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THE PRODUCTION, EXTRACTION, AND GERMINATION OF LODGEPOLE PINE SEED

By C. G. BATES

Senior Silviculturist, Lake States Forest Experiment Station, Branch of Research, Forest Service

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INTRODUCTION

The investigations into the qualities of lodgepole pine (*Pinus contorta*) seed reported in this bulletin were begun in 1910, at a time when the Forest Service contemplated very extensive reforestation in the West by the "direct-seeding" method. They were undertaken because of economic and technical difficulties encountered in obtaining the seed of this species in sufficient quantities and at such cost as to make the reforestation program feasible.

Although at the outset no great difficulty was met with in obtaining adequate supplies of cones, anticipation of future needs led in 1911 to a systematic study of the quantities of cones produced per unit area and of the intervals at which large crops may be expected.

As is well known, the cones of lodgepole pine do not open immediately upon ripening, and, like those of jack pine and the European Scotch pine (*Pinus sylvestris*), offer considerable resistance to artificial treatment. The first attempts to extract seed from the cones of this species were rewarded by many disappointments and by yields of seed so small as to make the price prohibitive. Forest officers reported that cones dried for as much as 24 to 48 hours at 150° to 200° F. for the most part failed to open or to yield seed of consistently acceptable quality.

The first conclusion was, naturally, that an extremely high temperature must be used to open all the cones; the second, that the temperature which would be effective would in all probability destroy the viability of the seed.

Fortunately, the Forest Service had European experience with Scotch pine seed extraction to fall back upon, of which Wiebecke's account (*14*)[1] is an example. As soon as reforestation on a large scale made the seed problem an important one, efforts were made to apply European methods to the extraction of lodgepole pine seed. From 1910 to 1913 a number of experiments conducted at seed plants then in operation yielded much valuable information which, in a large measure, solved the practical problems. However, in these large plants, when every effort was being made to obtain seed at a low cost, it was often impossible to control the conditions of extraction so as to produce clear-cut results of scientific value. Small experimental kilns employed since 1912 have given results that have added considerable refinement to the general conclusions already formed and have made more clear the principles involved. The early, rougher tests will be referred to in this bulletin only in so far as may be necessary to round out the data and conclusions from the later tests.

The practical results of seed extraction will always be found in the number of germinable seeds obtained. Besides attempting to reduce the cost of seed to a reasonable point, all of the tests since 1910 have kept well to the fore the necessity for producing seed of high quality. Consideration of the probable deleterious effect on the seed of overheating the cones has always been paramount, and every test of practical importance has been checked by a determination of its effect on seed quality.

The large number of germination tests thus called for, as well as those desired for seed lots to be used in the major reforestation work, soon directed a great deal of attention to the technic of seed testing. It was obvious that scientific conclusions should be drawn from germination percentages per se only after the most careful analysis and with the assurance that the various seed lots have received as nearly as possible the same mechanical treatment. For this reason the effort was made to adopt standard methods which would insure the most valid comparisons between different seed lots representing different cone treatments and between the same seed lots at different periods.

Although the principal aim of this bulletin is to record the studies directed toward the problem of lodgepole pine seed extraction at reasonable cost, it is desirable that the fundamental principles involved at all stages in the collection of cones, their storage and extraction, the testing and storage of seeds, and the final sowing and results to be expected should be made clear, in order that unexpected practical problems may in a large measure be solved in advance. Consideration will therefore be given at some length to a threefold concept of the problem. This will include, in logical order: (1) The natural

[1] Italic numbers in parentheses refer to Literature Cited, p. 91.

rate of production of lodgepole pine cones and seed, and variations from year to year, as these may affect both plans for seed collection and plans for securing natural reproduction after cutting; (2) the collection and storage of lodgepole pine cones and extraction of seed therefrom, both the practical features and physical principles involved; and (3) the characteristics of lodgepole pine seed germination, in the greenhouse and field, as influenced by the germinating conditions, by the seed source and quality, and finally by field conditions.

CHARACTER OF LODGEPOLE PINE CONES AND SEEDS

Lodgepole pine has for a long time been a tree of such unusual interest to botanists and foresters that it seems appropriate to review all of the available facts regarding it that may have a connection with the present study.

In so doing the general tendency to consider the lodgepole pine of the Rocky Mountains and of the Sierras as one botanical species [2] will be avoided. Discussion will be confined to the Rocky Mountain form, without attempting to depict the character of the Pacific form in any respect.

In his Life History of Lodgepole Burn Forests Clements (*5*) has considered in detail all the factors affecting the reproduction of this species, including the seed production and seed qualities, but this latter phase of his work is based on very meager information which will serve mainly as an introduction to the present study.

Mason (*10*) has considered the development of lodgepole pine in its economic aspects as influenced by growth, stocking, and yield, but also reviews much of Clements's information on seed, light requirements, etc. Both of these studies were confined to the Rocky Mountain form of lodgepole pine.

RELATION OF FIRE TO LODGEPOLE PINE DISTRIBUTION

In the central Rocky Mountains lodgepole pine occupies a zone or belt which may be described in a general way as extending from middle to high elevations. A better conception of the position of the species is given by thinking of it as having migrated along the line (generally at about 9,500 feet elevation), which represents the division between the middle forest zone of Douglas fir (*Pseudotsuga taxifolia*) and the higher zone of Engelmann spruce (*Picea engelmannii*). From this line it has spread both upward and downward, sometimes reaching quite or almost to the lower limits of Douglas fir and again, as on the Holy Cross National Forest in Colorado, occasionally going to timber line with the spruce.

On the whole, lodgepole pine has encroached on the fir zone much more than on the spruce. The reason for this is fairly apparent. In almost every spot where now are pure stands of lodgepole pine evidences may be found of a devastating fire, which evidently gave rise to these stands. Such a fire is dependent on two main conditions—sufficient dryness to start a conflagration and sufficient

[2] The two forms are frequently differentiated by the names *Pinus murrayana* and *P. contorta*, respectively, but the Forest Service has adopted the latter name for both forms.

density of stand to induce a crown fire. Where the latter condition does not exist and the fire is confined to the ground in whole or in part, many trees of the predominant species may be killed, but at least a few will survive to reseed the area. The two conditions favoring lodgepole pine succession, a dense stand and dangerous dryness, are more likely to be combined in the middle forest zone than in the spruce zone—hence the almost complete destruction of the Douglas fir forests and their supplanting by the more fecund, if short-lived, lodgepole pine.

It is the opinion of the writer, expressed in 1917 as a result of a study of seed behavior (*2*), and corroborated later by studies of the peculiar physiological functioning of trees of this species (*3*), that lodgepole pine is properly an "invader" of the central Rocky Mountain forests, and moreover that the invasion has been extremely recent, so that over large areas the mature lodgepole pine stands which we now possess represent the first generation of the species as a forest dominant in this region.

Without doubt, however, the vigor of lodgepole pine as an invader of areas denuded by fire results very largely from the character of its seed supply, which is such as to withstand fire to some extent, and so to be available for the immediate revegetation of denuded land.

Since so much speculation has been entered into as to the function of fire in reproducing lodgepole pine and favoring this species rather than the more permanent spruce and Douglas fir, it is desirable to make clear that only two relationships of fire to lodgepole pine forests have been satisfactorily established. Fire may dry and open the old cones on lodgepole pine trees, even while killing the trees themselves and all other seeds of forest trees. Seeds from such cones falling on the completely denuded ground are without immediate competition, and thus have the ample moisture supply which their frail character and slow-rooting habit require. Other effects of fire are practically equally balanced. Charcoal and ashes may possibly furnish temperatures favorable to lodgepole pine germination; contact with the mineral soil, which at times is much more moist than the duff and litter, possibly helps also; but chemical changes in the soil from burning are rather unfavorable to the vigor of lodgepole pine seedlings, since these appear to prefer soil with a moderately acid reaction.

SOIL PREFERENCES

A fact of considerable importance in the natural distribution of lodgepole pine, as well as in the possibility of further invasions and the management of existing stands, is the predilection of the species for siliceous soils. The growth of the tree is by no means inhibited by such soils as those derived from limestone and fine-grained igneous rocks, and yet in some cases the natural migration of the species appears to have been definitely determined by soil character. There is scarcely any doubt that this indicates some degree of fastidiousness on the part of lodgepole pine as to the mineral nutrients of the soil.

More important, however, is the inability of the species to contend with any severe degree of drought. Light sandy soils in general hold most of their moisture at considerable depth and thereby stimulate deep rooting of lodgepole pine seedlings; but it is perhaps more significant that these light soils do not, after denudation, encourage a heavy growth of herbaceous vegetation to compete with lodgepole pine seedlings for the moisture supply. Lodgepole pine prefers a light, and especially a well-drained soil, but the successful establishment of seedlings is more dependent on their having the field largely to themselves.

The seedlings of lodgepole pine, according to Clements's analysis and to present general ideas, are light-demanding; and they are not as well equipped by growth habit as those of spruce or Douglas fir to contend with severe competition. In short, lodgepole pine is rather an invader of freshly denuded or young soils than a climax forest contender and, in the language of the forester, has all the earmarks of a forest " weed."

An interesting illustration of distribution according to soil is found on the western slope of the Bighorn Mountains, Wyo., where a number of glacial flows have cut deep grooves in the native limestone formations of middle and low elevations, and have left these grooves filled with loose deposits of granitic material from the higher mountains. Almost without exception these moraines are occupied by lodgepole pine, whereas the parallel limestone ridges are as exclusively occupied by Douglas fir.

THE CONES

Cones of lodgepole pine vary greatly in size, according to the conditions of growth. The length varies from 1 to 3 inches and the diameter from three-fourths to 1½ inches. Cones of smaller size than this are often produced but are usually unfertilized and bear no seed. (Pl. 1, A.) Normal cones usually run from 1,500 to 2,000 to the bushel.

The normal shape of the lodgepole pine cone is ovate-acute, but this is frequently varied by a tendency to a one-sided development which results in a flattening or even a concavity of the undeveloped side. This arrested development usually occurs where the cone is closely appressed to a stem or branch "leader." Lack of development probably results both from failure of the pollen to reach the concealed surface and from the lack of light to keep active the tissues while they are still in a growing state. Zederbauer (*16*) in the study of the widely distributed mountain pine (*Pinus montana*) of Europe, which shows such great variation in cone form as to lead to the naming of numberless varieties, concluded that the form of the cone was very largely controlled by light and that the different varieties might result from differences in climate, altitude, and density of the stand.

The scales of the cone nearest the tip, with the exception of the first half dozen, are those most certain to bear viable seeds; the extreme basal scales never do. Undeveloped scales also are very likely to be barren. Of the average cone it would probably be correct to say that the seeds are entirely in the upper half. It is almost impossible, and wholly futile to bring about the spreading of the lower scales.

The weight of fresh, green lodgepole pine cones at the time of maturing is 38 to 50 pounds to the bushel. An average figure for cones as commonly collected is 42 pounds to the bushel. Since the excess moisture contained in green cones is very quickly lost, it is never equitable to purchase cones on a weight basis. Cones thoroughly dried at the temperature of boiling water weigh about 25 pounds to the bushel, original volume. In opening the cone scales spread widely, increasing the volume 100 to 150 per cent, according to the rate of drying and temperature of the treatment. With a 110° F. treatment very few of the cones open widely and many do not spread the scales far enough to permit the seed to fall out. With the more rapid drying at 170° or 200° even small, abnormal cones are forced to spread their scales wide.

The specific heat of cones dried at 150° F. has been determined to be approximately 0.43. The fuel value of cones, as very roughly determined, is approximately that of wood or about 8,000 British thermal units per pound of dry weight.

THE SEEDS

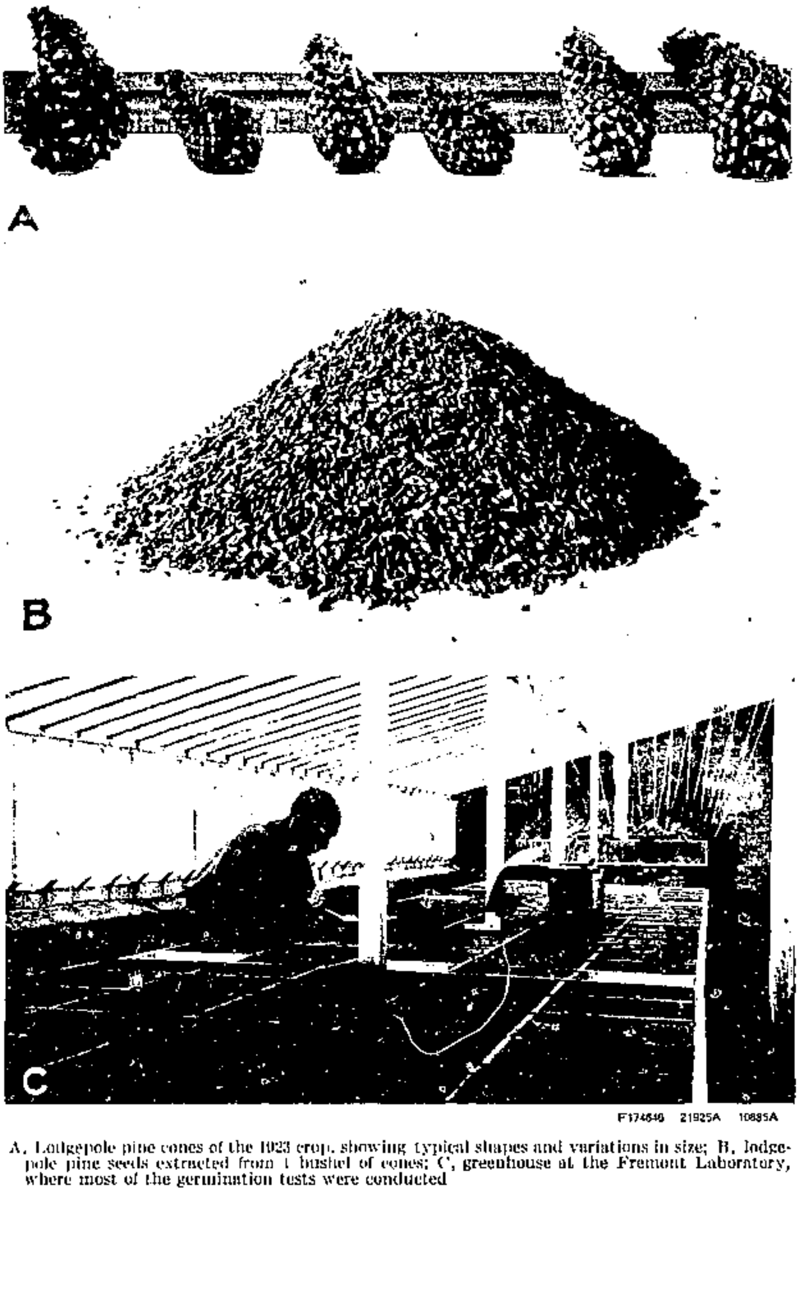
The seeds of lodgepole pine vary in length from 2 to 3 millimeters. They are typically somewhat flattened throughout and obtusely pointed at the small end. The normal color of the seed is black, with numerous excrescences of resin, which give it a slightly grayish tone. (Pl. 1, B.) Although brownish seeds are sometimes fertile, off color denotes lack of vitality in lodgepole pine perhaps more than in any other conifer. Hollow seeds are often nearly white, or black with large blotches of white.

Seeds of lodgepole pine as they come from the cone are enveloped in a thin membrane to which is attached the so-called "wing," resembling the samaras of ash and maple, but more thinly membranous. The wing acts as a slightly turned rudder, causing the seed to spiral in its descent, and in treating the seed, this wing, brittle and easily broken by rubbing, is always removed to reduce the volume and facilitate handling.

The number of fully developed seeds in each cone varies widely. An approximate maximum number is 50, the average for large lots of normal cones is about 40, and the minimum goes down to 1 or 2 in extreme cases.

The yield of seeds, with effective extraction methods, usually falls between one-third and one-half of a pound to the bushel of cones.

The normal number of seeds per pound in thoroughly cleaned lots, from which light seeds have been removed to a moderate degree, is 100,000. The size of the seed compares rather closely with that of jack pine (*Pinus Banksiana*), a close counterpart of lodgepole that in the Lake States yields an average of 129,000 seeds per pound. Engelmann spruce of the Rocky Mountains has smaller seed than lodgepole pine, whereas Douglas fir and Western yellow pine are 2.5 to 10 times as large. The extreme variations in number are from 85,000 to 160,000 seeds per pound, depending both upon size and dryness.



