do the cones after various durations of drying at different temperatures. (Compare fig. 36 with fig. 31.)

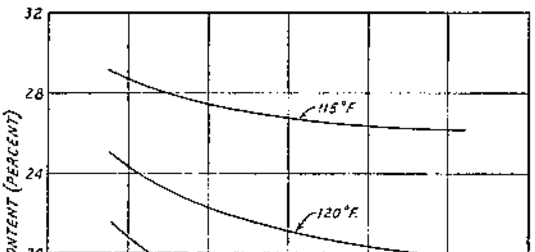


Figure 37.—Relation of seed moisture content to duration of cone drying at various temperatures for longleaf pine. Data from partially air-dried cones that were kiln-dried at 4 percent wood equilibrium moisture content.

Longleaf Pine

Relation of seed moisture content to duration of cone drying for longleaf pine is shown in figure 37. The kiln runs were all made at 4 percent wood equilibrium moisture content. The moisture condition of the seed from the cones dried at any of the kiln temperatures, except 135° F., is too high for subsequent safe storage. Drying the cones at 135° for 16 hours, however, produced seed that after cleaning had a moisture content below 10 percent, which is considered safe for subsequent storage of longleaf pine seed.

A comparison of figure 37 with figure 33 shows that the moisture content of the seed at any given time is greater than that of the cones. The larger size of longleaf pine seed as compared with eastern white pine, red pine, or jack pine seed probably accounts for the moisture condition of the seed lagging behind that of the cones.

VIABILITY OF SEED OBTAINED FROM KILN-DRIED CONES

The results of the laboratory testing of the many seed lots representing the drying of the four species of cones are presented in two forms. First, the viability of the seed sample is indicated by its germinative capacity value as of a time when germination was considered substantially complete. Second, the viability of the seed sample is indicated by the course of the germination. Differences in seed viability as indicated by the analysis of the germinative capacity data are checked by comparison with the course of germination curves.

The results of the field testing of the seed samples are summarized in tables and show the degree to which the field results corroborate the laboratory tests of the same seed samples.

In the analysis of both the laboratory and field tests of the different seed lots, measures of significant differences are based upon the 5-percent probability level.[6]

Eastern White Pine

LABORATORY TESTS

The mean real germinative capacity[7] of the various seed lots representing the 16 eastern white pine cone-drying experiments is given in table 6. The mean values are for the 26th day of germination. An analysis of variance of the germinative capacity data, in percentage, is given in table 7. Differences due to duration of treatment and those due to temperature, and the interaction between these two were all highly significant. Differences due to runs were significant.

Table 6.—*Mean real germinative capacity of eastern white pine seed obtained from kiln-dried cones* [1]

Temperature (°F.)	Germination for indicated cone treatment				Means
	2 hours	4 hours	8 hours	12 hours	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
100	94.3	94.8	95.2	93.4	94.2
120	95.8	97.6	92.7	94.1	95.0
140	94.6	93.5	91.9	93.7	93.4
160	79.2	69.9	45.4	34.8	57.4
Means	91.0	89.0	81.3	78.8	

[1] Values within heavy lines indicate reasonably safe treatments.

[6] See footnote 4, p. 19.

[7] Real germinative capacity is defined as the percent of the number of filled sound seeds capable of germination at the start of the test (ascertained by final cutting test and deducting empty seeds from total) which do germinate within a given period under optional conditions.

TABLE 7.—*Analysis of variance of real germinative capacity (in percent) of eastern white pine seed obtained from kiln-dried cones*

Source of variation	Degrees of freedom	Sum of squares	Mean square	Observed F [1]
Total	255	90,966.73		
Between temperatures	3	65,339.19	21,773.06	[2] 1,216.37
Between durations	3	6,668.68	2,222.89	[2] 124.18
Between runs	1	75.58	75.58	[3] 4.22
Interaction:				
Temperature × duration	9	14,308.70	1,589.86	[2] 88.82
Temperature × runs	3	134.32	44.77	2.50
Duration × runs	3	135.43	45.14	2.25
Temperature × duration × runs	9	295.12	32.79	1.83
Within classes (error)	224	4,009.71	17.90	

[1] F=variance ratio. [2] Highly significant. [3] Significant.

The least significant difference between any two pooled temperature or pooled duration means is

$$\sqrt{\frac{17.90\times 2}{64}}(1.979)=1.5 \text{ percent}$$

The 160° F. pooled temperature mean is significantly lower than the other three pooled temperature means. The 140° pooled temperature mean is significantly lower than the 120° temperature mean but not different from the 100° temperature mean. Only the 8- and 12-hour durations caused significant reductions in real germinative capacity. In table 6 the only important reductions in germinative capacity occurred at the 160° temperature and the differences due to duration are significant only because of the marked reduction in germinative capacity which resulted from drying at this temperature.

The least significant difference between any two means of table 6 is

$$\sqrt{\frac{17.90\times 2}{16}}(2.042)=3.1 \text{ percent}$$

The 160° F. temperature means for 2-, 4-, 8-, and 12-hour durations are all significantly lower than any of the other 12 values as well as being significantly different from each other. Within the blocked-out group of means in table 6, their pooled mean is 94.2; only those differing from this pooled value by

$$\sqrt{\frac{17.90}{192}+\frac{17.90}{4}}(1.972)=4.2 \text{ percent}$$

can be considered significant. None of these 12 values differ from their pooled mean by this amount. It may, therefore, be concluded that any temperature up to and including 140° for durations of 12 hours did not produce seed injury.

Drying air-dried cones at 140° F. for as long as 12 hours at 6 percent wood equilibrium moisture content produced seed having a moisture content less than 6 percent (fig. 34), a level which cannot be considered injurious.

The course of germination curves for the various seed lots obtained from the kiln-dried cones is shown in figure 38. The four different durations of drying at 100°, 120°, and 140° F. were pooled to plot mean curves for the three temperatures, since the individual curves did not differ appreciably. Interpretations of seed quality from these curves substantiate the findings in the analysis of the germinative capacity data, namely, that drying cones at a temperature of 140° at 6 percent wood equilibrium moisture content for a duration of 12 hours was not injurious to the contained seed. A kiln temperature

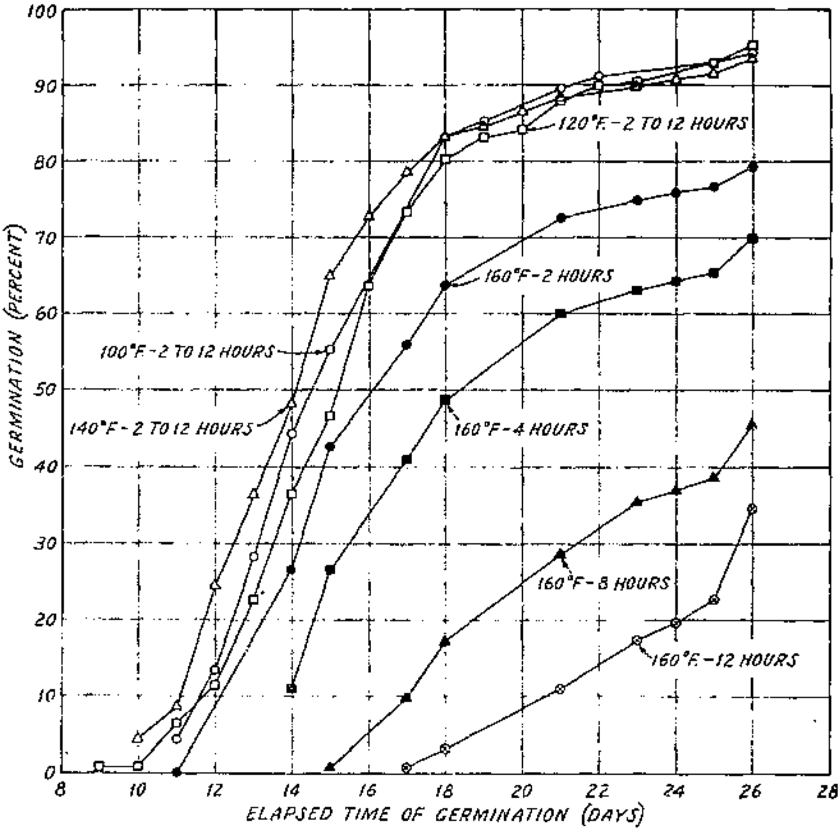


FIGURE 38. Course of germination of eastern white pine seed obtained from cones kiln dried for 2, 4, 8, and 12 hours at 100°, 120°, 140°, and 160° F. at 6-percent wood equilibrium moisture content.

of 160° is decidedly injurious and as the duration of cone drying at this temperature is increased the viability of the contained seed is significantly and substantially reduced.

FIELD TESTS

The summarized results of the field tests of the 16 lots of eastern white pine seed are given in table 8. Complete counts of seedlings by beds, 24, 31, 45, and 52 days after sowing, provided a basis for calculating field germinative capacity. A survival count was made at the end of the first growing season. Analysis of the field germinative-capacity data indicated that those seed lots that had a significantly low laboratory real-germinative-capacity value also had a low field apparent-germinative-capacity value. The values in italics in table 8 are from analyses significantly low as compared with the other values in the same column. The seed obtained from the cones dried at 100° F. for a duration of 4 hours also had a low field-germinative-capacity value, not considered as associated with the original kiln-drying of the cones.