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A, Lodgepole pine cones of the 1923 crop, showing typical shapes and variations in size; B, lodgepole pine seeds extracted from 1 bushel of cones; C, greenhouse at the Fremont Laboratory, where most of the germination tests were conducted

SEED PRODUCTION OF LODGEPOLE PINE

While many scattering observations on the seed production of lodgepole pine are to be found in the literature of American forestry, notably in the discussion by Clements (*5*), so far as known the only serious attempt to measure the fecundity of the species systematically over a period of years has been made by the Forest Service on the Medicine Bow National Forest in southern Wyoming and on the Gunnison National Forest in western Colorado. These two localities were chosen to represent different climatic regions likely to show very different results. (Table 1.) The Medicine Bow area, on a flat plateau at 9,000 feet elevation, is subject to low winter temperatures and heavy snow accumulations, is seldom free from killing frosts[3] in any month of the year, and suffers increasing dryness as the summer advances, although there is a slight increase in precipitation in July and August. The Gunnison area, at an elevation of about 9,200 feet on a steep northwest slope, is in a region subject to even lower winter temperatures and heavy snowfall, but by reason of its more southerly latitude appreciably warmer during the summer months. All of this portion of Colorado receives fairly abundant rains during July and August, which more nearly counterbalance the high evaporation rate.

TABLE 1.—*Normal temperature and precipitation of Medicine Bow area in southern Wyoming and Gunnison area of western Colorado*[1]

Month	Normal temperature		Normal precipitation		Month	Normal temperature		Normal precipitation	
	Medicine Bow	Gunnison	Medicine Bow	Gunnison		Medicine Bow	Gunnison	Medicine Bow	Gunnison
	°F.	°F.	Inches	Inches		°F.	°F.	Inches	Inches
January	14.7	12.5	1.35	1.38	September	42.5	44.6	1.32	1.48
February	10.0	15.2	1.53	1.37	October	34.4	34.9	1.01	1.32
March	21.8	23.4	1.13	1.50	November	25.1	24.7	1.02	.84
April	20.1	30.5	1.86	1.40	December	14.2	12.3	1.37	1.32
May	37.3	40.9	1.19	1.42					
June	46.3	49.7	1.23	1.41	Average or total:				
July	52.4	53.9	1.42	2.38	Year	32.0	32.9	16.00	17.78
August	51.0	52.2	1.57	1.03	Summer	49.9	51.9	4.22	5.75

[1] Southern Wyoming represented by Foxpark Station, 11-year record; Gunnison represented by Pitkin for precipitation and Crested Butte for temperature 13 years and 12 years, respectively. All records read from Climatological Data of the U. S. Weather Bureau.

DESCRIPTION OF THE EXPERIMENT

The two projects were started simultaneously in 1912, on a 10-year plan, both being completed with the collection of the seed crop for 1921.

In each project 10 contiguous plots were laid out, one of these to be cut each year for the collection of cones, since with this species it is impracticable to collect the cones except after felling the trees. The size of the plots was arranged to include about 100 trees in each, and in each plot the trees were classified at the outset into 15

[3] Killing as applied to ordinary vegetation. Of course, the native vegetation has become extremely hardy and is not affected by temperatures near 30° F.

groups, the numbers 1 to 5 representing relative heights as usually expressed by the words dominant, codominant, intermediate, oppressed, and suppressed. Within each of these five groups the trees were further differentiated as to crown fullness by the letters a, b, and c, trees with the fullest and most vigorous crowns being designated a. For a given height class the trees with widest crowns commonly have the largest diameters.

After this classification of the trees had been completed about 15 trees of representative development for their respective groups were selected on each plot, and from these the actual cone collections were to be made. Very few trees were allocated to the oppressed or suppressed groups, especially on the Gunnison area, and in consequence many of these groups are not represented. This is as it should be, since it will be noted that the lower grades, when cut, yielded little or no seed.

The cones having been collected from the sample trees and the seed extracted, weighed, counted, and tested, the method of computing the total yield was to increase the yield for each group in proportion to the ratio of total trees to sample trees in that group and then to reduce the yield to an acre basis.

In the collection of the cones those just maturing were separated from the unopened cones produced in previous years. The former will hereafter be called "new" and the latter "old" cones. The cones from two or more sample trees of a given class were usually combined into one lot, although in some instances individual trees have been followed through. There is no uniformity, or even similarity, in the productivity of individuals of a given class, so the entire set of sample trees gives only a fair stand average for each year, and the tree classes may be roughly compared only on the basis of 10-year averages.

All of the seed extracting was done in the experimental kiln at the Fremont laboratory of the Rocky Mountain Forest Experiment Station as soon as possible after the collection of the cones. The larger proportion of the seeds was extracted at moderate temperatures. When moderate temperatures were not effective, higher temperatures were employed to obtain maximum yields. There is no evidence that the germinability of the seeds was ever appreciably lowered by the drying treatment given.

Extraction of seeds from the 1918 and 1920 crops was delayed nearly a year. Since the conditions for cone storage in the interval were not ideal, it is possible that the relatively low germinative capacities of these two crops may be ascribed in part to this factor.

Five hundred seeds were used for each test, where that number was available. In a few instances, where the total number of seeds available was very small, the germination was estimated at 50 per cent without making any test.

COMPARISON OF THE MEDICINE BOW AND GUNNISON STANDS

A summary of the Medicine Bow plot tallies gives the average number of trees on that area as 443 per acre, whereas on the Gunnison area the number was 528. In mean age, the trees were practically the same in the two places, about 185 years, but the trees on the Medicine Bow area had a much larger average diameter. (Table 2.) This difference in growth is no doubt due in part to the less dense stand on the Medicine Bow, but it is probable also that the soil at Medicine Bow is more favorable to growth. The gneiss soil from the Medicine Bow locality has been shown by greenhouse tests to be peculiarly suited to the vigorous growth of lodgepole pine and, on the basis of these tests, must be rated at least 50 per cent higher than the soil from the Gunnison plots.

TABLE 2.—*Age and diameter of the sample lodgepole pine trees*[1]

Tree class	Average age		Average diameter breast high		Basis, trees	
	Medicine Bow	Gunnison	Medicine Bow[2]	Gunnison[3]	Medicine Bow	Gunnison
	Years	*Years*	*Inches*	*Inches*	*Number*	*Number*
1-a	197	203	14.1	8.3	5	18
1-b	201	193	11.9	7.6	6	10
1-c	195	191	10.2	6.7	4	5
2-a	200	185	11.1	6.8	8	11
2-b	199	199	10.0	6.0	9	8
2-c	186	169	9.1	6.4	6	4
3-a	196	168	9.1	5.4	8	7
3-b	187	172	7.9	5.0	12	5
3-c	172	163	7.6	4.8	8	4
4-a	194	80	6.7	4.6	5	1
4-b	171	140	6.3	4.1	4	1
4-c	170	-	5.8	-	5	-
5-a	189	100	5.2	3.5	3	1
5-b	154	140	4.0	3.7	3	1
5-c	151	-	3.9	-	6	-
Total or average	186	184	8.9	6.8	92	76

[1] Medicine Bow plots for the years 1915 and 1917–1920; Gunnison plots for the years 1917–1921.
[2] Averages determined by the usual algebraic method of basal areas.
[3] These are the average diameters for the groups represented, the sample-tree diameters in this case not having been recorded.

There is, then, on the Medicine Bow area a somewhat more open stand of larger, more limby trees, and more mature in the sense of having attained the stature of maturity. Some of these trees were infected with mistletoe, and recent observation in the same locality indicates that such trees are usually poor seed bearers. Pearson (*11*) found that some western yellow pines (*Pinus ponderosa*) infected by mistletoe yielded seed of lower vitality than the seed from healthy trees, although the quantities were not greatly reduced by anything less than very heavy infection. It is questionable whether these facts have any material bearing on the seed production of the two areas, since it will be shown in the later analysis that this is probably most directly controlled by local climatic conditions.

AMOUNT OF SEED PRODUCED

In Table 3 the weight and quality of the seed collected each year are given, together with the computed number of good seeds as measured by the total or final germination percentages. This final figure is shown graphically in Figure 1.

TABLE 3.—*Summary of lodgepole pine seed production per acre of forest*

Year	Medicine Bow					
	Current crop			Old cones		
	Weight	Germination capacity	Good seeds	Weight	Germination capacity	Good seeds
	Pounds	*Per cent*	*Number*	*Pounds*	*Per cent*	*Number*
1912	1.1805	56.4	90,078	1.9207	37.3	145,531
1913	.6702	[1] 72.0	73,893	1.7070	56.0	140,519
1914	.2312	[1] 78.0	[2] 10,510	.0700	78.0	[2] 0,669
1915	.7337	[1] 35.0	40,125	4.2196	41.4	226,004
1916	1.1016	65.6	108,254	0	0	0
1917	1.7977	58.9	135,582	3.1648	58.7	270,310
1918	.8668	[1] 61.8	56,350	6.7316	61.5	481,500
1919	0	0	0	4.6293	65.0	382,930
1920	1.6242	58.5	102,308	.7749	58.8	53,596
1921	.8800	81.5	97,711	.9621	68.2	90,987
Arithmetical mean	.9120	63.2	72,992	2.4187	59.0	180,707

Year	Gunnison					
	Current crop			Old cones		
	Weight	Germination capacity	Good seeds	Weight	Germination capacity	Good seeds
	Pounds	*Per cent*	*Number*	*Pounds*	*Per cent*	*Number*
1912	2.5337	67.9	226,121	16.6384	72.5	1,527,079
1913	2.1425	[1] 67.3	196,079	23.6280	74.5	2,320,168
1914	.0674	75.8	68,074	23.7042	62.7	1,781,263
1915	.0189	74.7	90,905	12.7084	68.3	1,143,195
1916	.4511	77.1	54,668	18.0968	73.8	2,086,405
1917	3.4242	67.0	319,074	5.6447	52.8	424,710
1918	7.4853	65.6	682,720	2.6416	45.0	183,828
1919	7.0084	83.4	827,074	5.6895	79.0	656,974
1920	7.3279	[1] 73.3	699,384	4.4947	63.3	401,728
1921	.2784	87.5	30,421	5.2542	80.2	508,316
Arithmetical mean	3.2328	74.0	320,053	11.9160	67.4	1,103,900

[1] The germination period has been for 62 days where noted. In 1912 the Medicine Bow crop was tested for 66 days; 1916, 66 to 89 days, with 75 days as the average; 1917, 88 days; 1919, 65 to 102 days, with 94 days prevailing; 1920, 66 days; 1921, 73 days. The 1912 Gunnison crop was tested for 66 days; the 1914 only for 50 to 52 days; the 1915 crop for 82 days; 1916, 89 days; 1917, 88 to 89 days; 1918, 62 to 109 days; 1919, 100 days; 1921, 84 days.

[2] Crop so small that all lots of new and old cones were lumped together. The proportion assigned to old and new is obtained from the cone weights.

The salient points brought out by Table 3 are as follows:

The Medicine Bow sample area has produced, as a 10-year average crop, 0.912 pound of clean seed, or 72,992 good seeds per acre, the term "good" being used throughout this discussion to denote seeds germinable within the period allowed and under the soil, moisture, and temperature conditions provided. These figures, while in every sense conservative as to actual seed production, may give an unduly optimistic impression of the number of seeds likely to germinate under field conditions, even with the complete elimination of destructive agents such as rodents, which undoubtedly destroy a large proportion of the crop each year.

The Gunnison area, on the same basis, has produced 3.2328 pounds of clean seed per year, equivalent to 320,053 good seeds to the acre. These figures compare well with the estimate made by Cox (*6*) in 1911, which showed a full crop for lodgepole pine to be about 4 pounds of seed per acre.

The value of old cones, as measured by the number of germinable seeds, is in the average year 2.48 times the value of the new cones for the Medicine Bow area and 3.45 times for the Gunnison area; or, in other words, in the one locality cones are retained for an average of two and one-half years, and in the other area for three and one-half years after the normal time of maturing. This ratio, or the tendency of trees to retain their cones without opening, is extremely variable as between individual trees under similar growing conditions and has never been adequately explained, but it is believed the

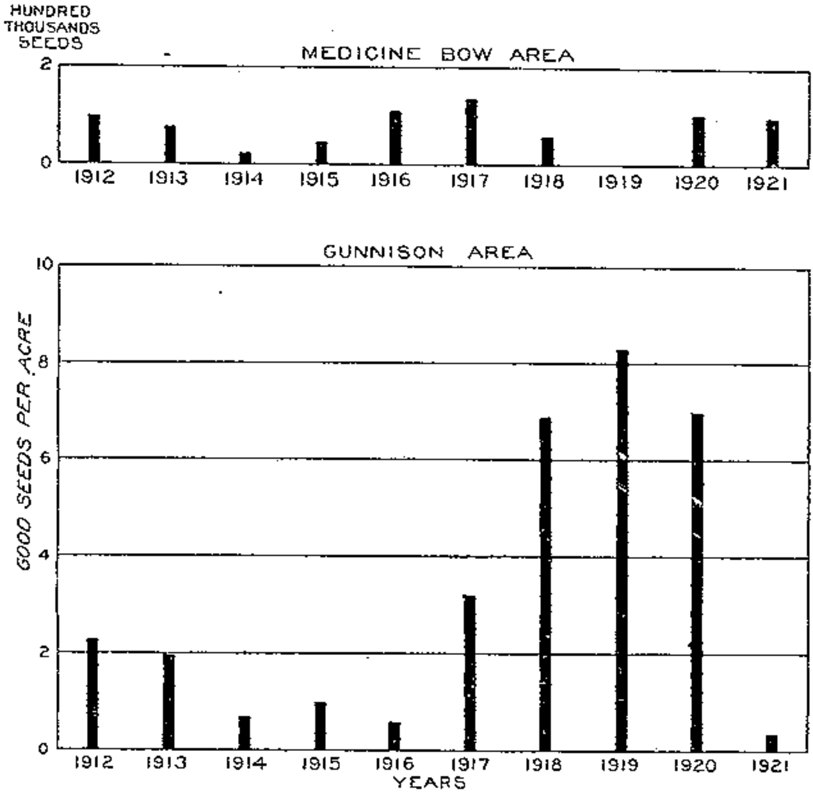

FIGURE 1.—Lodgepole pine seed production by years, all tree classes, new cones only

above data are sufficiently well grounded to indicate a distinct difference in this respect between the trees of the two localities.

For both localities the new seeds show higher germinative capacity than those from old cones, and the germination of Gunnison seed is distinctly better than that of the Medicine Bow seed. Individual germination percentages have no precise value in biological comparisons, but it may safely be said that the present data do show definite tendencies, and this will be substantiated later by a consideration of the germination rates. The average germination period was somewhat longer for the Gunnison seeds than for the Medicine Bow seeds, namely 77 days as against 71 days, but if the 6 additional days were given the Medicine Bow seeds their germination could hardly be increased more than 1 per cent.

PERIODICITY OF SEED PRODUCTION

The literature of forestry has frequently given expression to rather ill-founded beliefs in the periodicity of seed crops of the various forest trees and the reasons therefor. "Produces abundant crops of seed every three or four years" is a good sample of the expressions used, and where any explanation is offered for such periodic production the impression is usually conveyed that the production of a good crop so exhausts the vitality of the tree that it must rest for two or three seasons. From what is known of the irregularity of fruit crops and their dependence in large measure on weather conditions at the time of flowering, this prevailing idea appears illogical, and it is doubtful if it would be supported by any careful analysis of comparable and reliable data on the seed crops of different localities over a period of years, such as is offered incidentally by the present study. The degree of variation in successive crops of seed from the Gunnison and Medicine Bow areas, shown in Figure 1, furnishes no evidence that one good crop, or even two in succession, exhaust the ability of the trees to produce seed or lower their vitality in the slightest degree.

It will be noted for the Gunnison area that fairly good crops, better than the maximum Medicine Bow crop, were produced in 1912 and 1913. These were followed by three lean years, and the latter in turn by four successive years better than average. The poorest year for the Gunnison was 1921. The Medicine Bow production shows similar but less marked surges, including one year of complete failure.

While it is true that the successive crops on either area were not gathered from the same sets of trees, the several sets were in each locality subjected to the same climatic conditions. Crop failures, and likewise especially abundant seed crops, are usually widely effective, and crops may generally be described as uniformly good or bad over whole townships or larger areas. Although the two areas of this study should not be expected to fall within the same set of influences, it seems probable that the year-to-year variations shown by the plots used in each area may be thought of at least as characteristic of the areas involved.