TABLE 8.—*Summary of laboratory and field testing of eastern white pine seed obtained from kiln-dried cones* [1]

Original cone treatment		Laboratory tests		Field tests		Viable seed germinating in field	Viable seed producing 1-0 plants	Losses [3]
Kiln temperature (°F.)	Duration of treatment	Real germinative capacity	Apparent germinative capacity	Germinative capacity	Surviving 1-0 plants [2]			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Hours	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
100	2	94.3	91.1	76.7	58.0	81.3	61.5	25.0
100	4	94.8	93.1	*70.8*	50.5	74.7	53.3	29.1
100	8	95.2	93.3	73.8	54.5	77.5	57.2	26.3
100	12	92.4	90.1	77.3	60.7	83.7	65.7	21.9
120	2	95.8	94.6	75.8	52.9	79.1	55.2	30.2
120	4	97.6	96.8	79.1	59.1	81.0	60.6	25.5
120	8	92.6	92.6	76.6	57.9	82.7	62.5	24.5
120	12	94.1	92.9	75.1	51.6	79.8	54.8	31.9
140	2	94.6	94.6	78.7	57.8	83.2	61.1	26.8
140	4	93.5	93.1	76.1	50.6	81.4	63.7	21.9
140	8	91.9	91.9	75.8	55.0	82.5	59.8	27.6
140	12	93.7	93.0	77.1	60.7	82.3	64.8	21.8
160	2	*79.2*	79.0	*64.2*	*46.3*	81.1	58.5	28.1
160	4	*69.9*	69.9	*54.0*	*38.4*	77.3	54.9	30.6
160	8	*45.4*	45.4	*35.0*	*22.2*	70.1	48.9	*38.8*
160	12	*34.8*	34.7	*25.0*	*13.8*	71.8	39.7	*46.5*

[1] All kiln treatments were made at a 6-percent wood-equilibrium moisture content. Italic figures denote a significantly low value or significantly high loss.
[2] Survival is expressed in percent of the number of seed sown.
[3] Losses are calculated in percent of the number of seeds germinating in the field.

The field-germinative-capacity value of each of the 16 seed lots was less than the laboratory-capacity value for the same seed lot. Generally, however, the percent of viable seed that germinated in the field, based on the laboratory real germinative capacity, was about the same for all seed lots (table 8, column 7). The only seed lot that had a suspiciously low percent of viable seed germinating in the field was associated with a cone-drying treatment made at 160° F. for a duration of 12 hours.

The analysis of the survival data indicated that only those seed lots representing cone-drying treatments made at a temperature of 160° F. produced significantly fewer 1-0 plants. The field testing thus corroborates the laboratory testing, in that a drying temperature of 140° for cones at 6-percent wood equilibrium moisture content for a duration of 12 hours was not injurious to the contained seed. The fact that the two most severe cone-drying treatments, namely, the 160° for durations of 8 and 12 hours, provided seed that did not produce as many 1-0 plants (table 8, column 8) as the other seed lots would indicate that the mortality of plants in these two latter groups is higher than in the others. Knowing the number of seeds that had originally germinated and the number of surviving 1-0 plants, the difference represents the loss sustained during the first year's growth. These mean losses, calculated as a percent of the number of seeds germinating in the field, are given in table 8, column 9. Significantly increased losses are associated with the seed lots representing cone-drying treatments made at a temperature of 160° for durations of 8 and 12 hours. Not only did cones dried under these conditions yield seed having a significantly reduced viability, but the plants grown from these seeds succumbed more readily to normal nursery hazards.

Jack Pine

LABORATORY TESTS

The mean real germinative capacity of the various jack-pine seed lots representing 11 different cone-drying treatments is given in table 9. These mean germinative-capacity values are for the 20th day of germination. No blind seed were found in the cutting tests made on samples taken from each seed lot. The apparent germinative-capacity values are therefore considered as the real germinative-capacity values. It is obvious that cones dried at temperatures greater than 170° F. yield seriously damaged seed. The analysis of variance (table 10) includes the data of the first six cone-drying treatments only (table 9). Each cone-drying treatment is represented by three seed lots, each lot having four sublot germination samples. Little or no difference would ordinarily be expected between the germination of the three seed lots of each cone-drying treatment, as the drying conditions throughout the kiln were uniform. The analysis in table 10 indicates, however, that significant differences exist between seed lots of the same cone-drying treatment. This difference is caused by the lots within only two of the six drying treatments. One of three seed lots from the cones dried at 140° F. for 6 hours had a significantly lower germinative capacity than did the other two lots; and one from the cones dried at 140° for 15¼ hours had a significantly higher germinative capacity. These differences are believed to have resulted from variations in the handling of the cones or seed after the cones were dried. It is suspected that the dewinging procedure, namely, tramping the seed in grain sacks, is the causative factor.

Table 9. *Mean real germinative capacity of jack pine seed obtained from kiln-dried cones*

Temperature, ° F.	Duration of treatment	Germinative capacity	Temperature, ° F.	Duration of treatment	Germinative capacity
	Hours	*Percent*		*Hours*	*Percent*
140	3	56.9	170	22¼	11.8
140	6	63.8	195	2	.3
140	15¼	46.7	195	3	8.7
170	2	40.1	195	4	3.7
170	4	50.7	200	2	0
170	6	61.6			

Table 10. *Analysis of variance of real germinative capacity (in percent) of jack pine seed obtained from kiln-dried cones*

Source of variation	Degrees of freedom	Sum of squares	Mean square	Observed F[1]
Total	71	8,552.07		
Between treatments	5	5,021.32	1,004.26	[2]7.39
Between means of lots within treatments	12	1,630.27	[3]135.86	[2]3.86
Within lots	54	1,900.48	35.19	

[1] F= variance ratio.
[2] Highly significant.
[3] Used as error for testing mean square between treatments.

The least significant difference between any two germinative capacity means is

$$\sqrt{\frac{135.86\times 2}{12}}(2.074)=9.9 \text{ percent}$$

The three highest germinative capacity means—namely, 63.8, 61.6, and 56.9—do not differ significantly. Their pooled mean is 60.8 percent and the least significant difference between this pooled mean and any one of the other three means is

$$\sqrt{\frac{135.86}{36}+\frac{135.86}{12}}(2.013)=7.8 \text{ percent}$$

The other three means are significantly lower than 60.8 percent. It may be concluded, therefore, that kiln-drying at 140° F. for 6 hours is not injurious to jack pine seed, but drying at 140° for 15¼ hours is injurious. The apparent indication that drying at 170° for 2 or 4 hours is injurious, but that drying for 6 hours is not, is evidently in error; it may be supposed that the reduction in germinative capacity is caused by some other factor than kiln-drying. The moisture content of 4 percent to which the cones were dried at a temperature of 170° F. for a duration of 6 hours (fig. 35) cannot be considered to have injured them. A plausible explanation is that the seed first released from partially opened cones is of an inferior quality.

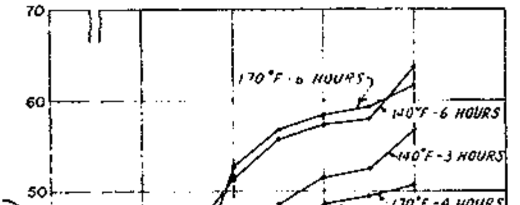


FIGURE 39.—Course of germination of jack pine seed obtained from cones kiln-dried at 140° F. for 3, 6, and 15¼ hours and at 170° for 2, 4, 6, and 22¼ hours at a 4-percent wood equilibrium moisture content.

The course of germinative curves for the seed lots obtained from the 140° and 170° F. cone treatments are shown in figure 39. The rise in some of the curves between the eighteenth and twentieth day of germination is caused by the added count on that day of the damped-off sprouts and sprouted seed that had not come up through the sand. The interpretation of these curves substantially corroborates the findings of the analysis of the germinative-capacity data. Temperatures of 140° or 170° F. and 4-percent wood equilibrium moisture content applied to cones for a duration of 6 hours were not injurious to the contained seed.

FIELD TESTS

Seed from 9 of the 11 jack pine cone treatments was carried into the field for additional testing. The field results are summarized in table 11.

TABLE 11.—*Summary of laboratory and field testing of nine lots of jack pine seed obtained from kiln-dried cones*[1]

Original cone treatment: Kiln temperature (° F.)	Duration of treatment	Apparent and real laboratory germinative capacity	Field germinative capacity	Surviving 1-0 plants[2]	Viable seed germinating in field	Viable seed producing 1-0 plants
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Hours	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
140	3	50.9	*42.5*	*40.2*	83.5	79.0
140	6	63.8	*54.2*	51.3	85.0	81.6
140	15½	*46.7*	*47.2*	*43.8*	101.0	95.6
170	2	*40.1*	*43.1*	*41.1*	107.5	104.2
170	4	*50.7*	*54.2*	*50.2*	106.9	98.7
170	6	61.6	59.9	54.8	97.2	91.4
195	2	*3.0*	*6.2*	*6.4*	206.7	213.3
195	3	*8.7*	*10.5*	*10.4*	120.7	120.2
195	4	*2.7*	*2.2*	*2.6*	81.1	72.4

[1] All kiln treatments were made at 4-percent wood equilibrium moisture content. Italic figures denote a significantly low value.
[2] Survival is expressed in percent of the number of seed sown.

A complete count of the germinated seed was made 67 days after sowing. The highest field germinative capacity for this day was associated with the cone drying treatment made at 170° F. for a duration of 6 hours. All other seed lots had significantly lower values. The percent of viable seed germinating in the field substantiates the reliability of the laboratory tests.

The surviving 1-0 plants were counted in the spring following the sowing of the seed and before the second year's growth had started. The mean number of surviving 1-0 plants is given in column 5 of table 11. The highest survival mean is associated with the original cone drying treatment made at 170° F. for a duration of 6 hours. All other survival mean values are significantly lower except the value associated with the cone drying treatment made at 140° for a duration of 6 hours. The percent of viable seed producing 1-0 plants, although very variable, does not indicate that any particular cone-drying treatment provided seed that was productive of weakened seedlings.

RED PINE

LABORATORY TESTS

The mean real germinative capacity of the red pine seed obtained from the kiln-dried green and stored cones is given in tables 12 and 13. The mean values are for the 30th day of germination. The analysis of variance of these germinative capacity data is given in table 14.

TABLE 12.—*Mean real germinative capacity of red pine seed obtained from kiln-dried green cones*[1] *at various drying temperatures and treatment periods*

Duration of treatment (hours)	Wood equilibrium moisture content	120° F.	130° F.	140° F.	150° F.	160° F.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
3	3	94.6	95.1	96.4	97.5	99.0
5	3	97.1	97.7	98.9	97.8	98.2
7	3	97.2	98.4	98.4	99.1	96.1
9	3	97.3	97.2	97.7	98.7	97.1
3	6	95.0	97.9	97.1	91.4	59.5
5	6	96.8	96.5	97.6	94.3	28.1
7	6	98.4	97.7	95.7	94.1	12.3
9	6	98.0	97.2	96.3	89.7	9.5
Means		96.8	97.2	97.4	95.3	62.5

[1] Values within heavy lines indicate reasonably safe treatments.

TABLE 13.—*Mean real germinative capacity of red pine seed obtained from kiln-dried stored cones*[1] *at various drying temperatures and treatment periods*

Duration of treatment (hours)	Wood-equilibrium moisture content	Storage	120° F.	130° F.	140° F.	150° F.	160° F.	170° F.
	Percent		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
3	3	Sacked	97.7	96.4	96.7	98.7	94.2	64.2
5	3	do	95.3	96.1	95.2	95.9	93.6	46.2
7	3	do	95.9	95.3	95.6	98.0	82.6	48.3
9	3	do	97.0	97.0	96.1	94.8	81.9	49.4
3	3	Trayed	98.0	97.0	96.2	98.5	97.4	93.7
5	3	do	97.9	97.4	98.4	98.4	96.7	95.8
7	3	do	96.2	97.3	98.3	98.4	98.7	96.8
9	3	do	97.9	98.2	97.9	95.8	97.5	97.1
Means			97.2	96.9	96.8	96.8	92.8	73.8

[1] Values within heavy lines indicate reasonably safe treatments.

TABLE 14.—*Analysis of variance of the real germinative capacity of red pine seed obtained from kiln-dried cones*

FRESH GREEN CONES

Source of variation	Degrees of freedom	Sum of squares	Mean square	Observed F[1]
Total	159	76,741.01		
Between temperatures	4	30,064.39	7,516.10	[2] 2,153.61
Between durations	3	455.44	151.81	[2] 43.50
Between equilibrium moisture contents	1	9,438.57	9,438.57	[2] 2,704.46
Interaction:				
Temperature×duration	12	3,127.13	260.59	[2] 74.67
Temperature×equilibrium moisture content	4	30,308.70	7,577.18	[2] 2,171.11
Duration×equilibrium moisture content	3	749.60	249.87	[2] 71.60
Temperature×duration×equilibrium moisture content	12	2,178.95	181.58	[2] 52.03
Within classes (error)	120	418.23	3.49	

STORED CONES

Source of variation	Degrees of freedom	Sum of squares	Mean square	Observed F[1]
Total	191	31,846.18		
Between temperatures	5	13,727.80	2,745.56	[2] 1,076.60
Between durations	3	181.79	60.60	[2] 23.76
Between storage	1	4,851.13	4,851.13	[2] 1,902.40
Interaction:				
Temperature×duration	15	361.85	24.12	[2] 9.46
Temperature×storage	5	11,489.03	2,297.81	[2] 901.10
Duration×storage	3	317.73	105.91	[2] 41.53
Temperature×duration×storage	15	550.29	36.69	[2] 14.39
Within classes (error)	144	366.56	2.55	

[1] F=variance ratio. [2] Highly significant.

GREEN CONES

Differences in mean germinative capacity due to temperature, duration of treatment, equilibrium moisture content, and their first and second order interactions were all highly significant. The least significant difference between the pooled temperature means (table 12) is

$$\sqrt{\frac{3.49\times 2}{32}}(1.999)=0.9 \text{ percent.}$$

The means associated with 150° and 160° F. are significantly lower than the 120°, 130° and 140° means, the differences between the latter of which are not significant.

The least significant difference between the following pooled duration means is

$$\sqrt{\frac{3.49\times 2}{40}}(1.991)=0.8 \text{ percent.}$$

Duration, hours:	*Mean real germinative capacity percent*
3	92.4
5	90.3
7	88.8
9	87.9

The foregoing duration means are all significantly different from each other. The pooled mean germinative-capacity values for treatment at 3- and 6-percent wood equilibrium moisture content are 97.5 and 82.2 percent, respectively. The difference is significant and therefore the 3 percent wood equilibrium moisture content is the superior drying condition.

From table 12 it appears that the important reductions in germinative capacity occurred when the cones were kiln-dried at 6 percent wood equilibrium moisture content, particularly at a temperature of 160° F. No striking or consistent reductions in germinative capacity are indicated when the cones were kiln-dried at 3 percent wood equilibrium moisture content. Among the latter group, having a mean of 97.5 percent, only those which differ by 1.9 or more percent can be considered significant. The 3-hour durations for 120° and 130° are significantly lower than 97.5 percent. It has been suggested that these drying conditions produced slightly inferior seed because of the small degree of cone opening. It may, therefore, be concluded that any temperature up to and including 160° for durations as long as 9 hours when dried at 3 percent wood equilibrium moisture content did not produce injury to the red pine seed.

All the important variance in germinative capacity is considered as associated with the 6-percent wood equilibrium moisture content treatment. As temperatures of 150° and 160° F. were injurious, it is believed that the important reductions in germinative capacity are to be found in the means associated with the different durations at these two temperatures. The pooled mean for the 120°, 130° and 140° treatments is 97.0 percent; only those values which are less by 2 percent or more than 2 percent can be considered as being significantly different. The 120° 3-hour treatment is significantly lower; but again this result is associated with slight cone opening and the release of inferior seed. Temperatures of 150° and 160° produced seed having a significantly lower germinative capacity. It may therefore be concluded that any temperature up to and including 140° for a duration of 9 hours, when dried at 6 percent wood equilibrium moisture content, did not injure the seed.

Any kiln-drying treatment whose germinative capacity values are within the blocked-out group of table 12 may be considered as safe.

The superiority of the 3 percent wood equilibrium moisture content treatment is associated with the seed moisture-time-temperature relationship. In that treatment, the moisture content of the contained seed is reduced at a faster rate than in the 6-percent treatment, thus decreasing the sensitivity of the seed to heat (fig. 36). Desiccation of seed to a low moisture content did not reduce the germinative capacity of seed; the cone-drying treatment at a temperatue of 160° F. for a duration of 9 hours at 3 percent wood equilibrium moisture content reduced the seed to a moisture content of 3.9 percent without seed injury.

STORED CONES

Differences in mean germinative capacity due to temperature, duration of treatment, storage conditions, and the first and second order interactions are all significant. (Table 14.) The least significant difference between the pooled temperature means (table 13) is

$$\sqrt{\frac{2.546 \cdot 2}{32}}(1.999) = 0.8 \text{ percent}$$

Only the 160° and 170° F. temperature means can be considered as significantly different. The least significant difference between the following pooled duration means is

$$\sqrt{\frac{2.546 \cdot 2}{48}}(1.986) = 0.6 \text{ percent}$$

Duration, hours	*Mean real germinative capacity, percent*
3	94.0
5	92.2
7	91.6
9	91.7

The 5-, 7-, and 9-hour durations do not differ by significant amounts, yet all three are significantly lower than the 3-hour duration.

The mean germinative capacity for the sacked and trayed cones is 87.4 and 97.4 percent respectively. The difference is significant with trayed storage being the superior storage method.

From table 13 it appears that the important reductions in germinative capacity occurred in kiln-drying the sacked cones. The mean germinative capacity for the trayed cones is 97.4 percent and among these values a difference of 1.6 is considered significantly different. Only one value, that for 170° F. and a duration of 3 hours, can be considered significantly low. As the 5-, 7-, and 9-hour durations at 170° and the 3-hour duration at the other temperatures did not produce significantly reduced germinative capacity means it is believed that the 3-hour duration at 170° was not caused by the kiln-drying treatment but rather is due to some unknown and unexplainable factor. It may be concluded that tray-stored cones produced seed that was not injured when kiln-dried at 170° for as long as 9 hours.

All the important variance associated with the experiment is considered as being caused by the sacked storage method. As only the 160° and 170° F. treatments produced significant differences, the important reductions in germinative capacity are expected to be found at these temperatures. The pooled mean germinative capacity of the sacked cones kiln-dried at 120° to 150° is 96.1 percent and only those that differ by 1.6 percent can be considered significant. The treatment at 150° for 7 hours is low although the 9-hour treatment at this temperature is not significantly different from the mean. All the 160° and 170° values are significantly lower than the pooled mean for the lower temperatures. It may be concluded, therefore, that the sacked cones were kiln-dried at 140° for 9 hours or 150° for 5 hours without injury to red pine seed.

Any kiln-drying treatment yielding germinative capacity values within the blocked-out group of table 13 can be considered as safe.