May forest-tree seed crops then be said to be dependent on local and perhaps temporary weather conditions and may they be forecast? With so many possibilities of weather conditions affecting a crop that requires two growing seasons to mature, a close correlation is hardly to be expected without a more exhaustive study than the available weather records will permit. It is believed, however, that a very simple explanation of the failures of these lodgepole pine seed crops is possible. This explanation was suggested by observation at the Fremont station of the repeated destruction of Douglas fir seed crops after the female flowers had appeared in abundance. This destruction appeared to be accomplished by freezing weather and late snows, and although rarely complete indicated that the pistillate flowers are sensitive to cold in the same sense as the flowers of our common fruit trees or that cold weather occurring at the critical time might prevent normal pollination.

A statement of minimum summer temperatures as presented in Table 4 should permit a surmise as to their effect on the young pistillate flowers on which cone crops are dependent. The record of temperatures for Foxpark very closely approximates that at Medicine Bow, less than a mile away; that for Crested Butte, some 30 miles distant from the Gunnison seed-producing area, is not so closely an approximation, but as it is in the same basin and at about the same elevation the two points would probably be subject to the same general influences. Thus the relative seasonal values are sufficiently indicative. It should be understood that in these forest types there is practically no vegetative activity before June.

TABLE 4.—*Minimum air temperatures for each month of growing season, at Foxpark and Crested Butte, Wyo., 1911–1920*

Date of minima: Year	Month	Day	Minimum temperatures at— Foxpark (Medicine Bow)	Minimum temperatures at— Crested Butte (Gunnison)
			° F.	° F.
1911	June	3	....	26
		23	22	....
	July	9	23	....
		31	....	30
	August	3	....	24
		25	19	....
1912	June	17	20	....
		18	....	20
	July	18	(1)	32
	August	9	....	20
		22	24	....
1913	June	8	25	....
		13	....	25
	July	1	....	28
		31	24	....
	August	1	27	....
		15	....	32
1914	June	24–25	26	....
		27	....	25
	July	3	31	....
		11	....	30
		19	31	....
	August	13	26	....
		25	....	28
1915	June	7	16	....
		13	....	20
	July	7	(1)	27
	August	7	(1)	27
1916	June	4	....	20
		7	14	....
	July	4	23	....
		5	....	29
	August	26	23	....
		28	....	28
1917	June	2	....	28
		6	20	....
		13	20	....
	July	3	....	30
		16	27	....
	August	24	23	....
		25	....	29
1918	June	30	19	32
	July	1	18	....
		2	....	34
	August	7	....	28
		30	20	....
1919	June	2	12	(1)
	July	8	24	(1)
	August	20	22	(1)
1920	June	20	22	15
	July	6	....	21
		9	27	....
		14	27	....
	August	23	28	17
Average minima:				
June			19.6	23.4
July			24.6	29.0
August			23.0	26.9
Normal mean:				
June			40.3	49.7
July			52.4	53.9
August			51.0	52.2

[1] No record for this month.

The general air temperatures for the summer as shown in Table 4 are 2° higher in the Gunnison region. This fact alone would go far toward explaining the much greater productivity of the trees. However, the 3° difference between the mean temperatures for June and the corresponding difference in mean minima are especially to be noted as affecting the development of pistillate flowers in the two regions.

The most certain evidence of a correlative variation in crops in individual years is obtained from consideration of the very unusual conditions prevailing at Foxpark on the 30th of June and 1st of July, 1918, when temperatures of 19° and 18° F., respectively, were recorded, the latter being much the latest minimum of similar severity at this station and the lowest July temperature during the 10-year period. This depression certainly explains the failure of the 1919 Medicine Bow crop, especially when it is known that the month of June, as a whole, had been several degrees warmer than normal. Likewise, the poorest crop on the Gunnison, that for 1921, is very certainly connected with the low minima for 1920, which were record breakers not only in June but also in July and August.

In contrast to these extremes, the four phenomenally large crops on the Gunnison appear to be connected with favorable temperatures in preceding years, which culminated in 1918, when there was no frost in either June or July. It is regrettable that there is no 1919 record to substantiate further this conclusion.

The other correlations are not so clear, and there is no desire to overstress this point by offering far-fetched explanations. Too little is known of the weight that should be given to different factors, such as time and severity of freezing temperatures. It does seem evident, however, that lodgepole pine seed crops, like fruit crops, are subject to injury by severe freezing, and that for this reason periodicity can be no more regular than the succession of favorable weather conditions, which has no regularity whatever except as limited by the laws of chance.[4] Forecasting seed crops for the pines, it is believed, can be based only on the evidence of cones that have successfully weathered their first growing season and which are therefore almost certain to mature.

Although lodgepole pine in the middle and higher mountain elevations has, no doubt, become inured to low temperatures during the flowering period, still there is reason, from the evidence here presented, for believing that at high altitudes and latitudes it may reach the limit of effective seed production, just as seed production of the aspen ceases toward but well within the upper edge of its vegetative zone.[5]

No claim is made that these data completely explain the sizes of the crops produced, for it is self-evident that there are many factors which might affect productivity after the flowers were past the frost-sensitive stage. But since with favorable climatic conditions lodgepole pine begins to produce cones at an early age, and trees of all sizes and nearly all degrees of vigor show ability to produce some seeds, it is probable that temperature has a more direct bearing on productivity for a given forest area than any other factor or group of factors.

COMPARATIVE FECUNDITY OF LODGEPOLE PINE

While this bulletin does not attempt to treat the seed problems of other species, it is important for a thorough consideration of the practical problems of lodgepole pine management to know how this species compares in seed-producing capacity with its neighbors of the mountain forest. For such a comparison, records for the other species are available from observations conducted in the same manner as those for lodgepole pine, and for almost the same period.

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[4] For example, the chances are only 3 in 100 that four successive seasons will have temperatures above the normal.

[5] This statement is based on limited observation, and may not represent a valid comparison because seed production in aspen is at best a weak and nearly disused function.

These observations, when tentatively assembled, show that the numbers of good seeds produced by western yellow pine, Douglas fir, and Engelmann spruce are of the same order of magnitude as the numbers for lodgepole pine, although only one area, occupied by Engelmann spruce on the Uncompahgre Plateau, in Colorado, has shown as high an average production as the Gunnison lodgepole pine area. The more important difference seems to be that all of the other species are a little more liable than lodgepole pine to complete crop failures, which may in some years be traced to unfavorable weather conditions.

This seems to be especially true of Douglas fir, whose pistillate flowers appear so early that there is an unusual risk of encountering damaging temperatures. The single area studied for this species shows five complete failures and two almost complete failures in a period of 10 years, with good crops in 1914, 1917, and 1920, and an average yearly production of 49,000 good seeds.

Engelmann spruce on the Uncompahgre Plateau, in the eight years from 1914 to 1921, inclusive, produced large crops in 1914, 1917, 1918, and 1920, and had three complete failures, the average production being 550,000 good seeds per acre. On the White River National Forest the production per acre has been only one-ninth as great, and four of the eight years have yielded failures or near failures. The three best years correspond to those for the Uncompahgre area, a circumstance which suggests the influence of rather general climatic conditions.

Western yellow pine on the Harney National Forest (Black Hills region of South Dakota) has produced 50,000 good seeds per acre as an average for the 11 years through 1922, but only 6,000 seeds per acre were produced on the Cochetopa area in Colorado. A low-lying area in the Colorado National Forest frequently resorted to for seed collecting has yielded an average of 61,000 seeds per acre in the eight years since 1915, but this average is obtained entirely from the crops of 1917 and 1920. In "periodicity" the relationship is close between the yield in the Black Hills and that in northern Colorado, but the seed yield from the Cochetopa Forest, considerably farther south, does not correspond to that in the other areas at all. This is perhaps due to the fact that the Cochetopa area is at a high elevation for western yellow pine.

AMOUNT AND QUALITY PRODUCED BY DIFFERENT CROWN CLASSES

The necessity for having large, full-crowned trees in order to obtain good seed crops is apparently less with lodgepole pine than with most other forest trees. Although the largest and most vigorous trees are the best seed producers, as is almost inevitable, the belt of productivity is wide, and good seed trees are to be found in the codominant and intermediate classes. The whole situation is stated in intelligible terms when it is said that lodgepole pine is a "prolific weed." The data on this subject, as presented in Table 5 and Figure 2, have an evident bearing on marking policy under either a shelterwood or selection system of cutting lodgepole pine.

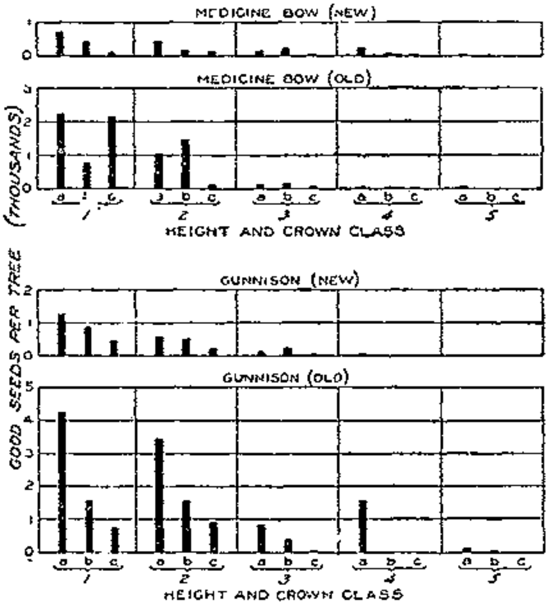


FIGURE 2.—Average tree production of good seeds for lodgepole pine trees of various classes. Under each numbered height class (representing dominants, codominants, intermediates, oppressed, and suppressed) crown classes are differentiated by letter—*a* signifying the fullest crowns

TABLE 5.—*Ten-year average seed and cone production per lodgepole pine tree, by tree classes*

Tree class	Average weight of cones per tree				Average weight of seed per tree				Basis, trees		
	Medicine Bow		Gunnison		Medicine Bow		Gunnison		Medicine Bow [1]		Gunnison [2]
	New cones	Old cones	New cones	Old cones	New cones	Old cones	New cones	Old cones	New	Old	
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*0.001 lb.*	*0.001 lb.*	*0.001 lb.*	*0.001 lb.*	*No.*	*No.*	*No.*
1-a	1.745	10.743	1.502	6.298	1.010	3.335	1.262	4.449	9	9	37
1-b	.850	2.504	.973	3.183	.565	.774	.838	1.777	9	9	15
1-c	.429	6.481	.696	1.084	.158	2.407	.543	.877	7	7	7
2-a	.751	4.884	.740	6.119	.509	1.410	.632	3.940	10	11	20
2-b	.602	7.824	.703	2.301	.273	2.246	.537	1.497	17	17	15
2-c	.166	1.731	.203	2.090	.165	.243	.214	.875	10	9	11
3-a	.203	1.318	.234	1.110	.205	.215	.145	.880	11	12	14
3-b	.320	1.210	.104	.913	.230	.229	.214	.804	17	18	9
3-c	.041	.187	.002	.018	.029	.029	.003	.010	12	12	6
4-a	.319	1.622	.050	[3] 2.100	.318	.052	.039	[3] 1.891	9	9	4
4-b	.042	.061	.000	-------	.026	.023	.000	-------	8	7	2
4-c	.020	.163	.000	-------	.016	.031	.000	-------	6	7	0
5-a	.036	.132	.000	.120	.023	.080	.000	.130	5	5	1
5-b	.007	.024	.000	.012	.006	.000	.000	.030	6	5	4
5-c	.000	.000	.000	.000	.000	.000	.000	-------	8	8	0
Total or average [4]	.407	2.922	.765	3.560	.254	.814	.623	2.381	144	145	151

[1] Total only for years in which some seed of the given group (old or new) was produced and excluding 1914 for both classes of Medicine Bow seed when the tree classes were lumped together.
[2] Same for old and new cones.
[3] Unusually high average, due almost wholly to product of one tree of 1914 crop.
[4] Total amounts divided by total number of sample trees.

The following points in regard to Table 5 may be emphasized:

Before attempting to discuss the tree averages it should be pointed out that even these 10-year averages are not to be depended upon for precise comparisons. A rough approximation from the original data indicates that within any group the average variation of individual trees from the mean for all trees of that class is from 75 to 125 per cent of the mean production. The probable error in the average figure where the largest number of trees is involved is about 11 per cent, and where there are only a few trees this may be as much as 45 per cent. Part of this variation may be connected with variations in the whole crop. These data, then, are only sufficient to indicate the tendencies of the several tree classes.

In the production of new cones on the Medicine Bow area there is a distinct tendency toward the highest production in the tallest trees, and in the largest-crowned trees of each height class, even those of the suppressed group showing some capacity for seed production. The apparent exception to this rule is in the superiority of class 3–b trees over those of class 3–a.

No consistent relation appears between the actual productivity of the groups and their retention of cones as shown by the size of the old crops. Rather is there a tendency toward larger crops of retained cones on trees of medium or small crown development. This fact appears to support the supposition that at the end of the second season lodgepole pine cones in a large measure are not ripe. That this should be more markedly true with small-crowned, undernourished trees seems strictly logical.

The same tendencies are even more clearly and regularly shown in the Gunnison crops, except that here the oppressed, suppressed, and intermediate small-crowned trees fail much more markedly to enter into seed production. A closer connection between productivity and retention of cones by the more important classes is apparent, and this, coupled with the fact that the Gunnison stands are in every sense more poorly developed than those on the Medicine Bow, bespeak the soundness of the idea that retention is due to immaturity.

The Gunnison stands contained more trees to the acre than the Medicine Bow stands; yet in the classification of the trees 74 per cent of those on the Gunnison are shown as dominant or codominant, whereas in the Medicine Bow tallies only 43 per cent of the trees are placed in these groups. This accounts in some measure for the greater production per acre of the Gunnison lodgepole pine. Being much more nearly even-aged, it presents an even, crowded canopy and equality of opportunity for a large number of trees. But although the acre production on the Gunnison is 4.4 times as great as on the Medicine Bow, a comparison of individual trees—class 1–a for example—yields a ratio of only 1.7 to 1; or for class 2–a, 1.9 to 1.

It is not amiss to point out, from the data in Table 5 and Figure 2, the strong contrast between the productivity of the cones from the two areas. Reduced to a bushel basis:

One pound of Medicine Bow new cones produces 492 good seeds.
One pound of Medicine Bow old cones produces 205 good seeds.
One pound of Gunnison new cones produces 806 good seeds.
One pound of Gunnison old cones produces 617 good seeds.

Part of the difference indicated above may be due to the fact that Medicine Bow cones are considerably larger, while probably having

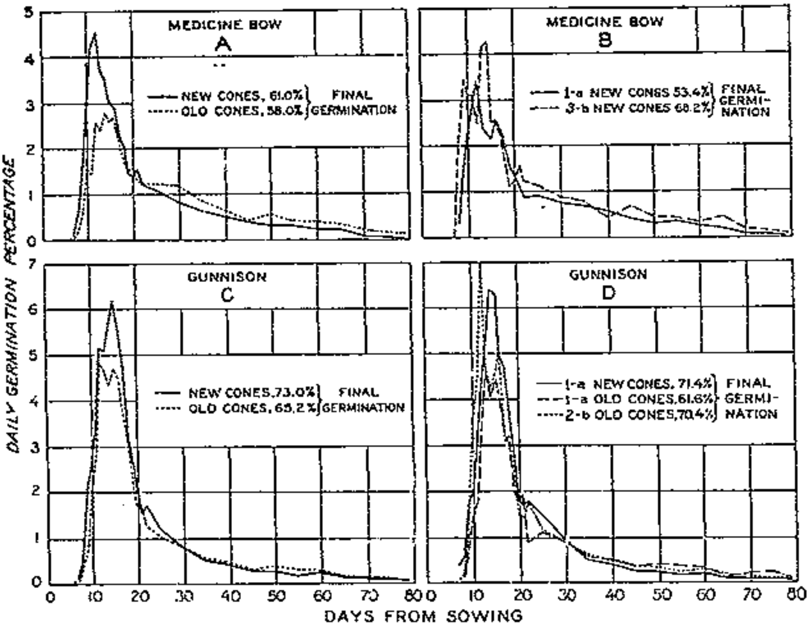


FIGURE 3.—Daily germination rates of lodgepole pine in percentage of seeds sown from new and old cones: A and C, average of all lots; B and D, average of selected lots

no greater number of seed-bearing scales. Vegetative development on the Medicine Bow, at least, is not hindered, and it is thought a

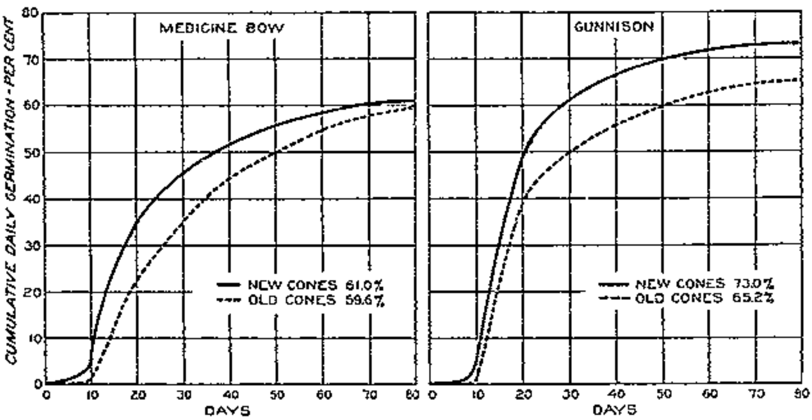


FIGURE 4.—Total germination of new and old lodgepole pine seed in percentage of seed sown, Medicine Bow and Gunnison

great part of the difference must, then, be due to failure of pollination of the cones.