Greatly increased sensitivity to temperature of seed from sacked-stored cones, as compared with seed from the tray-stored or green cone-drying treatments is indicated. The cause does not appear to be associated with the moisture content of the seed as the contained seed in green cones was at a higher moisture condition and withstood higher temperatures without injury. Comparing the seed moisture-

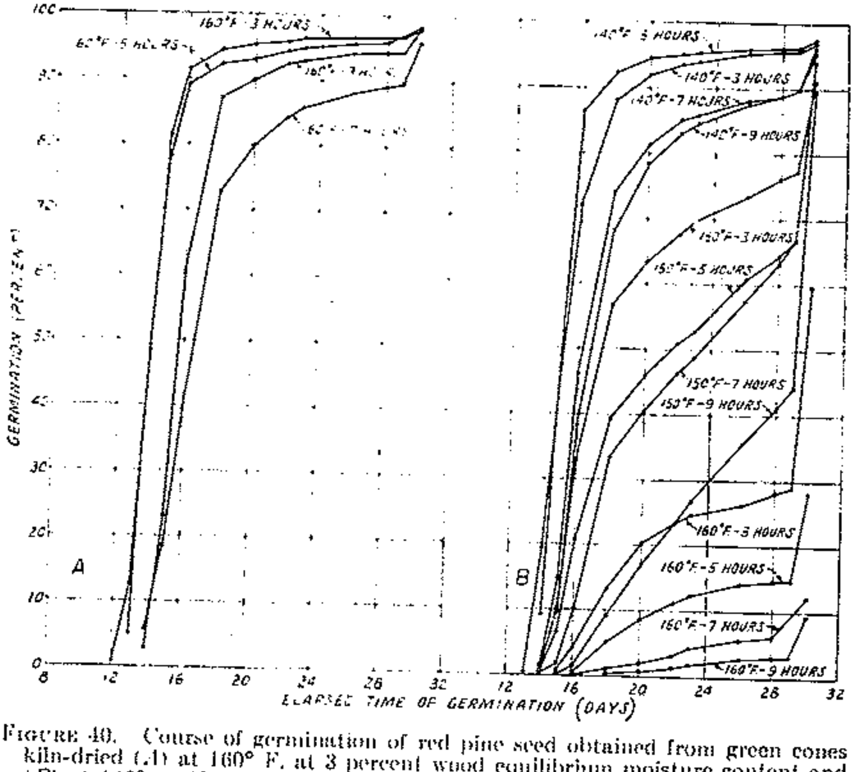


FIGURE 40. Course of germination of red pine seed obtained from green cones kiln-dried (*A*) at 160° F. at 3 percent wood equilibrium moisture content and (*B*) at 140°, 150°, and 160° at 6 percent wood equilibrium moisture content

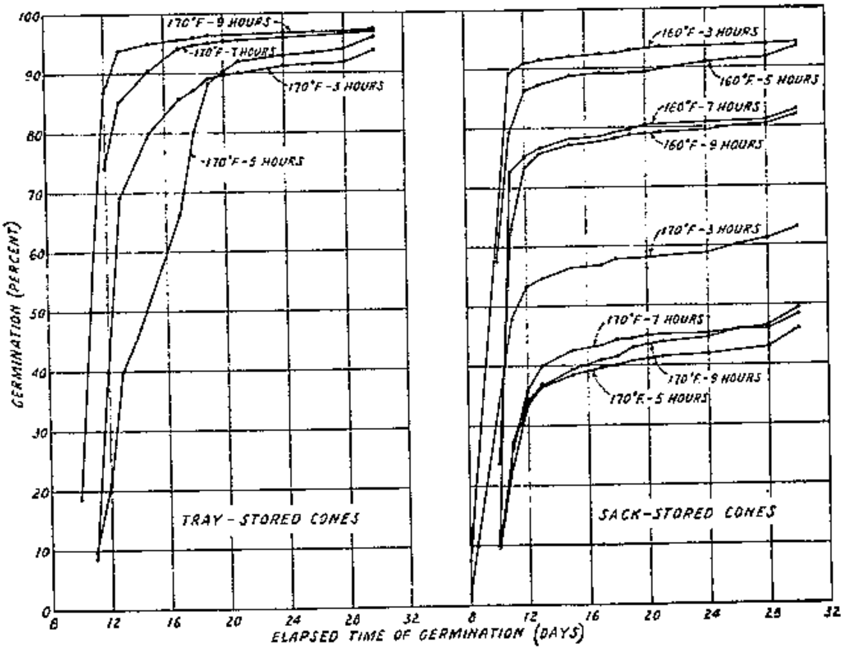


FIGURE 41.—Course of germination of red pine seed obtained from tray-stored cones, kiln dried at 170° F. at 3 percent wood equilibrium moisture content and for sack-stored cones kiln-dried at 160° and 170° at 3-percent wood equilibrium moisture content.

duration relationships in figure 36, as between the sacked cones and green cones, the seed of the sack-stored, kiln-dried cones reaches a lowered moisture condition quicker than the seed in the green cones. The heat sensitivity of sacked cones must be associated with some physiological change in the seed during the sacked storage period when cone and seed drying was inhibited.

The course of germination curves of the seed obtained from the green cones dried at a temperature of 160° F. at 3 percent wood equilibrium moisture content, and at temperatures of 140°, 150°, and 160° at 6 percent wood equilibrium moisture content, are shown in figure 40. The rise in the curves between the 28th and 30th days of germination is caused by the added count of those seeds that had sprouted, but had not appeared above the sand on the 30th day of germination when the seed was lifted. The seed from the cones dried at 140°, 150°, and 160° at 6 percent wood equilibium produced seed that had a greatly retarded germination. The number of sprouted seed found at the time of lifting on the 30th day of germination indicates the greatly reduced vigor of the sprouts to push through the sand. The course of germination curves indicate that the procedure of including these sprouted seed in estimating the germinative capacity as of the 30th day of germination is questionable, also that drying green cones at a temperature of 160° at 6 percent wood equilibrium is highly injurious. The superiority of 3 percent wood equilibrium moisture content is substantiated.

Some of the courses of germination curves of the seed obtained from the kiln-dried, stored cones are shown in figure 41. Although the analysis of the germinative capacity data indicated that drying tray-stored cones at a temperature of 170° F. for durations of 3 and 5 hours resulted in significantly lowered values, the course of germination curves for this treatment cannot be interpreted as giving greatly injured seed; in fact, the treatments of 7- and 9-hour durations at 170° produced the better seed. The reduction in seed viability in drying sack-stored cones at temperatures as high as 160° or 170° is indicated in figure 41 by comparison with the course of germination curves of seed obtained from tray-stored cones dried at that temperature.

FIELD TESTS

The summarized results of the field testing of 16 of the 88 red pine seed lots are given in table 15. The field-germinative-capacity data taken 41 days after sowing indicated that the original kiln drying of trayed cones at a temperature of 160° F. for a duration of 5 hours at 3 percent wood equilibium moisture content had a low field germinative capacity, in addition to those seed lots which had a significantly low laboratory real germinative capacity. No reasonable cause could be ascertained for this unexpected reduction. The survival data taken 127 days after sowing indicated that the original kiln drying of sack-stored cones at a temperature of 130° for a duration of 9 hours at 3 percent wood equilibium moisture content had a significantly low survival count as well as those seed lots that had a low laboratory real germinative capacity. The seed lot that was unexpectedly low in field germinative capacity stood up in the survival count. The percentage of viable seed germinating in the field substantiates the reliability of the laboratory tests. The percent of viable seed producing 1-0 plants is consistent except for possibly one treatment, seed from green cones kiln-dried at 160° for 9 hours at 6 percent wood equilibrium not only had a low germinative capacity but also produced plants having a high mortality.

TABLE 15.—*Summary of laboratory and field testing of 16 lots of red pine seed obtained from kiln-dried green and stored cones* [1]

Original cone treatment			Storage method	Laboratory tests		Field tests		Viable seed germinating in field	Viable seed producing 1-0 plants
Temperature (°F.)	Duration of treatment	Wood equilibrium moisture content		Real germinative capacity	Apparent germinative capacity	Germinative capacity	Surviving 1-0 plants [2]		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Hours	*Percent*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
130	5	3	None	97.7	97.1	73.7	57.6	75.4	59.0
130	9	3	do	97.2	96.8	80.4	59.7	82.7	61.4
130	5	6	do	96.5	94.1	69.3	49.3	71.8	51.1
130	9	6	do	97.2	94.6	77.6	62.6	70.9	64.4
130	5	3	Sacked	96.1	93.0	70.7	53.3	73.5	55.5
130	9	3	do	97.0	95.1	70.8	*47.7*	73.0	49.2
130	5	3	Trayed	97.4	97.1	73.4	50.5	75.4	51.9
130	9	3	do	98.2	98.1	72.1	50.6	73.5	51.6
160	5	3	None	98.2	97.6	72.9	53.0	74.3	54.0
160	9	3	do	97.1	97.0	74.5	58.8	76.7	60.6
160	5	6	do	*28.1*	28.0	*14.7*	*8.0*	52.4	21.4
160	9	6	do	*9.5*	9.5	*5.4*	*.8*	35.8	8.4
160	5	3	Sacked	*93.6*	89.1	*62.6*	*36.7*	66.8	39.2
160	9	3	do	*81.9*	80.5	*66.2*	*46.9*	80.9	57.3
160	5	3	Trayed	96.6	94.0	*61.3*	49.9	63.5	51.7
160	9	3	do	97.5	96.1	77.0	60.1	78.9	61.6

[1] Italic figures denote significantly low values.
[2] Survival is expressed in percent of the number of seed sown.

Longleaf Pine

LABORATORY TESTS

The mean real germinative capacity of the various seed lots representing the 15 different cone-drying experiments is given in table 16. These mean values are for the 30th day of germination. An analysis of variance of the percentage data is given in table 17. Differences due to temperature, duration of drying, and the interaction of these two are highly significant.

The least significant difference between any of the pooled temperature means is

$$\sqrt{\frac{7.93\times 2}{12}}(2.074)=2.4 \text{ percent}$$

All the pooled means differ by significant amounts. With increasing kiln temperatures of 5° from 115° F. the germinative capacity is proportionately reduced.

Table 16.—*Mean real germinative capacity of longleaf pine seed obtained from kiln-dried cones* [1]

Temperature (°F.)	Germinative capacity for indicated cone treatment			Means
	8 hours	12 hours	16 hours	
	Percent	*Percent*	*Percent*	*Percent*
115	90.6	92.6	92.7	92.0
120	87.8	86.4	85.6	86.6
125	80.9	79.7	80.9	80.5
130	79.7	71.3	69.2	73.4
135	72.7	66.6	62.5	67.3
Means	82.3	79.3	78.2	

[1] Values within heavy lines indicate reasonably safe treatments.

Table 17.—*Analysis of variance of real germinative capacity of longleaf pine seed obtained from kiln-dried cones* [1]

Source of variation	Degrees of freedom	Sum of squares	Mean square	Observed F [1]
Total	59	5,549.70		
Between temperatures	4	4,715.87	1,178.97	[2] 148.67
Between durations	2	184.70	92.35	[2] 11.65
Interaction: Temperature×duration	8	292.20	36.52	[2] 4.61
Within classes (error)	45	356.93	7.93	--

[1] F=variance ratio.
[2] Highly significant.

The least significant difference between any of the pooled duration means is

$$\sqrt{\frac{7.93\times 2}{20}}(2.023)=1.8 \text{ percent.}$$

The 8-hour duration is significantly higher than the 12- and 16-hour duration means and the difference between these latter two means is not significant.

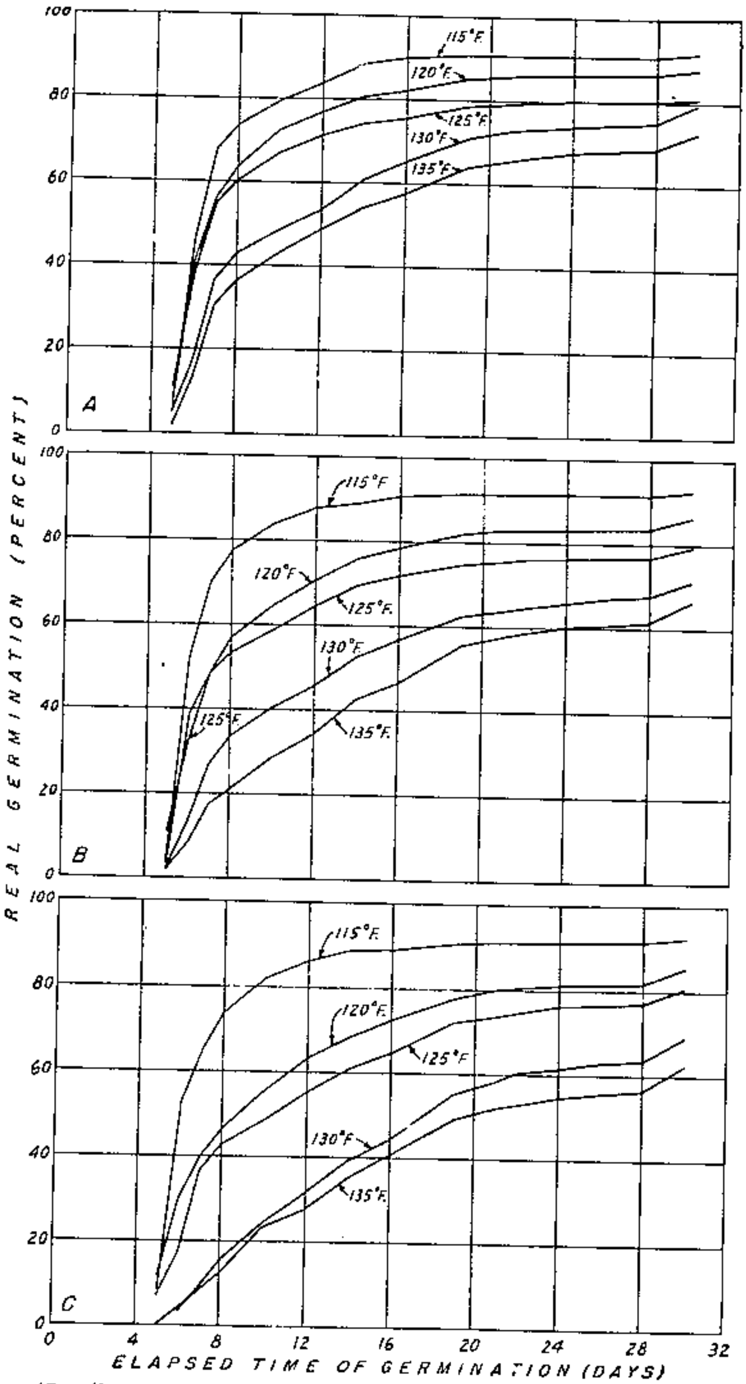


FIGURE 42.—Course of germination of longleaf pine seed obtained from cones kiln-dried at various temperatures for (*A*) 8 hours, (*B*) 12 hours, and (*C*) 16 hours.

The least significant difference between any two individual means of table 17 is

$$\sqrt{\frac{7.93\times 2}{4}}(2.447)=4.9 \text{ percent.}$$

The 8-, 12-, and 16-hour durations at 115°, 120°, and 125° F. do not differ by as much as 4.9 percent, and it may be concluded that at these temperatures increasing the duration of drying from 8 to 16 hours was not injurious. At 130° and 135° the 8-hour duration means are significantly higher than the 12- or 16-hour duration means.

The mean of the three 115° F. durations is 92.0 percent with the pooled means of the 120° and 125° significantly lower. It may be concluded that 115°, as blocked out in table 17, is the better of the five temperatures studied. It is possible that kiln temperatures lower than 115° may have produced seed having a significantly higher germinative capacity. Air-dried cones seldom produce seed having as high a germinative capacity as 92.0 percent and it may be concluded that a kiln temperature of 115° is reasonably safe.

The course of germination of the various seed lots is shown in figure 42. Increasing kiln temperature above 115° F. appears to reduce the viability of the obtained seed at all three duration periods.

FIELD TESTS

The summarized results of the field tests of the 15 lots of seed are given in table 18. The field germinative capacity data are for counts made 21 days after sowing. The analysis of the field germinative capacity indicated that temperature and duration of cone drying produced significant differences in field germination. Temperature was particularly influential in this respect as was indicated by the laboratory tests. The seed from cones dried at a temperature of 115° F. germinated the best in the field. Increasing kiln temperatures above 115° produced poorer seed.

TABLE 18.—*Summary of laboratory and field testing of longleaf pine seed obtained from kiln-dried cones* [1]

Original cone treatment [1]		Laboratory tests		Field tests			
Kiln temperature (° F.)	Duration of treatment	Real germinative capacity	Apparent germinative capacity	Germinative capacity	Plants, percent [2]	Viable seed germinating in field	Viable seed producing utilizable 1-0 plants
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Hours	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
115	8	90.6	89.9	83.5	49.5	92.2	54.6
115	12	92.6	91.7	84.9	55.1	91.7	50.5
115	16	92.7	92.2	85.2	53.6	91.9	57.9
120	8	*87.8*	84.7	*78.5*	*50.2*	89.8	57.2
120	12	*86.5*	82.1	*77.8*	*48.4*	90.0	56.7
120	16	*85.6*	82.9	*74.7*	*40.8*	87.2	47.7
125	8	*80.9*	75.5	*69.6*	*42.8*	86.0	52.9
125	12	*79.7*	75.2	*64.8*	*43.8*	81.3	54.9
125	16	*80.9*	78.2	*68.1*	*40.7*	84.1	50.3
130	8	*79.7*	76.5	*67.4*	*37.3*	84.6	46.8
130	12	*71.5*	68.0	*55.7*	*33.3*	78.2	46.7
130	16	*69.3*	65.3	*55.4*	*32.5*	80.0	46.6
135	8	*72.7*	69.9	*58.7*	*30.3*	80.8	50.0
135	12	*66.6*	63.5	*57.8*	*26.5*	71.8	39.8
135	16	*62.5*	60.7	*52.8*	*26.9*	84.5	47.9

[1] All kiln treatments were made at 4-percent wood equilibrium moisture content. Italic figures denote significantly low values.

[2] Plants percent is the percent of clean seed sown that developed into utilizable 1-year seedlings.

The percent of viable seed germinating in the field (table 18, column 7) indicates that all seed lots germinated about the same, although a slight superiority, which may have no significance, is noted in favor of the 115° F. cone-drying treatments.