The superior vigor of the Gunnison seed has already been pointed out. Data on the germination of the seed of each tree class are given in Table 6, while in Figures 3 and 4 are shown the daily germination rates of a few lots selected for high or low vigor.

TABLE 6.—*Summary of germination tests of lodgepole pine seed by tree classes for 10 years without reference to sizes of crops represented*

Tree class	Medicine Bow seed from—						Gunnison seed from—					
	New cones			Old cones			New cones			Old cones		
	Tested	Germinated		Tested	Germinated		Tested	Germinated		Tested	Germinated	
	No.	*No.*	*P. ct.*	*No.*	*No.*	*P. ct.*	*No.*	*No.*	*P. ct.*	*No.*	*No.*	*P. ct.*
1-a	4,217	2,252	53.4	2,711	1,281	47.3	4,535	3,237	71.4	5,000	3,079	61.6
1-b	3,085	1,756	56.9	1,573	916	58.2	2,925	1,960	67.0	4,303	2,857	66.4
1-c	1,237	798	64.5	1,604	1,027	64.0	2,000	1,538	76.9	2,731	1,807	66.2
2-a	3,504	2,203	62.9	2,825	1,714	60.7	3,964	3,045	76.8	4,561	3,171	69.5
2-b	2,893	1,594	55.0	3,368	2,122	63.0	3,592	2,577	71.7	4,681	3,294	70.4
2-c	1,779	1,164	65.4	500	260	52.0	1,074	849	79.1	2,457	1,566	63.7
3-a	1,771	953	53.8	1,500	727	48.5	1,553	1,112	71.6	3,493	2,379	68.1
3-b	3,069	2,092	68.2	2,190	1,333	60.9	1,314	967	73.6	1,724	751	43.6
3-c	489	335	68.5	391	303	77.5	------	------	------	17	11	64.7
4-a	1,702	1,354	79.6	571	346	60.6	178	138	77.5	847	471	55.6
4-b	252	158	62.7	273	148	54.2	------	------	------	------	------	------
4-c	131	84	64.1	365	118	32.3	------	------	------	------	------	------
5-a	142	66	46.5	455	330	72.5	------	------	------	281	199	70.8
5-b	38	23	60.5	------	------	------	------	------	------	183	142	77.6
5-c	------	------	------	------	------	------	------	------	------	------	------	------
Total or average	24,314	14,832	61.0	18,326	10,625	58.0	21,135	15,423	73.0	30,278	19,727	65.2

Table 6 indicates some tendency toward low germination in the tree classes which produce the largest quantities of seed, and vice versa. There is no doubt that some of the differences between the tree classes represent real differences in quality, but in view of their irregular distribution it seems futile to attempt an explanation. Part of the irregularity in values may without doubt be ascribed to the inevitable differences in handling large and small lots of cones. In Figure 3, in which rates of germination of a good and poor lot of Medicine Bow seed are compared, no essential difference appears in the character of the two germination curves. The good seed is better at all stages.

On the other hand, for both areas, the new seed not only has appreciably higher final germination value but also is ahead of that from old cones in the early part of the germinating period and has fewer stragglers coming on later.

This superiority of new seed both in vigor and final germination will appear inconsistent with the theory that the cones and seeds are not wholly mature at the end of their second year of growth. If this theory were correct, the seeds should show better vigor a year or two after their theoretical maturity. But it should be borne in mind that the average retention period of the old cones is about three years and that the lots as treated include cones from 1 to possibly 20 years old, of which the oldest are on the point of decay. As brought out by Clements (*5*), the very old cones sometimes contain only one or two seeds which have not decayed, so it is reasonable to suppose that those remaining are far past their prime of vigor.

In Figures 3 and 4 the great contrast in germinative vigor between the Medicine Bow and Gunnison seeds is readily apparent, and this is important because of its possible bearing on the adaptability of seeds grown in one region for use in another locality where different climatic conditions call for a different kind of response.

SEED COLLECTING AND EXTRACTING

CONE COLLECTING

Seed collecting should be concentrated in the years when the best crops are produced. Fortunately, as with all the pines, the evidence necessary to predict the approximate size of the crop is available a year in advance, and preparations may be made accordingly. However, none of the facts at present available argue for the concentration of seed-collecting and extracting operations in any one locality. The tendency of all plants to adapt themselves to the requirements of a given locality is ample evidence of the desirability of collecting seed as near as possible to the point where it will be used. When the Forest Service first faced the problems of lodgepole pine seed collecting, two arguments—the probability of a very large demand for seed and the apparent mechanical difficulties involved in extraction—led to the concentration of the work in two kilns of large capacity at Fraser and Foxpark. To-day it is clear that neither of these arguments has weight. In spite of the fact that it is entirely feasible to keep lodgepole pine seed in good condition for several years, a number of facts argue against the plan of large collecting and extracting operations.

Since a good seed year in one locality may coincide with failure in others, small plants in the various localities will prove more adaptable to seed supply. The number of settlers who can be depended upon as cone pickers is usually quite limited in the mountain localities, and the difficulty of securing cones increases with the number demanded; therefore a small quantity can probably be gathered at a lower cost per bushel than a large quantity. The proved simplicity of the extracting operation presents an argument for simple, inexpensive equipment and relatively small-scale operations such as can be conducted locally by a permanent, nontechnical force.

As has been stated in describing the seed-production experiments, picking cones from standing lodgepole pine trees is not feasible. The other methods are to pick cones from trees felled for timber and to take cones from squirrel hoards. The feasibility of picking the cones from felled trees depends entirely on cutting operations properly located and timed and the rate at which cutting proceeds, since the period when the cones may be gathered advantageously usually lasts only a few weeks.

The pine squirrel, common in nearly all lodgepole pine forests, begins cutting the current season's cones by September 1, or even slightly earlier. One of the great advantages in collecting cones which the squirrels have cut and hoarded arises from the infallible judgment of the squirrels in selecting the cones with the most and best seeds in them. It is worthy of note that sound, old cones are always collected to some extent with the new cones. Some of these cones are buried, singly, beneath or near the parent tree, and are lightly covered with dry-needle litter. This appears to be done mainly at the beginning of the season, and may be a provision for causing the cones to ripen. In hollow logs and other shelters, and also in spots where large piles of cone fragments have accumulated, caches of considerable size are made. Possibly the average volume placed in one spot is as much as a peck. Caches yielding a bushel or more are frequently reported by collectors.

Although the number and sizes of such hoards are variable, good collecting conditions will permit the experienced individual to collect from 5 to 10 bushels per day, and since whole families may carry on the work, under such conditions, the work yields very good wages. The price paid by the Forest Service in the past has probably averaged at least 75 cents a bushel, and no doubt to get the same results to-day it would be necessary to pay a dollar. Since the average yield is only about one-third of a pound of seed per bushel of cones, the cost of the seed is necessarily high, even if the extracting is done inexpensively.

CONE STORAGE

Squirrels often store the cones where they will remain moist or wet and yet cool enough to tend to discourage molding and decay. The purpose of the squirrels is plainly to keep the cones from drying and opening before the seeds are needed as food. For the forester's purpose the cones should be stored where as many cones as possible can be opened by sun and air drying, thus simplifying the work that must be done by artificial heat. It is important, since a portion of the cones open promptly and fully, that the bin or crib used for their temporary storage should have a smooth, tight floor. If storage continues well into the winter, a considerable part of the seed crop may be collected from the floor of the bin. On the whole, a tight bin seems preferable to an open one of the corncrib type, provided only that it is well ventilated by screened openings above the cone piles. The cones dry very little within the large pile, under any circumstances, and in the open crib the loss due to mice and other rodents may more than balance the gain through drying. If the cones are no more than ordinarily moist in the caches, little danger of molding or heating in the bins need be apprehended.

SEED EXTRACTING

As a result of the early experiments in the extraction of lodgepole pine seed, the difficulty of opening the cones quickly and cheaply seemed almost insurmountable. Following the suggestions of Clements's small-scale experiments (*5*), many different treatments of cones were attempted, two of which seem worthy of mention, namely, roasting over a flame and superficial leaching with hot lye water to remove the resinous coat. The former proved not wholly impracticable in opening the cones promptly, but too dangerous to be employed where less drastic measures were possible. The lye treatment was found to have no accelerating effect in ordinary practice, any water treatment merely requiring additional drying to be done, but gave promise of effectiveness with badly casehardened cones.

The detailed description to follow is confined to those tests which have given the most fundamental facts and at the same time have pointed out the reasons for earlier failures. The two most important tests in drying cones and extracting seed were made at the Fremont field station, beginning in 1912 and 1914, respectively. In addition, numerous poorly controlled experiments in conjunction with, and as processes in, the development of the Fraser and Foxpark seed plants will be referred to incidentally.

THE EXPERIMENTAL KILNS

Although the kilns used for the artificial drying of cones at the Fremont station were exceedingly simple in plan, the principle involved is of such importance with respect to both present results and future operations along this line that a close study of the details is desirable.

The earliest experience with lodgepole pine cones dried on shelves placed around the walls of a tight room with a stove in the center indicated that more was required to open the cones than merely a warm atmosphere.

In the large, mechanically operated extracting plant built at Foxpark, Wyo., in 1911, it had been found that to make high temperatures effective for large masses of cones, even when these were being constantly churned and exposed in a revolving drum, rapid air circulation was necessary. However, in treating a large mass of cones with forced circulation of the air, the difficulty lies in the fact that the first cones to be reached by the hot-air blast extract so much heat from it that cones farther away receive only a tempered and moistened air current. In short, the drying process requires not merely temperature, but a supply of dry air brought rapidly to the surface of each cone where evaporation is taking place.

The experimental kiln first constructed was built almost entirely of matched flooring. A hollow column about 18 inches square and 4 feet high, with a smaller column topping it, was designed to serve as a flue to conduct the hot air upward, without artificial aid in circulation.

The air, which had been heated in a horizontal iron duct placed over a gasoline stove, was introduced through the side wall at the bottom of the column. In rising through the space within the walls the hot air encountered only the resistance of thin layers of cones placed on four trays of the same dimensions as the interior of the kiln. These consisted of frames 2 inches high, with bottoms of one-fourth-inch hardware cloth, placed one above the other.

About one-third of a bushel of cones could be placed on these four trays without having more than one full layer on each, so that the circulating air would inevitably come in contact with the surface of each cone. The amount of air which could pass through the first tray of cones would pass through the second, third, and fourth layers with little additional friction, whereas if the entire mass of cones were placed on one tray the openings between cones of the first layer would be almost completely closed by other cones which would wedge themselves in. Likewise, the small flue above the cones offered no undue friction, having a capacity fully as great as the aggregate of openings between the cones.

In this flue a small anemometer was placed, to indicate the rate and volume of air movement. To aid in controlling the temperatures in the kiln, two thermometers were inserted through its walls below the cones, giving the temperature of the incoming air. Two additional thermometers were similarly inserted in the space above the trays, to indicate the temperature of the air after passing through the four layers of cones. With the data thus obtained and the known specific heat of air, it was possible to compute the quantity of heat consumed in the process of drying the cones.

The first really quick and effective drying was attained with this kiln, and was evidently obtained solely by the circulation through the cones of an enormous volume of air in comparison with the volume of the cones themselves. During an effective drying process some 10,000 to 15,000 cubic feet of air passed through the kiln to dry one-third of a bushel of cones.

In this first kiln radiation was found to comprise such a large part of the total heat loss and its value depended so much on outside temperatures and other variables that it seemed questionable whether the calorimetric computations for drying in this kiln could have much value.

Accordingly, and with enlarged capacity as a distinct need, a second kiln was constructed in 1914 of galvanized iron throughout, entirely covered with one layer of 1/4-inch sheet asbestos. (Pl. 2, A.) This kiln was 2 feet square, about 100 inches in total height, and accommodated six trays resting loosely on cleats, on which a bushel of cones could readily be placed. Four thermometers were placed below the cones and four above, while three were hung in the room as a basis for computing the radiation factor. A perforated metal diaphragm below the trays assisted in an even distribution of the entering hot air, and a similar diaphragm above the trays prevented the formation of especially strong currents in any sector. Although much more air and heat were used, the radiation loss was little greater than in the first kiln, and hence a smaller factor in the total heat loss.

In the first kiln the trays were usually removed and shaken at the end of each hour to extract the seeds as rapidly as they loosened. This allowed considerable cooling. In the later metal kiln the trays were shaken without being removed, the seeds falling to the bottom, which was built in the form of a funnel below the level of the entering air current. The seeds might be removed from the bottom of the funnel at any time; but as the space remained fairly cool, this was seldom done until the extraction was completed.

The essentials of the experimental kiln, which experience indicates as the essentials of any extracting kiln, are therefore as follows (see also appendix):

A steady supply of hot air.

Natural circulation of the hot air, which will rise readily through successive layers of cones if the kiln has the characteristics of a flue.

The cones in a single layer on each tray. The several trays should be frequently changed in position, since the lowest one always receives the most heat. In a continuous operation the loaded trays should be constantly moved downward, receiving the most severe treatment only after most of the moisture is extracted.

Frequent shaking of the trays, the loose seeds falling to an unheated floor or receptacle.

Adequate insulation, so that the heat is available for evaporation and is not wasted in radiation. This is hardly more important where calorimetric measurements are being made than where large operations demand strict economy.

THE 1912 OR ARAPAHO TESTS

The Fraser River Basin from which the Arapaho cones came is almost wholly granitic in its soil and rock. Hence, it is safe to say that the cones have to some extent the qualities of the siliceous-soil form of lodgepole pine. However, the granitic soil is by no means a poor soil. It has great depth, excellent moisture-holding properties, and undoubted fertility. Its chemical reaction is strongly acid (pH 4.5 to 5.2). The region is well watered, and the conditions favoring growth are not excelled anywhere in the lodgepole pine zone of Colorado and Wyoming. The stands are usually dense and well developed.

The 1912 tests involved air drying as well as kiln drying of the cones. Fifteen bushels of cones, probably very largely from squirrel hoards, gathered in the fall of 1912 for the Fraser seed plant, were ·ipped in December of that year to the experiment station. The l. included about 10 per cent of old cones, the usual proportion found in collections from squirrel hoards. As the cones had been stored in bins at Fraser from 6 to 12 weeks and were shipped in ordinary sacks, considerable slow drying preceded their first weighing. However, this had not proceeded to a point to permit any seed loss.

At Fremont the cones were first thoroughly mixed and then divided into 15 equal lots of 35 pounds, or approximately a bushel, each. The 15 lots in ordinary burlap sacks were placed in a large, loosely constructed and loosely covered but mouse-proof box, which was set on posts in such a manner as to permit free air circulation on all sides. Until October, 1913, no provision was made to exclude rain and snow completely, and thus, after a few months of consistent moisture loss, the cones during the rainy period gained in weight.

The weight of each sack was obtained at monthly intervals, and each month a sack weighing very close to the average weight for all was taken for the kiln extracting test. The bushel of cones treated in each of the 15 tests from December 19, 1912, to April 18, 1914, known as tests 1 to 15, was divided into three lots of equal volume. One of these lots (A) was treated at approximately 110° F., a second (B) at 140°, and the third (C) at 170°. The seed was thoroughly shaken from all open cones before the division was made and was cleaned and germinated as lot D for the current test.