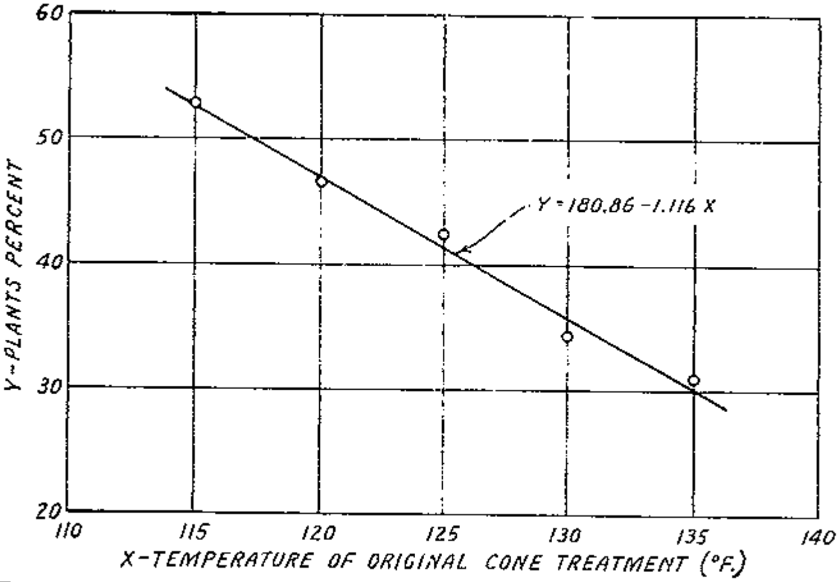


FIGURE 43.—Relation of plants percent and temperature of original cone treatment for longleaf pine.

Probably the most convincing test of the influence of cone drying is in the plants-percent data giving the number of graded and utilizable 1–0 plants per 100 seed sown. The mean plants-percent values for the seed obtained from the various lots of kiln-dried cones are given in table 18, column 6. An analysis of the data indicates that the only factor influencing plants percent is the temperature of the original cone-drying treatment. The least significant difference between any of the following mean plants-percent values, durations pooled, is 4.2 percent.

Temperature of cone treatment (°F):

Temperature of cone treatment (° F.):	*Mean plants, percent*
115	52.7
120	46.5
125	42.4
130	34.3
135	30.9

All other mean plants-percent values are significantly different from the 115° F. group but not from each other. The relation of plants percent to the temperature of the cone treatment is shown in figure 43. The relation is linear and for every 5° F increase in kiln temperature plants percent is reduced by 5.6 percent.

SEED-HEATING EXPERIMENTS

Species Studied

The heating of bare seed to determine safe drying schedules has received considerable attention by various investigators.[5] In order to compare the quality of the seed obtained by schedules based upon this method with that obtained by schedules based upon the kiln drying of cones, a series of tests was made on eastern white pine, red pine, and longleaf pine seed. These seed heat-treating experiments were factorially designed.

EASTERN WHITE PINE

Random samples from the supply of air-dried eastern white pine seed were heat-treated at 100°, 120°, 140°, and 160° F. for 2, 4, 8, 12, and 16 hours at two different moisture levels. The two moisture-content levels consisted of air-dried seed and seed soaked in distilled water at 68° F. to a moisture content of about 30 percent. Preliminary experiments indicated that a 2-hour soaking period was necessary to bring the seed to an average moisture of 30 percent. Two replications of the complete experiment were made.

RED PINE

Samples randomly selected from the supply of red pine seed were heat-treated at 120°, 130°, 140°, 150°, and 160° F. for 3, 5, 7, and 9 hours at the following four different moisture levels: As extracted; room-dried; soaked 3 hours; and soaked 2 days. The seed at the time it was taken out of storage was at an average moisture content of 9.2 percent. By room-drying the seed over night in the laboratory, an average moisture content of 7.0 percent was obtained. Seed soaked for 3 hours had an average moisture content of 17.2 percent. Soaking for 2 days provided seed at its apparent maximum moisture content, the average being 42.4 percent.

LONGLEAF PINE

Samples of longleaf pine seed randomly selected from the supply were heat-treated at 100°, 120°, 140°, and 160° F. for 5, 8, 11, and 14 hours at two seed moisture-content levels. Soaking seed in distilled water at 68° for 7 hours produced seed at about 45 percent moisture content. A soaking period of 72 hours was required to produce longleaf pine seed at its maximum moisture content of about 98 percent.

EXPERIMENTAL APPARATUS

Bare eastern white and red pine seed samples were heat-treated in small glass bottles placed in a water bath controlled at the desired temperature. The bottles of seed were mounted on a frame revolving about a horizontal axis, the bottles being held with a stirrup and coil spring, the whole being submerged in the water bath. The tumbling motion imparted to the seed by the revolving frame appeared to

[5] Morris, William G. VIABILITY OF CONIFER SEED AS AFFECTED BY SEED MOISTURE CONTENT AND KILN TEMPERATURE. Jour. Agr. Res. 52: 855-864, illus. 1936.

change constantly the seed in contact with the walls of the bottle, thus providing uniform heating of the seed sample. The bottles were connected to each other with rubber tubing that extended through the axle of the revolving frame. A piece of glass tubing was drawn to a fine orifice and connected to the rubber tubing extended up and out of the water bath. As the seed reached the temperature of the bath, the expansion of the gases in the bottles was relieved through the tubing connections, yet the orifice was so small that little if any air exchange took place during the heat-treatment. After the required duration of heat-treatment, the seed samples were taken out of the bath, room dried if they had been soaked prior to heat treatment, put into small tin cans, and stored in a refrigerator until all the treatments were completed, at which time the seed was sown in germination flats.

Because of the larger size and bulk of the unwinged longleaf pine seed, the heat-treating technique just described could not be used. Instead a desiccator holding the seed samples and placed in a small kiln operating at a temperature which maintained the desired treating temperature inside of the desiccator, as measured by thermocouples, was used. Circulation of air in the desiccator was obtained by rotating a fan in the desiccator by means of an outside motor. Some drying of the longleaf pine seed samples could not be completely prevented. The samples were weighed in and out of the desiccator and the change in moisture condition was from an average value of 45.2 percent to 33.1 percent. The seed samples soaked for a sufficiently long time to reach maximum moisture content conditions were heat-treated in cheesecloth bags submerged in water maintained at the various temperatures. After heat-treatment the seed was room-dried and stored in tin cans in a refrigerator until the treatments were completed.

Viability of Heat-Treated Bare Seed

The results of the experiments in heat-treating bare seed are given only in terms of germinative capacity. The course of germination curves are not shown.

EASTERN WHITE PINE

The germinative capacity of heat-treated bare eastern white pine seed varied with the temperature, duration of treatment, and the seed moisture content. Each heat-treated seed sample of the experiment provided four germinative tests. Since preliminary analysis indicated that the runs did not produce significant differences, the eight viability measurements are considered in the final analysis as coming from a single test. The analysis is made only on the data for the 100°, 120°, and 140° F. treatments, as at both moisture levels the 160° treatments are lethal. The germinative capacity of the heat-treated seed is given in table 19. The mean moisture content of the air-dried seed was 10.6 percent. The mean moisture content of the soaked seed was 27.1 percent. An analysis of variance of these data is given in table 20. Differences due to temperature, duration, moisture content, the first order interactions of moisture × temperature and temperature × duration, and the second order interactions are all highly significant.

TABLE 19.—*Mean real germinative capacity of heat-treated, bare eastern white pine seed* [1]

Condition of seed[2] and temperature (°F)	Germinative capacity for indicated heat treatment				
	2 hours	4 hours	8 hours	12 hours	16 hours
Air-dried:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
100	83.1	79.8	83.1	81.1	79.0
120	81.6	84.0	81.8	82.0	77.5
140	77.8	75.1	*67.1*	*24.0*	*23.6*
Soaked:					
100	74.7	76.4	72.2	*50.6*	76.1
120	71.8	74.1	68.8	*33.8*	*10.1*
140	0	0	0	0	0

[1] Italic figures denote a significantly low value.
[2] Air-dried seed at 10.6 percent moisture content; soaked at 27.1 percent.

TABLE 20.—*Analysis of variance of the real germinative capacity of bare eastern white pine seed treated at three temperatures for five different durations at two moisture levels*

Source of variation	Degrees of freedom	Sum of squares	Mean square	Observed F[1]
Total	239	257,593.13		
Between moisture levels	1	54,276.35	54,276.35	[2] 490.39
Between temperatures	2	112,940.62	56,474.81	[2] 510.25
Between durations	4	18,658.82	4,664.70	[2] 42.15
Interaction:				
Moisture×temperature	2	19,627.59	9,813.80	[2] 88.67
Moisture×duration	4	72.06	18.02	.16
Temperature×duration	8	6,533.34	816.67	[2] 7.38
Moisture×temperature, ×duration	8	22,233.21	2,779.15	[2] 25.11
Remainder (error)	210	23,242.11	110.68	

[1] F = variance ratio.
[2] Highly significant.

Soaking air-dried bare eastern white pine seed for 2 hours in distilled water at 68° F. did not influence its germinative capacity. To test the probability of such soaking affecting the germinative capacity, irrespective of subsequent heat treatment, four random samples of seed were germinated, two of which had been soaked for 2 hours. The germinative capacity of these seed samples and the analysis of the data are given in tables 21 and 22. Differences due to treatment were not significant. It may be concluded that the soaking of the seed in distilled water at 68° for 2 hours has not affected its germinative capacity. Any significant differences in germinative capacity of heat-treated seed as between the two moisture levels studied is a function of heat treatment and the moisture condition and not the preliminary soaking process. The mean real germinative capacity of air-dried eastern white pine seed as used in these tests was 80.8 percent. This is good evidence that seed first to fall from opening cones is lower in viability than average. Seed obtained in the kiln-drying experiments gave more than 90-percent germinative capacity.

TABLE 21.—*Real germinative capacity of air-dried and of air-dried and soaked bare eastern white pine seed prior to heat-treatment*

Air-dried seed		Air-dried and soaked seed	
Sample 1	Sample 2	Sample 1	Sample 2
Percent	*Percent*	*Percent*	*Percent*
80.40	82.8	76.8	83.2
78.00	80.8	82.4	77.6
79.60	82.0	83.2	80.8
78.80	72.0	82.4	86.0
General mean			80.8

TABLE 22.—*Analysis of variance of real germinative capacity of air-dried and soaked bare eastern pine white seed prior to heat treatment*

Source of variation	Degrees of freedom	Sum of squares	Mean square	Observed F[1]
Total	15	202.24	13.48	
Between treatments	1	36.00	36.00	[2] 3.03
Remainder (error)	14	166.24	11.87	

[1] F = variance ratio.
[2] Not significant.

Bare eastern white pine seed at a mean moisture content of 10.6 percent was heat-treated at 140° F. for 4 hours and at 120° for 16 hours without injury. The least significant differences between any two means is

$$\sqrt{\frac{110.677 \times 2}{8}}(2.145) = 11.3 \text{ percent}$$

Using the mean germinative capacity of the air-dried unheated seed as the basis of testing what heat treatments have significantly reduced germinative-capacity values, any mean value of 69.5 percent (80.8−11.3) or less can be considered as influenced by the heat treatment given. The italicized values in table 19 are significantly low. Bare eastern white pine seed at a moisture content of 10.6 had a reduced viability when heat treated at 140° for 8 hours. At 120° F. or less a 16-hour treatment was not injurious.

Bare eastern white pine seed at a mean moisture content of 27.1 percent was heat-treated at 120° F. for 8 hours without injury. A temperature of 120° for a duration of 8 hours appears to be the limit in severity of treatment. Heating the seed at this moisture content at 140° for only as long as 2 hours was lethal.

RED PINE

The germinative capacity of heat-treated, bare red pine seed also varies with the temperature, duration of heat-treatment, and seed moisture content. The mean germinative capacity values of the heat-treated seed are given in table 23 and the analysis of variance is given in table 24. Differences due to temperature, duration, moisture content, and first-order and second-order interactions are highly significant.

TABLE 23.—*Mean real germinative capacity of heat-treated, bare red pine seed* [1]

Condition of seed [2] and temperature (°F.)	Real germinative capacity for indicated heat treatment			
	3 hours	5 hours	7 hours	9 hours
	Percent	*Percent*	*Percent*	*Percent*
Room-dried:				
120	98.6	98.5	99.2	98.2
130	98.9	98.4	98.9	98.2
140	98.8	99.1	98.6	99.1
150	96.6	97.5	98.1	97.5
160	97.6	97.2	97.5	97.2
As extracted:				
120	98.1	98.4	98.7	98.8
130	97.6	97.7	96.7	98.4
140	98.3	98.5	98.3	98.1
150	98.1	97.6	98.4	96.5
160	98.0	96.1	95.8	*87.7*
Soaked 3 hours:				
120	98.5	98.3	98.5	98.6
130	98.8	98.7	98.9	97.5
140	98.5	96.0	97.7	96.2
150	96.7	*83.0*	0	0
160	.1	0	0	0
Soaked 2 days:				
120	95.1	*92.6*	*47.1*	*46.1*
130	*1.2*	*1.0*	0	0
140	0	0	0	0
150	0	0	0	0
160	0	0	0	0

[1] Italic figures denotes significantly low values.
[2] Room-dried seed at 7.0 percent moisture content; as extracted, 9.2 percent; soaked 3 hours, 17.2 percent; soaked 2 days, 42.4 percent.

TABLE 24.—*Analysis of variance of the real germinative capacity of bare red pine seed treated at five temperatures for four durations at four moisture levels*

Source of variation	Degrees of freedom	Sum of squares	Mean square	Observed F [1]
Total	319	603,404.87		
Between means of temperature	4	68,302.82	17,075.70	[2] 7,456.64
Between means of duration	3	4,371.18	1,457.06	[2] 636.27
Between means of seed treatment of moisture content	3	372,463.33	124,154.44	[2] 54,215.01
Interaction:				
Temperature×duration	12	6,032.09	502.67	[2] 219.51
Temperature×treatment	12	120,056.67	10,004.72	[2] 4,368.87
Duration×treatment	9	4,492.14	499.13	[2] 217.96
Temperature×duration×treatment	36	27,226.35	756.29	[2] 330.26
Remainder (error)	240	550.20	2.29	

[1] F=variance ratio.
[2] Highly significant.

Soaking or room drying air-dried, bare red pine seed did not influence its germinative capacity. During the course of the seed heat-treating experiment, random samples of the air-dried seed as extracted, as room-dried, as soaked for 3 hours, and as soaked for 2 days were germinated without subsequent heat treatment. The results and analysis of these tests are given in tables 25 and 26. Differences due to treatments were not significant. Any conclusion drawn from the analysis of the germinative capacity of the heat-treated seed is a function of the heat treatments given. The mean real germinative capacity of the red pine seed as indicated by these tests was 96.4 percent.

TABLE 25. *Real germinative capacity of bare red pine seed after various treatments prior to heat treatment*

Seed treatment	Germinative capacity				Mean
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
As extracted	95.7 98.3	95.8 96.2	98.0 96.7	96.8 95.9	96.7
Room-dried	98.3 99.2	97.6 90.3	93.0 95.0	99.2 98.4	97.4
Soaked 3 hours	98.0 97.0	96.6 97.9	97.1 93.8	97.5 95.0	96.7
Soaked 2 days	96.7 96.2	95.9 96.3	86.4 96.3	96.0 94.1	94.7
General mean					96.4

TABLE 26. *Analysis of variance of bare red pine seed after various treatments prior to heat treatment*

Source of variation	Degrees of freedom	Sum of squares	Mean square	Observed F[1]
Total	31	162.14	5.23	
Between treatment	3	30.75	10.25	[2] 2.10
Remainder	28	131.39	4.69	

[1] F=variance ratio.
[2] Not significant.

Bare red pine seed withstands higher temperatures for longer periods of heating without injury when the seed is dry. The least significant difference of any two mean values is

$$\sqrt{\frac{2.29\times 2}{4}}(2.447)=2.6 \text{ percent}$$

Using 96.4 percent as the expected germinative capacity of unheated seed, any mean germinative capacity value of treated seed of 93.8 (96.4 − 2.6) or less has been significantly lowered by treatment. The italicized values in each seed group in table 23 indicate significantly reduced germinative-capacity values. Thus room-dried seed at a mean moisture content of 7.0 percent withstood 160° F. for 9 hours of treatment; seed, as extracted, and at a mean moisture content of 9.2 percent, withstood 160° F. for 7 hours or 150° for 9 hours; seed soaked for 3 hours and at a mean moisture content of 17.2 percent withstood 150° for only 3 hours and at 140° for 9 hours; seed soaked 2 days, at a mean moisture content of 42.4 percent, withstood 120° for only 3 hours. The influence of the moisture condition of red pine seed on germinative capacity when heat-treated is striking.

LONGLEAF PINE

Longleaf pine seed was very sensitive to heat-treatment. Germinative capacity tests indicated that seed heated at 140° and 160° F. resulted in killed seed. The analysis of the germinative-capacity data is limited to the seed heat-treatments made at 100° and 120°. The mean real germinative capacity of seed heat-treated at these two temperatures is given in table 27. An analysis of variance of the data is given in table 28. Differences due to temperature, duration, moisture content, and two of the first-order interactions were highly significant. As only two temperatures are analyzed and a significant difference is indicated between the two, one temperature is superior to the other. From table 27, 100° is less deleterious than is 120°. Likewise, from table 27, the lower moisture-content condition is the least influenced by temperature and duration of heating.

TABLE 27.—*Mean real germinative capacity of heat-treated longleaf pine seed* [1]

Condition of seed [2] and temperature (°F.)	Real germinative capacity of heat-treatment (hours)—for indicated duration			
	5	8	11	14
	Percent	*Percent*	*Percent*	*Percent*
Soaked 7 hours:				
100	72.2	70.2	68.6	62.2
120	73.5	67.0	*50.0*	*41.3*
Soaked 72 hours:				
100	75.5	77.9	75.3	71.0
120	*28.2*	*6.0*	*1.8*	*.7*

[1] Italic figures denote a significantly low value.
[2] Seed soaked 7 hours was at 45 percent moisture content; 72 hours, 96 percent.

TABLE 28.—*Analysis of variance of mean real germinative capacity of heat-treated longleaf pine seed*

Source of variation	Degrees of freedom	Sum of squares	Mean square	Observed F [1]
Total	95	73,436.89		
Between moisture content	1	10,740.82	10,740.82	*331.40*
Between temperature	1	34,163.01	34,163.01	*1,054.09*
Between duration	3	4,646.70	1,548.93	*47.79*
Interaction:				
Moisture×temperature	1	18,523.15	18,523.15	*571.53*
Moisture×duration	3	341.04	113.68	3.51
Temperature×duration	3	2,052.50	684.20	*21.11*
Moisture×temperature×duration	3	376.80	125.60	3.88
Remainder (error)	80	2,592.70	32.41	

[1] F=variance ratio. Italics indicate highly significant values.

The least significant difference between any two means is

$$\sqrt{\frac{32.409\times 2}{6}}(2.228)=7.3 \text{ percent}$$

The germinative capacity of unheated samples of this longleaf pine seed was found to be 67.1 percent. Mean germinative-capacity values in table 27 less than 59.8 percent (67.1—7.3) are considered significantly reduced by heat treatment. Soaked longleaf pine seed at a moisture content of 45 percent was heated at 100° F. for 14 hours and at 120° for 8 hours without injury. At a mean moisture content of over 80 percent it was heated at 100° for 14 hours without injury, but at 120° even a 5-hour duration of heating resulted in considerable injury to the seed.