Although these 15 extracting operations, made at various stages in the air drying of the cones, are not of the greatest value, they point the way to certain rather definite conclusions, and for this reason the data will be presented in part as corroborative evidence.

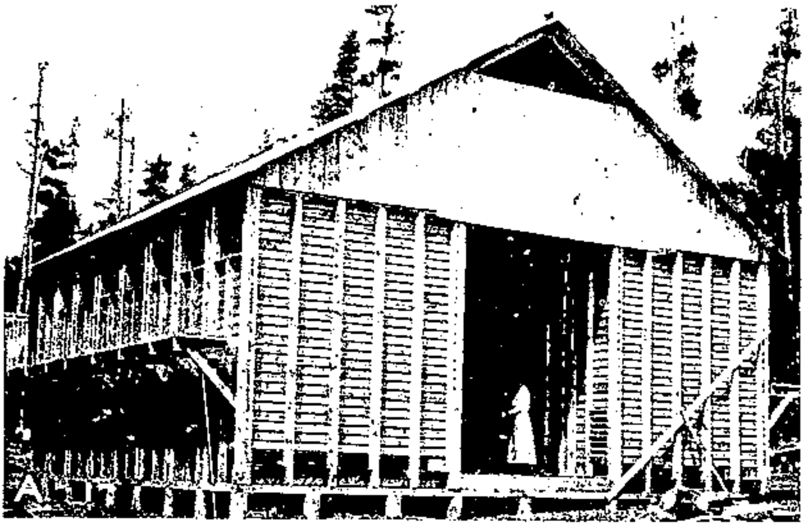
THE 1914 TESTS

With the expectation of eliminating all factors which had materially detracted from the results of the earlier tests, a new set of experiments was begun with the crop of 1914. Cones were obtained from two widely separated localities representing different soil, climatic, and growth types. These localities, Gunnison and Medicine Bow, are the same as those represented in the seed-production study, save that for the Gunnison locality a limestone soil type was chosen in order to test certain theories regarding the relative quality of lodgepole pine grown on a neutral or alkaline soil.

PLATE 2

F193131 21913A 25111A

A, The second experimental cone kiln, used in 1914-15. Gasoline burners were inserted under the duct at the right. The "damper" just above duct on wall of kiln is for turning the lower distributor diaphragm to dump the seeds into the hopper; B, cone-drying shed used in the 1914 tests of air-drying; C, relative expansion of siliceous cones (left) and limestone cones (right) after 9 months air drying



F723A 21911A 11923A

A, A desirable form of a cone-storage and drying shed, with ventilation between the 4-foot bins, Foxpark, Wyo.; B, beds in which field tests of lodgepole seeds were made at the source, in 1914, Leadville National Forest; C, the set of beds in which spring and summer field tests were made at Fremont in 1912. In the left foreground the wire cover has been removed

The Medicine Bow cones were from a siliceous soil of gneiss origin, composed of particles of all sizes from large pebbles to the finest clay, and chemically slightly acid (pH 5.8 to 6.3). The cones were obtained from squirrel caches in a stand about 200 years old, were uniformly of good size and normal development, and were almost entirely of the 1914 crop.

The Gunnison cones were from a limestone site. Limestone sites on the Gunnison, in general, bear much lighter stands of lodgepole pine than the granitic sites. As a consequence, the trees are larger crowned and would ordinarily be considered good seed bearers. On account of the physiological dryness of a limestone soil, however, it appears probable that seed production is limited in these trees just as it is limited by the competition for moisture in denser stands. The limestone conditions, perhaps because conducive to occasional excessive droughts, are more likely to produce a quantity of subnormal or underdeveloped cones.

The 20 bushels of cones from each of the two localities just described were collected and shipped in oiled sacks designed to protect them from drying and were weighed at the Fremont laboratory with a minimum of delay. The Medicine Bow cones were unquestionably almost as fresh as when picked. The Gunnison cones, although received only nine days later, had been collected during a much longer period and had dried considerably. The difference in weights, amounting to 5 pounds per bushel, is partly due to the delay in shipping, but may also be partly a result of growth on a limestone soil and of other factors peculiar to growing conditions on the Gunnison.

Each of these cone collections was divided into five equal parts for tests at 3-month intervals. The 4-bushel lots to be extracted immediately were divided each into four parts and kept in the oiled sacks until the extractions were made. The other 4-bushel lots were placed in trays for storage. Each tray measured 2 by 5 feet and was 8 inches deep, the sides being of boards, the bottom of hardware cloth and muslin, and the top open. Four bushels of cones filled one such tray to a depth of about 6 inches. The trays were placed in tiers in a small shed, with a space of 4 inches between. The south side of the shed was closed by a screen, so that there was at all times opportunity for moderate air circulation. (Pl. 2, B.) A canvas hanging several inches outside the screen cut off direct insolation and excluded rain and snow. The conditions of storage were largely such as might be duplicated in a drying shed of any capacity.

Of the Medicine Bow cones there were, unfortunately, not quite 16 bushels available for storage. The lots extracted at quarterly intervals, therefore, were only 0.9062 bushel each, and to make all tests comparable it was necessary to correct the actual data of extraction in this proportion.

The Medicine Bow cones were weighed a second time when the Gunnison cones were placed in storage. The third complete weighing and second extraction occurred 55 days after storage; the fourth, 161 days (March); the fifth, 252 days (June); and the last, 425 days, or one year after the second extraction.

THE LOSS OF WATER BY CONES

Since the opening of cones and yielding up of the seed is now thought of as a process dependent upon drying, it is well to consider first just what happens in drying and what quantities are involved.

LOSS IN AIR DRYING

The monthly weighings of the 1912 crop of Arapaho cones should give a very good idea of the rate of drying at different stages and different times of the year were it not for the fact, as already stated, that these cones were not wholly protected from wetting by storms. Hence it is found that for the period from March to October, 1913, there was no general loss of weight, and the drying which occurred after the latter date is simply a delayed process which should have occurred during the spring and summer months. In addition it

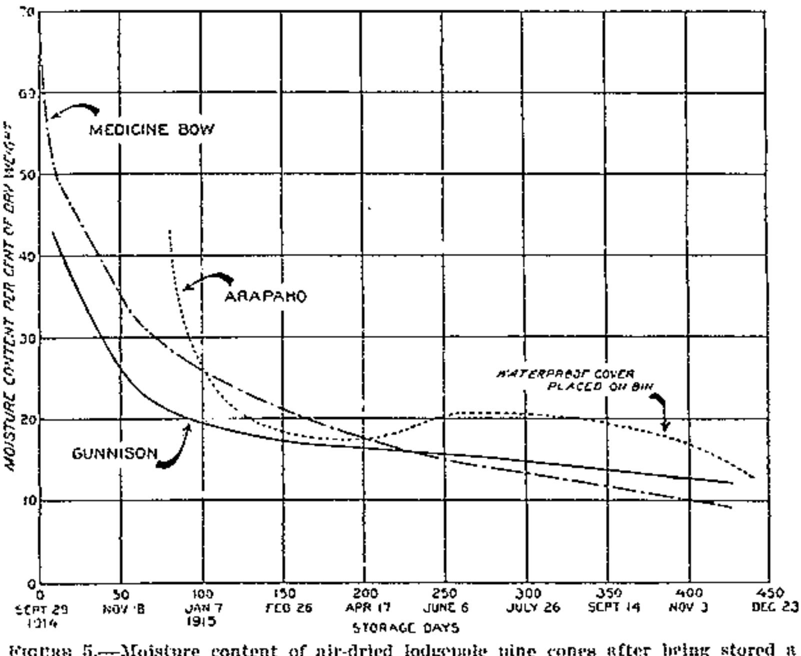


FIGURE 5.—Moisture content of air-dried lodgepole pine cones after being stored a specified number of days. Some drying occurred of Gunnison cones before first weighing and considerable drying of Arapaho cones

should be recalled that the cones had dried considerably before the first weighing.

The weighings of the two crops of 1914, while not so numerous, give clear and concrete results. The Gunnison cones were already partly dried and the Medicine Bow cones had lost a large amount of water before the Gunnison cones were placed in storage. It therefore seems best to consider both collections as having started drying at the same time.

The amount and rate of air drying of the three cone crops are shown in Figure 5. In computing moisture losses it is necessary to assume that different lots of the same cone crop started with equal amounts of moisture and to compute from that a basic weight for each lot of cones. As none of these have been desiccated to absolute dryness, a weight slightly below that reached by drying at 170° F. is taken, namely, about 24 pounds for Medicine Bow cones and 25 pounds for Gunnison cones. Since these weights do not include the seed extracted, equal allowance is made for the weight of this seed at all stages.

It is seen that Medicine Bow cones, starting from a very green state, lost about 63 per cent of moisture in a period of 14 months. One-third of this amount, or 21 per cent, was lost in the first 9 days and 30 per cent, or almost one-half in the first month, despite the fact that this initial drying occurred in rather cool fall weather. Drying continues at a gradually decreasing but still important rate to the end of the 14-month period.

With the Gunnison cones from a limestone soil the initial drying was also rapid but not so long continued. From March to June the drying was very slow, but during the summer months increased slightly. The shape of the curve indicates that in a perfectly fresh state these cones may have held almost as much moisture as the Medicine Bow lot. The fact that drying ceases sooner, however, indicates that the limestone cones have a stronger attraction for water, which is held within the cells and imbibed in the ligneous material.

Of the drying of the Arapaho cones little need be said except that under similar conditions they would obviously have dried as rapidly, and to as low a final point, as the cones from Medicine Bow.

No record was made of the amount of opening of cones at each weighing. The different behavior of the Medicine Bow cones from siliceous soil and the Gunnison cones from limestone soil was, however, noted from the outset, and is clearly shown by Plate 2, C. At 252 days, when the photograph was taken, the siliceous cones had lost 56 per cent out of a total moisture content of 72 per cent, had expanded 44 per cent of their original volume, and had released 27 per cent of their seed. The limestone cones had experienced a total water loss of about 36 per cent of an assumed content of about 51 per cent when green, had expanded 6 per cent, and released 13 per cent of their seed.

The siliceous cones began opening on the tops of the trays within 24 hours of the time when air drying began. The limestone cones did not open to any appreciable extent for several weeks, and then not completely. In both lots there was wide variation between individuals.

In contrast to the rate of air drying in this experiment, it will be well to note the results obtained in two large-scale tests conducted almost simultaneously with the 1912 tests at the Fremont field station.

At the Idlewild seed-extracting plant on the Arapaho National Forest 75 bushels of cones collected between September 15 and November 15, 1912, were placed in a special bin beneath the main extracting plant on February 14, 1913, their weight at that time being 32.78 pounds per bushel. At the end of one year about 5 per cent of the cones, occupying the top layer or contiguous to the walls, had opened fully, and others less completely. The volume of the entire cone mass had decreased slightly. The cones weighed 27.62 pounds per bushel. They required 6 to 6.5 hours to open as completely as green cones do in 8 hours and yielded about 10 per cent less seed. It is evident that these cones had lost considerable moisture before being stored. Their weight may be roughly estimated to have been the same as that of the cones of the same crop stored at the Fremont station in December, 1912, namely, 35 pounds per bushel. They had, then, in 14 months, lost about 7.4 pounds, or 21 per cent of their green weight, or 31 per cent of their probable dry weight. The same result was obtained two or three months sooner at Fremont.

At the Foxpark seed-extracting plant, Medicine Bow National Forest, 60 bushels of cones placed in a drying bin of the corncrib type increased in volume about 5 per cent during a year, and about 45 per cent of them opened partially or completely. Their moisture loss was slightly in excess of 30 per cent of their bone-dry weight, but it is probable that a small item in this loss was the removal of cones by squirrels.

These results are cited mainly to show that air drying on a large scale can be effective, though necessarily slower than in the ideal drying trays used at Fremont. Such being the case, it would seem that large-scale extracting operations might well be postponed until the warmest weather of the summer, though this has never been tried.

LOSS IN KILN DRYING

If these same cone lots are considered in their action under artificial drying treatments, it may be expected that the characteristics shown during air drying will be still more clearly demonstrated.

In Table 7 the important data of the kiln-drying process are given. Figure 6, which shows the amount of drying and the time required to accomplish complete opening of the cones, is, of course, purely diagrammatic inasmuch as the drying rate must be shown by straight lines, rather than curves. Since intermediate weight determinations can not be made without seriously disturbing the operation of the experimental kiln and the calorimetric observations, these have not been made in any of the more important tests.

From Table 7 and Figure 6 the following facts are evident:

Starting with the same moisture content, cones treated at a high temperature yield slightly more moisture at a much higher hourly rate than cones treated at a low temperature. They also open more completely.

The rate of kiln drying decreases consistently with older cones; or, in other words, the lower the initial moisture content the slower the loss at a given temperature, in spite of the fact that with less moisture to evaporate each cone has a greater supply of heat.

The final degree of dryness is lower in cones with lower initial moisture. Thus the moisture content of fully opened fresh Medicine Bow cones, about 12 per cent as the average for all temperatures, is greater than the moisture content after 14 months of air drying and before any artificial treatment is given. This is also indicated in a general way by the Gunnison cones, although the final moisture content in these cones did not decrease appreciably beyond that occurring after 55 days of storage.

The rate of drying of the Gunnison (limestone) cones is much less rapid than that of Medicine Bow (siliceous) cones, even when cones of the same initial moisture content are compared.

TABLE 7.—*Degree and rate of drying of lodgepole pine cones under different degrees of artificial heat after various periods of air drying, in terms of percentages of the dry weights of the cones*

MEDICINE BOW CONES, 1914 [1]

Period of air drying (days)	Water content before kiln drying [2]	Water content after drying at different kiln temperatures				Moisture loss at different temperatures				Hourly rate of drying at different temperatures [3]			
		110° F.	140° F.	170° F.	200° F.	110° F.	140° F.	170° F.	200° F.	110° F.	140° F.	170° F.	200° F.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
0	71.6	14.4	13.1	10.9	9.5	57.2	58.5	60.7	62.1	3.0	4.5	6.7	7.8
55	32.6	11.0	9.2	7.7	6.4	21.6	23.4	24.9	26.2	2.2	3.0	6.2	8.7
161	20.4	8.4	6.7	7.3	4.6	12.0	13.7	13.1	15.8	1.7	3.4	6.6	7.9
252	15.5	7.0	6.5	5.6	4.3	8.5	9.0	9.9	11.2	1.4	3.0	5.0	7.5
425	9.0	3.6	2.9	1.7	.6	5.4	6.1	7.3	8.4	.8	2.0	3.6	5.6
Av.		8.88	7.68	6.64	5.08	20.94	22.14	23.18	24.74	1.8	3.4	5.6	7.5

GUNNISON CONES, 1914 [4]

Period of air drying (days)	Water content before kiln drying	110° F.	140° F.	170° F.	200° F.	110° F.	140° F.	170° F.	200° F.	110° F.	140° F.	170° F.	200° F.
9	43.0	7.8	7.0	4.6	6.0	35.2	36.0	38.4	37.0	1.8	4.0	6.4	9.2
55	24.5	7.0	8.5	5.8	4.2	17.5	16.0	18.7	20.3	1.2	3.2	4.7	5.8
161	16.4	6.6	5.7	4.4	3.5	9.8	10.7	12.0	12.9	.6	2.1	4.0	6.4
252	15.2	6.8	5.5	4.5	4.0	8.4	9.7	10.7	11.2	.7	1.0	3.4	4.5
425	12.0	6.4	6.1	4.8	5.0	5.6	5.9	7.2	7.0	.4	1.5	2.9	4.7
Av.		6.02	6.56	4.82	4.54	15.30	15.60	17.40	17.08	1.0	2.5	4.3	6.3

ARAPAHO CONES, 1912 [5]

Period of air drying (days)	Water content before kiln drying	110° F.	140° F.	170° F.	200° F.	110° F.	140° F.	170° F.	200° F.	110° F.	140° F.	170° F.	200° F.
80	43.2	9.1	10.3	9.5	------	34.1	32.9	33.7	------	1.7	4.7	8.4	------
111	24.5	7.6	7.6	8.5	------	16.9	16.9	16.0	------	1.0	3.4	5.3	------
144	20.3	6.0	4.9	5.1	------	14.3	15.4	15.2	------	.7	2.6	3.8	------
182	18.5	3.7	4.7	.0	------	14.8	13.8	18.5	------	1.4	2.0	6.2	------
202	18.1	2.5	2.8	.9	------	15.6	15.3	17.2	------	1.3	3.8	4.3	------
414	16.2	5.3	5.8	0	------	10.9	10.4	16.2	------	1.0	2.1	8.1	------
472	11.3	3.4	1.2	.9	------	7.9	10.1	10.4	------	.7	3.4	3.5	------
Av.		5.37	5.33	3.56	------	16.36	16.40	18.17	------	1.1	3.1	5.7	------

[1] Units of 0.9062 bushel, except first test.
[2] Actual water content of cones kiln dried at each period. For average of all cone lots remaining in the bins at each period, see Figure 5.
[3] For record of number of hours required in extracting processes for Medicine Bow and Gunnison cones see Figure 6 or Tables 12 and 13.
[4] Units of 1 bushel.
[5] Units of one-third bushel.