The soaking of longleaf pine seed prior to heat treatment did not influence its germinative capacity. The mean germinative capacity of seed that had not been soaked was 66.7 percent; that of a sample soaked for 7 hours was 60.7 percent; and that of samples soaked for 72 hours was 73.8 percent. The analysis of the data indicated that no significant differences existed among these three mean values. The general mean of the tests is 67.1 percent, which was used as the basic germinative capacity value in testing the influence of the heat treatments.

Comparative Influence of Cone Drying and Seed Heating

EASTERN WHITE PINE

Eastern white pine cones from the same source that furnished the seed for the seed heat-treating study were kiln-dried at 140° F. for a duration of 12 hours without injury to the seed. Assuming that the seed in these kiln-dried cones had a moisture content of about 27 percent, the seed heat-treating study indicated seed injury when treated at 120° for 12 hours. As in the kiln-dried, air-dried cones that were partially open the seed dried independently of the cones, it is believed that the cone-drying procedure was essentially a seed heat-treating process. The difference in results of the two techniques therefore constitutes a measure of the effect of seed desiccation during the cone-drying process.

RED PINE

Dry red pine seed withstood a temperature of 160° F. for 9 hours without injury. Kiln-drying green cones at this temperature and duration at 3 percent wood equilibrium moisture content produced the same result. The desiccation of the seed during cone drying reduces the seed moisture substantially and quickly enough to withstand the higher kiln temperature.

LONGLEAF PINE

The cone-drying experiment with partially air-dried cones of a crop from a different locality and of a different year indicated that a kiln temperature of 120° F. for a duration of 8 hours at 4 percent wood equilibrium moisture content was injurious to the contained seed. Longleaf pine seed at a moisture content of 45 percent was heated at 120° for 8 hours without injury, but 11 hours of treatment caused a reduction in seed-germinative capacity. Comparison of the cone-drying and seed-heating results cannot be critical as the seed and cone sources were different, yet the results are in fair agreement. Although the cone-drying process allows for seed desiccation, heat sensitivity is not greatly decreased, presumably because the rate of drying of this large seed is comparatively slow.

CONCLUSION

The introduction of steam-heated dry kilns having forced-air circulation and temperature control into the field of cone drying has increased the efficiency of seed-extraction procedures. The practicability of the installation of such a cone kiln, is of course, determined by the volume of cones to be dried, their cost, labor costs, and the value of the obtained seed. Both public and private agencies producing conifer tree seed can economically install modernized kiln equipment, modified to meet specific requirements and limitations, when cone volumes are approximately 5,000 bushels per year.

As a complement of the cone kiln, good cone-storage facilities are required. Cones of species like longleaf, slash, shortleaf, lodgepole, eastern white, and red pine respond to air-drying, thereby reducing the time required to kiln-dry them to a low moisture content. Modernized kiln equipment, however, is capable of efficiently drying relatively moist cones without danger of seed injury.

A definite relation exists between water loss and degree of cone opening. Jack pine cones may be expected to release good volumes of seed when dried to a moisture content of 5 percent. Eastern white and red pine cones require drying to 6 percent. Rapid drying to these low cone moisture conditions is in the interest of economy. Such a procedure requires that a low equilibrium moisture content be maintained in the kiln.

The following schedules for eastern white, jack, and red pine are recommended for use in the Forest Products Laboratory cone kiln. The longleaf pine schedules apply to a forced-air circulation kiln of the type similar to that described for the W. W. Ashe Extractory. All schedules are based on only one year's collection of cones, for one locality, for each species. Cones ripened under different weather conditions and on a different site might be expected to vary somewhat in their response to kiln treatment. It is suggested that each kiln operator test the effectiveness of the schedules, by simple measurements of cone moisture content, seed yield, seed moisture content, and possibly germination tests in a manner similar to that used in the studies here reported.

Eastern White Pine

The recommended practice in the handling of eastern white pine cones for seed extraction is to first air dry, or precure, them. The air-drying process in a well-ventilated storage shed is a preventive against molding. In addition, air-drying seems to allow the resinous coatings to change sufficiently in structure so that the scales readily respond to drying.

The recommended constant temperature to be used for air-dried eastern white pine cones is 140° F. This is a 20° increase over the temperatures usually recommended for convection cone dryers. In conjunction with this temperature general experience indicates that 3 percent wood equilibrium moisture content should be maintained. At 140°, 3 percent wood equilibrium moisture content corresponds to a 17-percent relative humidity, or a wet-bulb temperature of 93°.

The cones should be kiln-dried to about a 6-percent moisture content to obtain maximum cone opening and seed release. At 140° F. and 3 percent wood equilibrium moisture content, air-dried cones should attain a moisture content of 6 percent well within 12 hours of drying.

Jack Pine

A constant temperature of 170° F. is recommended for kiln-drying jack pine cones. The wet-bulb temperature should be reduced to 116° which, in conjunction with the kiln temperature of 170°, will maintain a 20-percent relative humidity, or a 3 percent wood equilibrium moisture content. At these drying conditions, maximum seed yields are expected within 7 hours of drying.

Red Pine

Mature red pine cones can be kiln-dried immediately after harvest. It is recommended, however, that they be air-dried prior to kiln-drying in order to reduce the time required in the kiln to obtain maximum seed yields. Storage in sacks cannot be recommended; instead, tray storage similar to the method used for eastern white pine is recommended.

Newly harvested moist cones can be kiln-dried at 160° F. without injury to the contained seed, provided a 3 percent wood equilibrium moisture content is maintained; but seed yields are less than that obtained at lower kiln temperatures. At 3 percent wood equilibrium moisture content the wet-bulb temperature will be 100° F. With these drying conditions maximum seed yields can be expected in 9 hours of treatment.

A temperature of 170° F. can be used to kiln-dry red pine cones provided they have previously been air-dried to a moisture content of about 25 percent. At this temperature a 3 percent wood equilibrium moisture content, corresponding to a wet-bulb temperature of 118°, must be maintained. At 170° the maximum seed yields can be expected in 4½ hours, which is 50 percent less time than it takes to obtain maximum seed yields from green cones.

As a general recommendation for the handling of red pine cones it is suggested that tray storage be adopted as a standard practice. If seed is immediately required the moist cones can be dried at 150° F. Cones that can be stored should be allowed to air dry as long as possible. At most northern extractories this would mean that the cones could air dry from harvesting to some time in March. Air drying for 4 or 5 months under suitable storage conditions should put the cones in a moisture condition so that they can be kiln-dried at 170° F. If, however, the extractory operator is uncertain as to the degree of dryness of the tray-stored cones it is recommended that a kiln temperature of 160° and a wet-bulb temperature of 109° be used. The time required to obtain maximum cone opening and seed yields will depend upon the degree of dryness of the cones at the time they are kiln-dried.

Longleaf Pine

Recommendations for the handling and drying of longleaf pine cones are tempered by the necessity for producing seed at a moisture condition consistent with seed-storage requirements. The recommended drying condition for newly harvested or partially air-dried cones is a kiln temperature of 115° F. and as low a relative humidity as can be obtained. The obtained seed will be suitable for immediate sowing but probably will be too moist for prolonged storage.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE WHEN THIS PUBLICATION WAS LAST PRINTED

Secretary of Agriculture	CLAUDE R. WICKARD.
Under Secretary	PAUL H. APPLEBY.
Assistant Secretary	GROVER B. HILL.
Director of Information	MORSE SALISBURY.
Director of Extension Work	W. L. WILSON.
Director of Finance	W. A. JUMP.
Director of Personnel	ROY F. HENDRICKSON.
Director of Research	JAMES T. JARDINE.
Director of Marketing	MILO R. PERKINS.
Solicitor	MASTIN G. WHITE
Land Use Coordinator	M. S. EISENHOWER.
Office of Plant and Operations	ARTHUR B. THATCHER, *Chief.*
Office of C. C. C. Activities	FRED W. MORRELL, *Chief.*
Office of Experiment Stations	JAMES T. JARDINE, *Chief.*
Office of Foreign Agricultural Relations	LESLIE A. WHEELER, *Director.*
Agricultural Adjustment Administration	R. M. EVANS, *Administrator.*
Bureau of Agricultural Chemistry and Engineering.	HENRY G. KNIGHT, *Chief.*
Bureau of Agricultural Economics	H. R. TOLLEY, *Chief.*
Agricultural Marketing Service	C. W. KITCHEN, *Chief.*
Bureau of Animal Industry	JOHN R. MOHLER, *Chief.*
Commodity Credit Corporation	CARL B. ROBBINS, *President.*
Commodity Exchange Administration	JOSEPH M. MEHL, *Chief.*
Bureau of Dairy Industry	O. E. REED, *Chief.*
Bureau of Entomology and Plant Quarantine	LEE A. STRONG, *Chief.*
Farm Credit Administration	A. G. BLACK, *Governor.*
Farm Security Administration	C. B. BALDWIN, *Administrator.*
Federal Crop Insurance Corporation	LEROY K. SMITH, *Manager.*
Forest Service	EARLE H. CLAPP, *Acting Chief.*
Bureau of Home Economics	LOUISE STANLEY, *Chief.*
Library	RALPH R. SHAW, *Librarian.*
Bureau of Plant Industry	E. C. AUCHTER, *Chief.*
Rural Electrification Administration	HARRY SLATTERY, *Administrator.*
Soil Conservation Service	H. H. BENNETT, *Chief.*
Surplus Marketing Administration	MILO R. PERKINS, *Administrator.*

This bulletin is a contribution from

Forest Service	EARLE H. CLAPP, *Acting Forester.*
Division of Forest Products	G. W. TRAYER, *In Charge.*
Forest Products Laboratory	C. P. WINSLOW, *Director.*

U. S. GOVERNMENT PRINTING OFFICE: 1941

END