The absolute moisture of dry limestone cones is greater than that of the siliceous. The exact amount of this final moisture is not determinable because the dry weight has not been absolutely determined. It should be noted, however, that the above statement holds when the limestone cones have been assigned a dry weight of 25 pounds per bushel as against 24 pounds for the siliceous.

The siliceous cones, on the average, yield their water four times as fast at 200° F. as at 110°, while the limestone cones show a ratio of more than 6 to 1.

Under the 110° F. treatment siliceous cones and limestone cones both respond at a uniformly decreasing rate for the different periods of air drying; but siliceous cones always show quick drying at 200°, while for limestone cones even this temperature becomes much less effective with low moisture content.

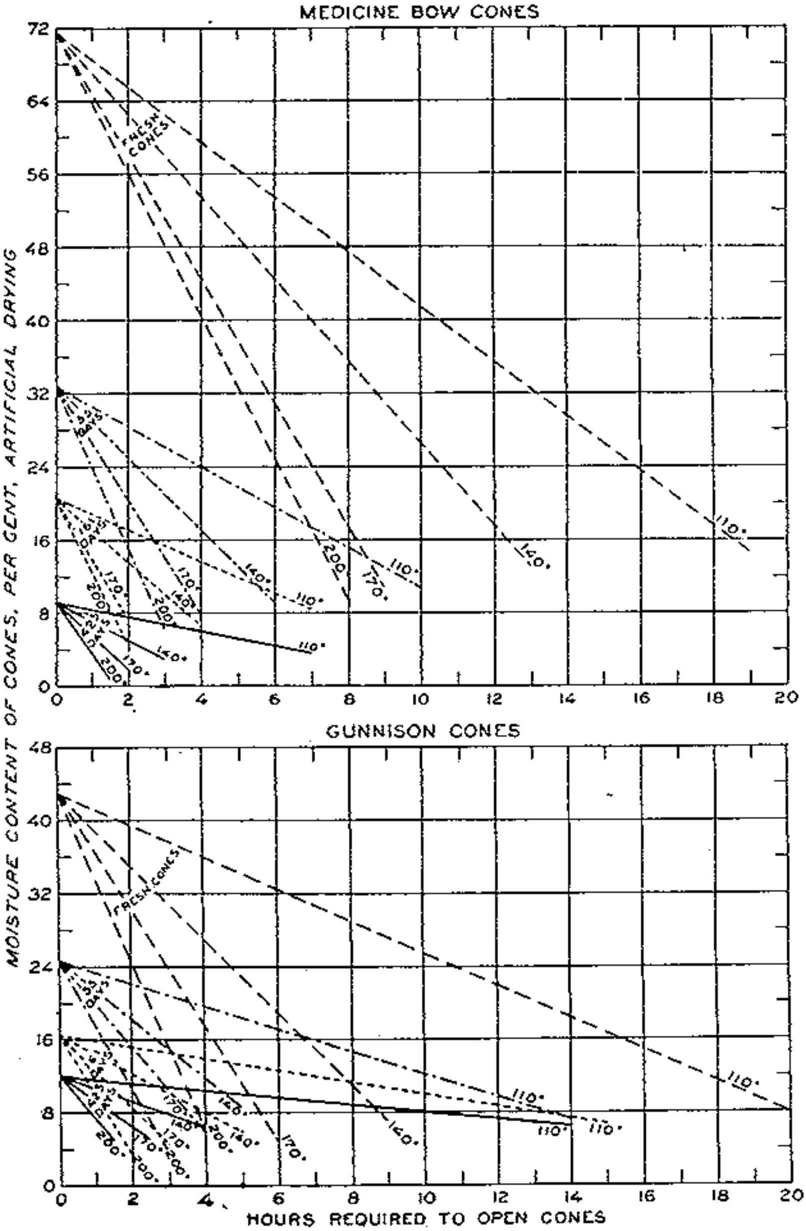


FIGURE 6.—Rate of drying in kiln at 110°, 140°, 170°, and 200° F., comparing fresh cones and cones air-dried for 55, 161, and 425 days

These facts seem to justify the following deductions:

The opening of cones is not wholly a matter of the absolute dryness attained, but involves a certain change in moisture content and, as indicated by the results of air drying, to be effective this change must be brought about in a brief period.

Under similar circumstances limestone cones retain their moisture more tenaciously than those from a siliceous soil, and high temperatures are proportionately more effective with them. From this it may naturally be expected that the limestone cones will use more heat for a given amount of drying.

THE RELATIVE IMPORTANCE OF TEMPERATURES IN OPENING CONES

A popular misconception as to the importance of temperatures per se in opening cones is well illustrated by the early attempts to open lodgepole pine cones in hot rooms lacking ventilation. Even though present tests have not been so conducted as to differentiate clearly between the effects of temperature and of dry air, some very obvious facts go a long way toward showing that heat alone is insufficient.

It should be understood that when the temperature of the air in the kiln is raised the relative dryness of the air, and therefore its drying power, is greatly increased. Thus, if air with a relative humidity of 50 per cent at 50° F. is warmed to 110° its relative humidity becomes only 7 per cent, and if warmed to 200°, only 0.8 per cent. Air at 200° has nearly ten times the capacity for moisture of air at 110°. This ratio is suggestive of the much more rapid drying which occurs at 200°.

Some tests have been made which seem to show considerable acceleration of the drying process when the air circulation is increased without raising the temperature, but not all the conditions of these tests are comparable.

A bushel of cones spread in the sun could absorb heat rapidly enough to open in four hours, if their rate of heat used were the same as that in a kiln process; yet it is a known fact that they would not open in any such time in the sun, because the air around them at ordinary temperature has relatively small capacity for carrying off the moisture.

Finally, the action of heat alone does not tend to cause the opening of cones. Too much heat causes a certain degree of flexibility of the cone scales and retards rather than aids the opening process.

The important consideration, therefore, is to bring dry air into contact with the cones, the heating process being only one of the means by which the air can be made dry, and being wholly ineffective if, while warming, the air is allowed to accumulate large quantities of vapor.

TABLE 8.—*Total and germinable seeds obtained by kiln drying Arapaho lodgepole pine cones after various periods of air drying* [1]

Test No. [2]	Seed released by air drying			Seed extracted at 110° F.			Seed extracted at 140° F.		
	Extracted	Germinable seed [3]		Extracted	Germinable seed		Extracted	Germinable seed	
	Number	*Number*	*Per cent*	*Number*	*Number*	*Per cent*	*Number*	*Number*	*Per cent*
1	0	0	0	16, 124	8, 223	51	17, 612	11, 870	67
2	1, 560	785	50	14, 424	7, 674	53	17, 808	7, 603	43
3	3, 273	2, 042	62	14, 508	7, 702	54	16, 452	8, 654	53
4	5, 103	2, 909	57	13, 935	7, 553	54	15, 270	8, 215	54
5	2, 756	1, 648	60	13, 103	7, 325	56	16, 134	9, 325	58
Average	2, 538	1, 477	58	14, 419	7, 707	53	16, 655	9, 151	55
6	6, 240	3, 563	57	12, 243	6, 685	55	14, 916	8, 180	55
7	10, 551	3, 841	36	11, 805	5, 341	45	13, 585	6, 303	46
8	11, 388	5, 671	50	6, 698	3, 831	57	11, 485	5, 145	45
9	14, 847	5, 582	38	8, 915	4, 110	46	10, 145	4, 230	42
10	13, 712	5, 567	41	9, 039	4, 661	47	11, 339	5, 988	53
Average	11, 348	4, 845	43	9, 938	4, 927	50	12, 294	5, 973	49
11	22, 028	10, 882	49	8, 362	4, 047	48	8, 420	4, 130	49
12	13, 746	6, 103	44	10, 303	5, 100	50	11, 208	6, 242	55
13	19, 884	9, 982	50	6, 423	3, 218	50	8, 334	3, 867	46
14	15, 981	7, 128	45	8, 340	5, 504	66	9, 646	6, 077	63
15	20, 367	9, 207	46	7, 008	3, 592	51	9, 092	4, 201	46
Average	18, 401	8, 672	47	8, 105	4, 292	53	9, 354	4, 903	52
Average all tests	10, 762	4, 908	46	10, 821	5, 642	52	12, 768	6, 676	52

Test No. [2]	Seed extracted at 170° F.			Total yield per bushel of cones		
	Extracted	Germinable seed		Weight of clean seed	Germinable seed	
	Number	*Number*	*Per cent*	*Gms.*	*Number*	*Per cent*
1	17, 508	10, 610	61	197. 82	30, 703	60
2	17, 291	7, 850	45	207. 28	24, 002	47
3	16, 704	8, 419	50	201. 10	26, 877	53
4	16, 005	8, 835	55	198. 23	27, 512	55
5	15, 924	8, 663	54	191. 97	26, 061	56
Average	16, 686	8, 875	53	199. 28	27, 211	54
6	15, 326	8, 521	56	197. 47	26, 958	55
7	14, 107	6, 122	43	207. 41	21, 607	43
8	10, 895	5, 303	49	171. 38	20, 040	50
9	11, 730	5, 114	44	187. 16	19, 045	42
10	11, 734	5, 562	47	188. 19	21, 788	47
Average	12, 758	6, 142	48	190. 32	21, 868	47
11	9, 684	4, 834	50	194. 67	23, 893	40
12	10, 807	5, 205	49	189. 49	22, 740	49
13	9, 603	4, 427	46	185. 23	21, 494	40
14	8, 533	5, 598	66	168. 70	24, 307	67
15	8, 175	4, 856	59	186. 64	21, 916	49
Average	9, 360	5, 002	53	184. 95	22, 870	51
Average all tests	12, 935	6, 673	52	191. 52	23, 990	51

[1] Kiln-dried tests represent one-third bushel for each temperature. Seed released by air drying come from the whole bushel.
[2] Tests at approximately monthly intervals after December, 1912.
[3] Computed from mean final germination.

EFFECT OF VARIOUS TREATMENTS ON QUANTITY AND QUALITY OF SEED

The practical and technical value of preliminary drying and of extractions made at successive periods and at various temperatures may now be considered in the light of the seed yields obtained.

ARAPAHO CONES OF THE CROP OF 1912

The extractions of 1-bushel lots were accomplished at approximately monthly intervals from December, 1912, to April, 1914, each bushel lot being divided into three equal parts, as already described. Table 8 shows these yields, and Figure 7 the germination of the various seed lots.

Examination of the data in Table 8 reveals a slightly greater number of seeds obtained from the first treatment than from any subsequent treatment, and a considerably greater number of good seeds. The deficits in the latter half of the series would at first thought seem to indicate that considerable numbers of seeds were lost. It is practically certain that there was no destruction of seeds in the storage bin; in the frequent handling of the sacks a few seeds may have worked out through the burlap. The probability is that, both in this series and in the 1914 series, the apparent loss of seeds after long periods of storage means little more than that the opening of the cones can not be carried far enough to obtain a full yield. If there has been any avoidable loss, it may be safely disregarded, for it may be taken as a certainty that the loss has been less than would occur in any large-scale storage operation.

After each of the 15 extractions in this series, a sample of each of the three or four lots was sown as soon as possible to determine the viability of the seed. Along with each such current test, after the first one, samples of the three lots of test 1 were also sown, in order that there might be a check or control upon any variations in the apparent germinability of the seed currently extracted due to the time or space factor. These so-called check tests, of which 11 were made after the initial test of test 1, and 2 more in August, 1914, are, of course, subject to the sampling and space error, as will be pointed out in discussing them in connection with the general errors of all seed tests. The space errors of the checks should, however, be the same as those of the current lots, as the two groups were always sown very close together.

In Figure 7 are shown the repeated germinations of the three lots of test 1, the germination of the lots extracted in each succeeding monthly test, and finally the germination of the 15 tests when sown simultaneously in August, 1914. In each instance the arithmetic mean of the three or four lots of a test is used in plotting, since the object of the chart is solely to bring out time variations. The results synchronous with tests 7 and 9 are very poor; for test 10, germination of the check lots was extraordinarily high. As the current extractions of tests 7 and 9 also germinated very poorly, the natural inclination is to state that here the check tests have shown their worth—that tests 7 and 9 germinated 8 to 9 per cent below the average of all tests because of some variation in the germinating conditions. However, when it is noted that in the August, 1914, retests of all lots, tests 7 and 9 duplicated their previous performance, the conclusion must be that something was inherently wrong with the seed itself and that the parallelism between the original tests and the check tests was in the nature of a coincidence.

Other observations have shown the possible importance of mold on the cones, the spores of which would readily be transmitted to the

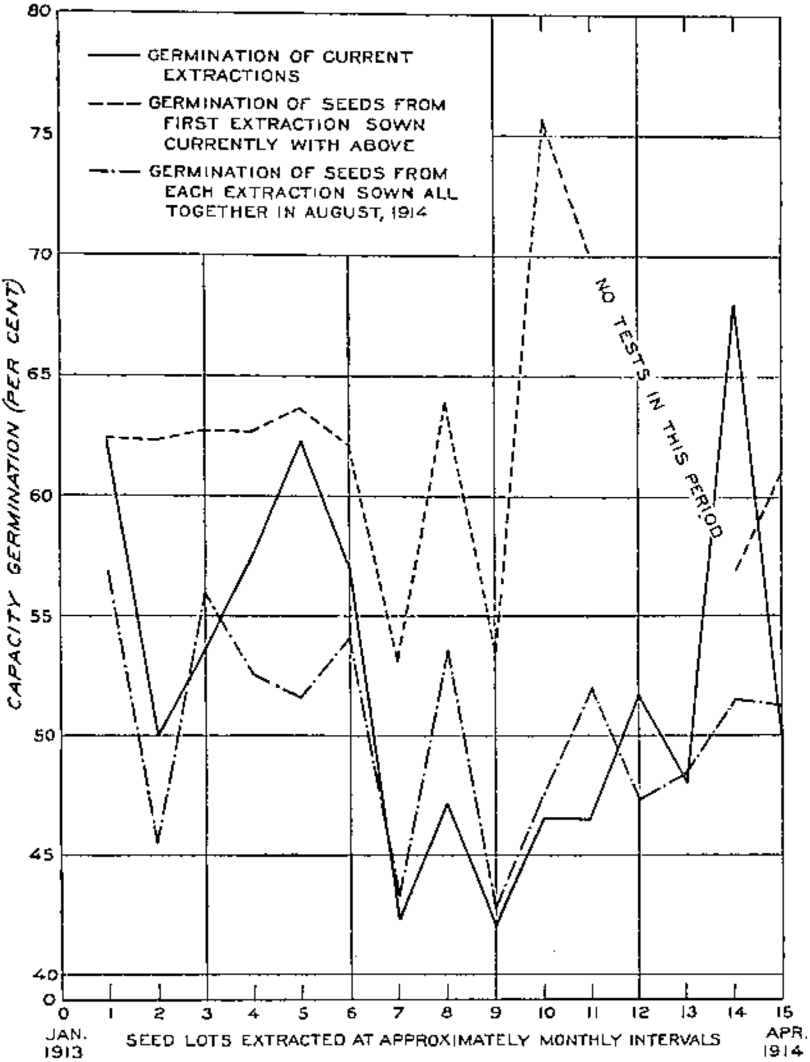


FIGURE 7.—Germination tests of seeds from Arapaho lodgepole pine cones compared as to effects of cone storage and seed storage

seeds, and from one lot of seeds to another, unless complete sterilization occurred in the kiln. That this was the factor influencing tests 7 and 9 and other synchronous germination tests it can not be definitely proved but is deduced from the fact that at the time of these tests, during the warmest months of the year, the cones in storage had absorbed rain water.

It must be admitted that implicit faith can not be placed in any single germination test, nor in the results of the various extractions so far as they depend upon these tests. However, with the exception of tests 5 and 14, the immediate germination and that in August, 1914, when two samples of each lot were taken, are sufficiently similar so that general tendencies at various periods can hardly be denied.

The germination data given in Figure 7 should be compared with Table 8, with the fact in mind that the indicated quality of the seed may be influenced by the completeness of the extraction. In test 8, for example, the relatively high quality of the seed is fully offset by the small number extracted, these facts suggesting that only the best of the seed was obtained. Although no conclusive test has ever been conducted to prove the point, results at the Foxpark seed-extracting plant, where the seed was taken off in six successive periods, indicate that the best seed is obtained fairly early in the process, possibly being from the cones which because of better development open more readily. The last 15 per cent of the entire seed yield showed a germinative value 15 to 20 per cent below that of the best seed. It is, of course, impossible in such a test to eliminate possible effects on the last seed of longer exposure to heat.

It is plainly evident that the first extraction from this collection of cones yielded the best seed and also the greatest amount. The average figures for the 12 periodic germinations of this seed of test 1 indicate a slight superiority of the seed extracted at 110° F., but this is scarcely better than that taken at 170°, and, considering the probable error of the average in any case, it is hardly reasonable to state that any lot was appreciably affected by the extracting conditions.

The low average percentage of germination noted in tests 6–10 is to be accounted for by the wetting of the cones in the storage bin during the summer of 1913, a condition which probably reached its culmination about October, as shown by the high moisture content of the seeds released by air drying. In fact, it is evident that the loose seeds suffered more from this condition than those still in the cones.

In the first group of five tests the 140° F. treatment is slightly superior in germination percentage to the other artificial extractions. In the second group seed extracted at 110° leads by a slight margin, while in the third period seed extracted at the highest temperature is better than that extracted at 110° by less than 1 per cent. It may be concluded that a temperature as high as 170° certainly does not harm the seed in either fresh or partly dried cones.

As the wide variations between lots similarly treated seriously detract from the reliability of the averages and leave no significant differences in the average germination after various treatments, it is not safe to state from these results that high temperatures used in extracting the seed are positively beneficial. It is, however, desired to point out possibilities along this line which are substantiated by the later and more complete data.

If now a return is made to Table 8 it will be seen that the practical results of these tests are reasonably clear. The yield of seed obtained prior to the artificial drying of the cones increases more or less regularly with continued air drying, 5.4 per cent of the total germinable seeds being obtained without the use of artificial heat in tests 1–5, 22.1 per cent in tests 6–10, and 37.9 per cent in tests 11–15. There is, however, a slight decrease in the total weight of seed obtained from the bushel units. Both on account of poor yields and poor germination the tests in the middle period show the lowest number of good seeds obtained. In the third period, despite slightly lower yields, a better showing is made as a result of higher germination value.

As between the various temperature treatments there is no marked difference except that 110° F. is seen to be about one-sixth less effective than the other temperatures at all stages.

MEDICINE BOW AND GUNNISON CONES OF THE CROP OF 1914

About 20 bushels of 1914 cones from the Medicine Bow and a like quantity from the Gunnison area were each divided into five tests, numbered 21–25 and 31–35, and these in turn, at the time of extraction, each into four lots, A. B, C, and D, to be treated at 110°, 140°, 170°, and 200° F., respectively. Tests 22 and 32 were air-dried 55 days, tests 23 and 33 for 161 days, tests 24 and 34 for 252 days, and tests 25 and 35 for 425 days. Tests 21 and 31 were made with the fresh cones. Seed lot E of each test was made up of the seed obtained from the 4-bushel sample after air drying only.

Germination tests on the various lots of seed were made in greater numbers than previously, in the hope of eliminating the variations inevitable in single tests, and also were made at different periods, to show more definitely the relations between the immediate or fresh quality of each lot of seed and its keeping quality or vigor after a certain period in storage. It is almost invariably true that seed is not used immediately after extraction. The seeds not sown immediately were stored in bottles, sealed as tightly as possible, and kept in a room whose yearly range of temperatures is from about 30° to 50° F. The periods of storage were 21 months, 24 months, 7 years, and 11 years. In some instances the wax seal applied to screwcap bottles was not adequate to prevent the absorption of moisture by the seeds, while in others the seeds appeared to have kept perfectly dry. Hence, at the end of the long storage periods only scattered tests could be made, all lots which were either sticky or moldy being eliminated. In general, the few results obtained after 7 years of storage were about 10 per cent higher than those obtained after a storage period of 11 years.

Duplicate and triplicate tests made at any one time show very little variation and indicate that more than usual reliance can be placed on these tests as a whole.

The test at 24 months, virtually an extension of the 21-month germination of duplicate tests, the two involving 2,500 seeds of each lot extracted, is given separately in Table 9 in order to demonstrate the progressive tendency of either seed deterioration or seed improvement with aging. There is, however, a factor which enters into the comparison of germination results at 21 and 24 months which should be explained. The five samples of each lot needed for both tests were counted out simultaneously just prior to the test at 21 months, and the three samples which were not used until the 24-month test were stored, not in their respective jars, but in envelopes, under ordinary room conditions. Thus it may be assumed that the Medicine Bow seeds, which in the extracting process were not subjected to such severe drying, might in moderately warm air give off some moisture, while the Gunnison seeds, because of more severe treatment previously and a greater affinity for water, might be in a condition to absorb moisture from the atmosphere. This may not be the correct explanation, but it is evident that only some such opposed actions in the two groups can account for the improved vigor of the Medicine Bow seeds between the 21-month and 24-month tests, despite the slight change in vigor of the Gunnison seeds.

TABLE 9.—*Germination from the 1914 extractions of Medicine Bow and Gunnison cones at different periods and at four different temperatures*

MEDICINE BOW CONES

Period of storage (days)	Extracting temperature	Moisture left in seed [1]	Final germination of stored seed sown at stated periods after extraction					Moisture in seed at 11 years [7]
			Immediate [2]	21 months [3]	21 months (extra drying [4])	24 months [5]	7 and 11 years [6]	
	°F.	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
None	110	7.67	42.3	48.6	(8)	57.5	56.8 (*2*)	12.43
	140	7.11	60.5	54.5	(8)	65.3	54.0 (*1*)	8.96
	170	4.05	65.1	63.5	(8)	69.4	49.6 (*1*)	8.77
	200	5.56	61.9	55.1	(8)	61.6	49.6 (*1*)	8.52
	All.	6.10	57.4	55.4	(8)	63.4	53.3 (*5*)	9.67
Average of 55, 161, 252, and 425	110	4.82	75.8	72.7	77.0	76.4	60.6 (*4*)	11.00
	140	4.08	78.2	76.0	83.4	83.0	75.8 (*3*)	9.01
	170	3.20	74.5	70.3	73.8	76.0	75.2 (*3*)	7.54
	200	2.84	67.2	60.8	63.4	68.0	48.0 (*3*)	7.67
	[9] 0	4.47	64.4	68.0	67.4	76.8	54.1 (*4*)	9.83
55	All.	3.72	72.0	62.9	70.5	70.1	62.8 (*10*)	9.50
161	All.	4.28	74.6	72.0	80.2	78.6	55.1 (*4*)	9.33
252	All.	4.37	70.8	73.2	71.5	79.6	69.3 (*3*)	8.70
425	All.	3.16	70.7	70.1	69.8	75.8	---------	---------

GUNNISON CONES

Period of storage (days)	Extracting temperature	Moisture left in seed	Immediate	21 months	21 months (extra drying)	24 months	7 and 11 years	Moisture in seed at 11 years
None	110	5.21	83.6	82.1	(8)	84.3	71.2 (*2*)	9.51
	140	4.55	77.3	83.1	(8)	83.6	74.3 (*2*)	6.37
	170	3.50	57.8	62.5	(8)	57.4	59.8 (*2*)	6.70
	200	3.87	46.1	50.7	(8)	44.4	41.4 (*2*)	6.68
	All.	4.28	66.2	69.6	(8)	67.4	61.7 (*8*)	7.32
Average of 55, 161, 252, and 425	110	3.97	69.5	78.1	75.6	78.7	72.8 (*1*)	8.85
	140	3.88	74.1	75.4	78.4	74.1	48.6 (*1*)	4.55
	170	3.12	66.3	73.0	80.2	72.0	53.0 (*2*)	10.71
	200	2.97	70.4	72.2	72.6	73.8	53.3 (*2*)	8.57
	[9] 0	5.24	70.6	75.2	77.4	75.5	63.4 (*1*)	---------
55	All.	3.49	67.5	73.3	78.9	72.9	61.2 (*2*)	7.82
161	All.	3.63	71.7	72.5	76.8	73.2	52.9 (*4*)	9.08
252	All.	3.99	76.7	78.6	74.9	76.5	63.4 (*1*)	---------
425	All.	4.22	64.9	74.6	76.8	77.1	---------	---------

[1] On basis of dryness attained in 4 hours at 170°, which gives merely indication of condition of seed after extracting process. See footnote 4.
[2] Duplicate tests, except for lot E extracted without storage, which were in triplicate.
[3] In duplicate; time computed from date of collecting cones.
[4] Seeds referred to in footnote 1, dried after being thoroughly cleaned.
[5] In triplicate.
[6] In 1921 only 12 lots were tested (500 seeds of each), while in 1925, 27 valid tests were made. Italic numbers in parentheses indicate number of tests entering into averages.
[7] By drying thoroughly at temperature of boiling water.
[8] Samples of seed not retained.
[9] Lot E, made up of seed obtained from air-drying cones only.

In addition to the tests of normally extracted seed at 21 months, single samples were sown at the same time comprising seed of all the lots (except tests 21 and 31, the dried samples of which were inadvertently discarded) which had been used to determine the moisture content of the seeds immediately after the extracting processes. These samples had been dried for four hours in the hot-air current of the kiln, at about 170° F., without any protection whatever, to determine how severe a treatment could be tolerated without serious injury to the seed.

Only one other fact need be mentioned in considering the comparability of the various germination results. The tests made on each lot immediately after extraction were obviously subjected to different time factors in the germinating process. It is believed, however, that tests 24 and 34, germinated in July, 1915, were the only ones materially affected by variable greenhouse conditions. The early germination of these groups was undoubtedly retarded by heavier watering of the testing tills than is customary, but this probably had very little effect on the final germination.

The immediate germination of the eight lots of tests 21 and 31 was carried on for only 52 days. Germination of the Gunnison seed was practically complete in this period. Estimates made from the current rates at the end of the period indicate that the Medicine Bow seed had not completed germination by about 7 per cent in lot 21 A, 6 per cent in 21 B, and 1 per cent each in lots C and D. The actual germination results are shown in Table 9, but in computing a balanced average for each lot the above allowances are made with the Medicine Bow seed.

In Table 9 the germination from the first extraction of both lots of cones is given in detail, because with the green cones the effects of different temperatures were quite marked. For later extractions the differences were neither marked nor consistent, and it therefore seems best to rely on the averages for different periods and different extracting temperatures.

QUALITY OF SEED AFTER VARIOUS PERIODS OF STORAGE

An examination of Table 9 brings out the following points:

Even with an average allowance of about 4 per cent, as noted just above, the seed extracted from the fresh Medicine Bow cones is decidedly inferior to all extracted later. The inferiority of fresh Gunnison seed is much less marked, the first extraction being in fact a little better than the last. Here, however, the higher temperatures seem to have had a very deleterious effect. This difference is due, no doubt, to the greater dryness of the Gunnison cones at the time of the first extraction; the fact that the first extraction of the still drier Arapaho cones treated in 1912–1914 gave the best and the most seed seems to indicate that only an extremely moist, green condition need be avoided.

In the later germination tests that were made this inferiority of the first extraction of Medicine Bow seed is maintained. There can be, therefore, little doubt but that the kiln drying of very fresh cones is unsatisfactory. That it is rather a question of deficient treatment with low temperatures than of positive injury, however, seems to be indicated by the fact that the 55-day, 110° F. extraction (lot 22 A), made a strong showing after additional kiln drying of the seeds. The definite improvement of germination after 24 months, after the probable opportunity for air drying of the Medicine Bow seed, lends weight to the idea of insufficient drying at the outset. In this connection Hiley (*8*) has recently found that a 4-hour exposure of freshly gathered spruce seed at 122° raised the germination percentage from 21 to 96, and that seed kept over until the following summer gave 90 per cent germination as a result of natural after-ripening.

The highest immediate germination of Medicine Bow seed from stored cones, as a group and regardless of kiln temperature, is obtained in the third extraction, 161 days after collection of the cones, when, as will be seen by reference to Figure 5, the greater part of the moisture of the cones had been lost. However, the leading position of the third extraction is not maintained when germination is delayed, for the fourth extraction shows up better after a period of a year or more. This change is well illustrated in Figure 8. With Gunnison cones the best results were obtained in the fourth extraction.

It may then be stated definitely, considering the average results with all temperatures, that there is greatest danger in the treatment of fresh cones and least after the greater part of the possible air drying has been accomplished.

QUALITY OF SEED OBTAINED AT DIFFERENT EXTRACTING TEMPERATURES

In Figures 8 to 12 similar extracting operations have been grouped and all of the results of germination tests are shown. These figures will help to make clear the quality of seed obtained under treatment of the cones at different temperatures.

From the average showing for each temperature as summarized in Table 9, and excluding the first extractions of both classes of cones from such averages because of rather obvious disadvantages which the fresh cones suffered, it may be concluded that for the Medicine Bow cones, after 2 to 14 months of air drying, the best seed was produced by extractions at 140° F. The seed was only slightly injured by treatment at 170°, but appreciably so at 200°. The relatively poor showing of the 110° treatments is probably due to failure to dry the seed sufficiently, as is the poor showing of the seed entirely air-dried. The former, however, is properly treated so that it does not greatly deteriorate with age, at least for several years, while the air-dried seed is liable to deterioration after two or three years.

For the drier Gunnison cones from a limestone soil the extracting temperature of 110° F. appears to be best at nearly every period and in the averages. A fairly steady decline for each increase in temperature becomes very marked after long storage of the seed. The air-dried seed is nearly as good as that obtained at 110°. It appears that the better maturing of these cones before picking and before the first extraction eliminates the need for artificial ripening.

To sum up, then, it may be said that air drying the cones for a few months is definitely beneficial to the seed and eliminates much of the danger in the use of the more effective higher temperatures in the extracting process. Kiln drying after a reasonable amount of air drying is not only necessary to obtain all of the seeds from cones not fully ripened at the end of their second growing season but is also desirable to improve the moisture condition and probably the

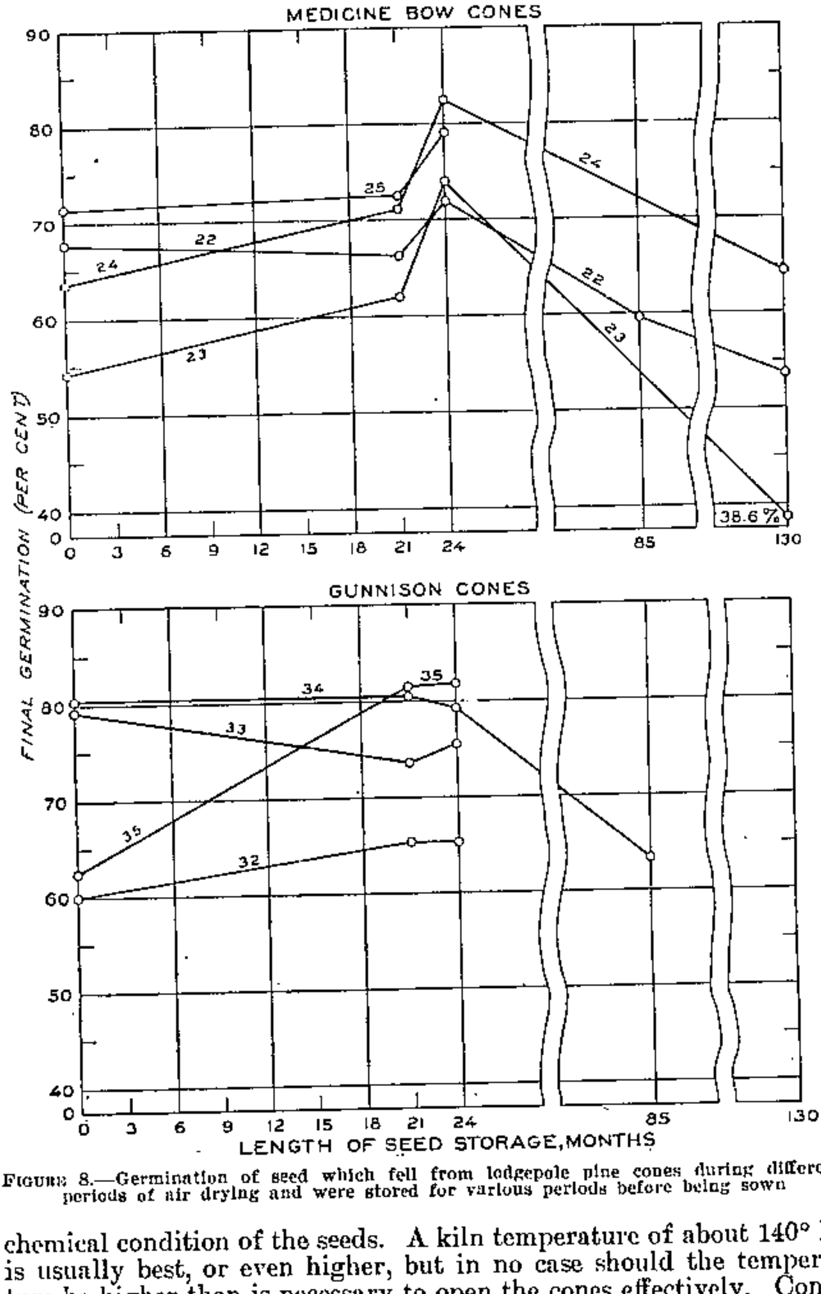


FIGURE 8.—Germination of seed which fell from lodgepole pine cones during different periods of air drying and were stored for various periods before being sown

chemical condition of the seeds. A kiln temperature of about 140° F. is usually best, or even higher, but in no case should the temperature be higher than is necessary to open the cones effectively. Cones from a limestone soil appear to ripen more thoroughly than the usual run of lodgepole pine cones, and the seed are not, therefore, stimulated by the application of artificial heat. In any case, as clearly shown in Figure 8, the danger in the use of high tempera-

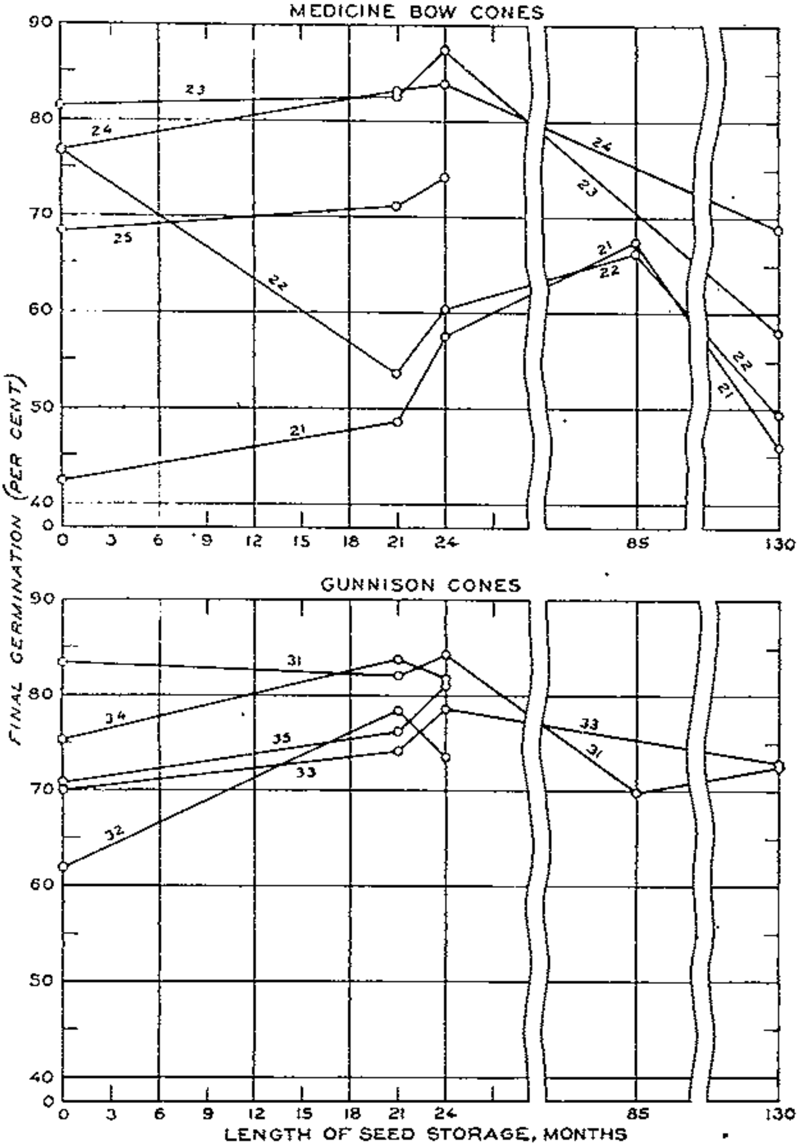


FIGURE 9.—Successive germination of seed extracted at 110° F., after different periods of cone storage

tures is relatively less as air drying of the cones advances, indicating that injury is caused by the combined effect of heat and moisture, or steaming of the seed, rather than by temperature alone.

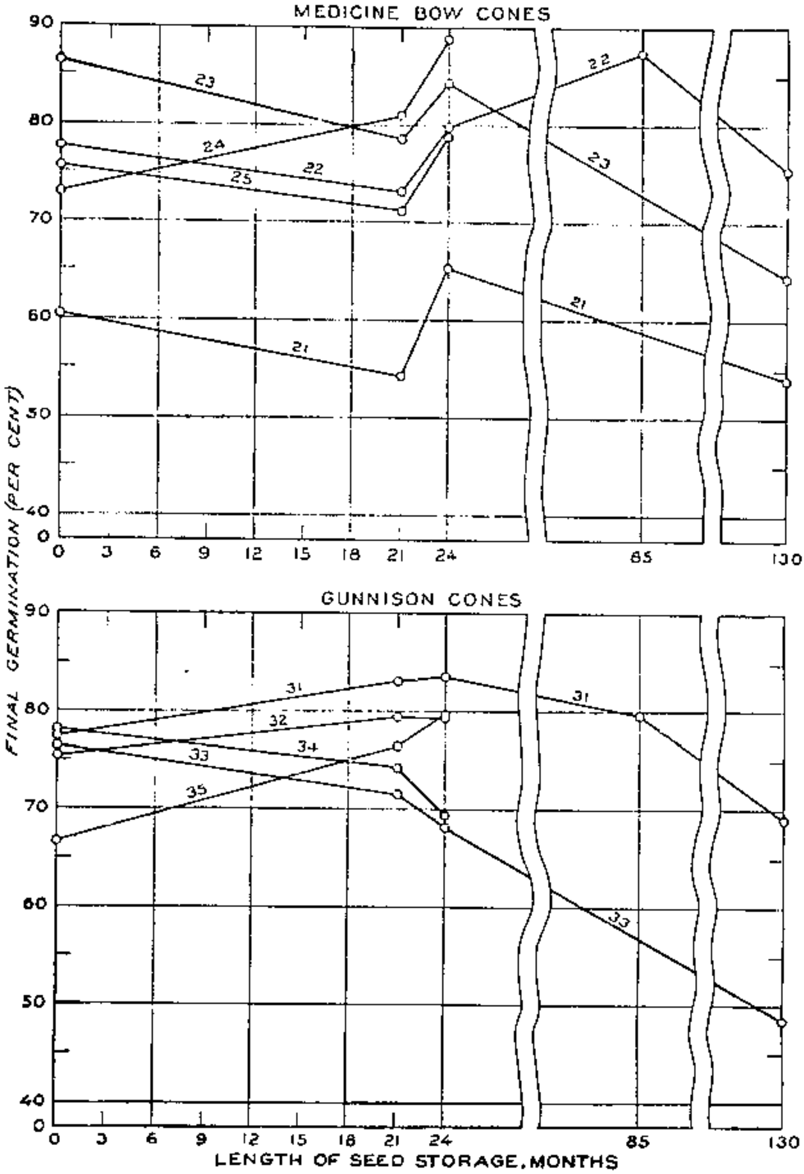


FIGURE 10.—Successive germinations of seed extracted at 140° F. after different periods of cone storage

EFFECT OF ADDITIONAL DRYING OF THE SEED

As has been stated, a 10-gram sample of the seed of each lot extracted in this experiment (excepting tests 21 and 31) was dried in the kiln for four hours at about 170° F. Since the object was as much to determine the physiological effect of this treatment as to attain a standard of dryness, this temperature was used in preference to a higher one, which might have destroyed the life of the seed.

The moisture contents of the seed lots were computed on the basis of the weights attained after these exposures.

No tests were made on any of the samples until the end of a 21-month storage period, and then space in the greenhouse permitted but a single sowing. These single tests are, therefore, compared only with the simultaneous tests on the samples of normal seed.

If the average differences in the Medicine Bow group are first examined, it is seen that germination of all of the kiln-extracted seed

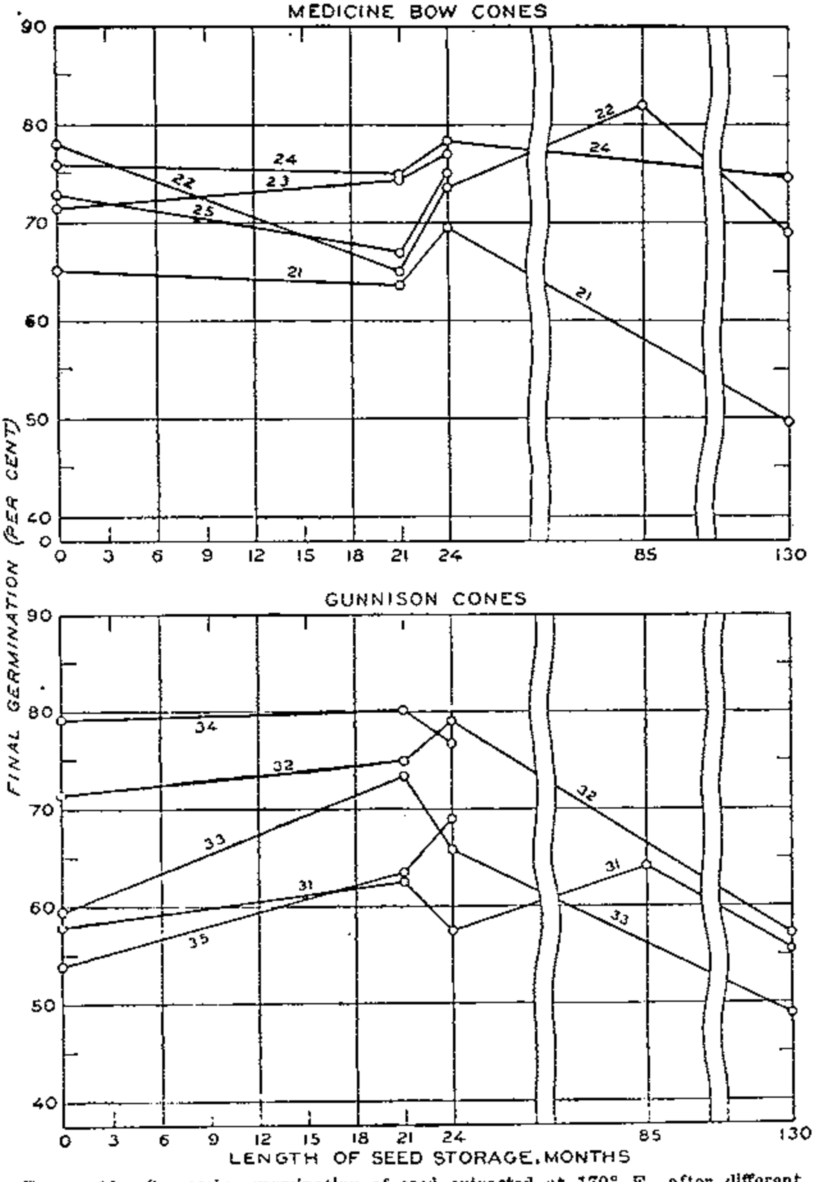


FIGURE 11.—Successive germination of seed extracted at 170° F., after different periods of cone storage

was stimulated, while that of the air-dried seed was not. The greatest stimulation due to this additional and direct drying was to the lots kiln-dried at 140° F., which as a group gave the best account of themselves at this time.

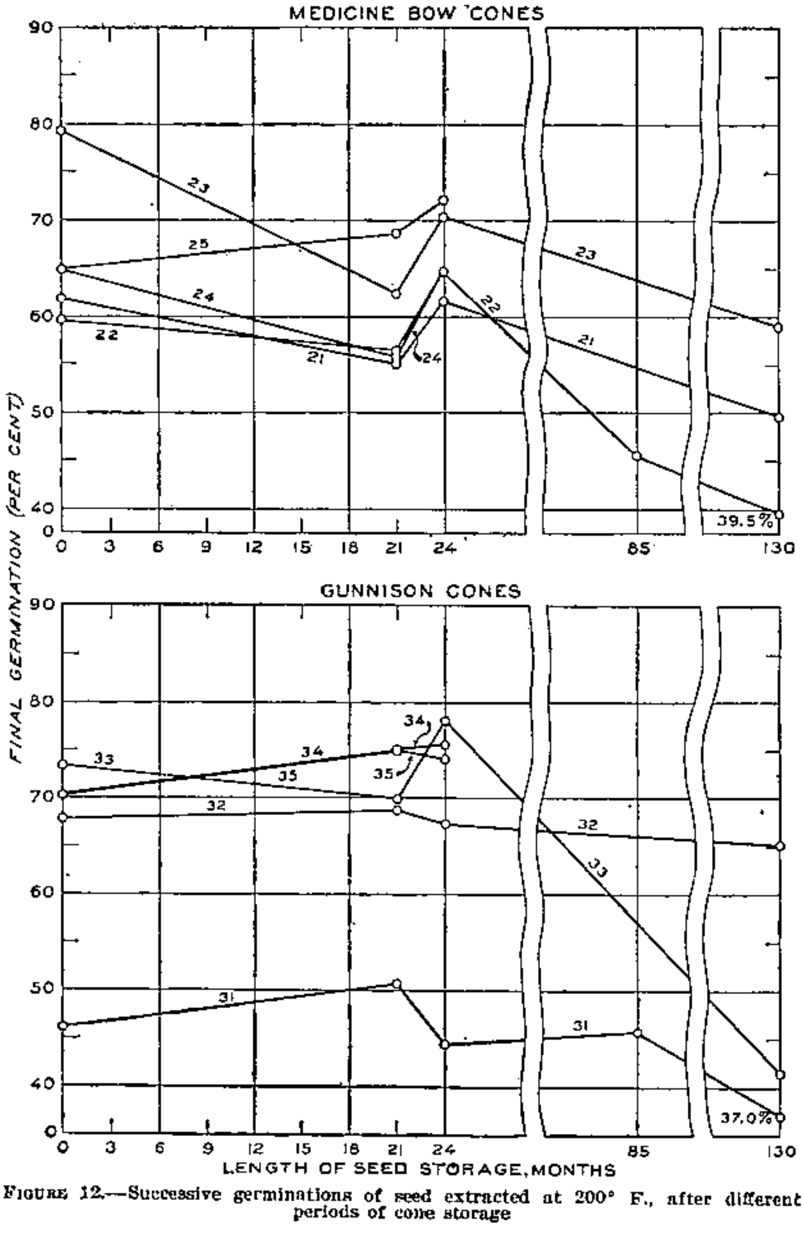


FIGURE 12.—Successive germinations of seed extracted at 200° F., after different periods of cone storage

In the Gunnison group it is found that the 110° F. extractions were not stimulated, and it will be noted that at 21 months these gave higher germination than any of the other lots. The inference might be drawn that these seed lots dried at 110° had been dried at just about the proper rate to have the best effect on germination. The other differences are so erratic that it is unsafe to attempt to draw conclusions from them.

Stimulation from this kiln-drying of the seed from Medicine Bow cones considered by storage periods is evident in the 55-day and 161-day periods, whereas in the last two periods there was a slightly injurious effect, the only marked exception being one lot (25 B), the normal seed of which at 21 months germinated poorly for an unaccountable reason. The same generalization may be made of the Gunnison seed, one lot (35 C) having a positive effect on the last group which can not be accounted for and should be given no weight.

To justify the use of the word "stimulating" in discussing this effect of the additional seed drying, it is only necessary to refer to the germination rates in specific tests as shown by the proportionate amounts of the whole occurring in the early periods. For example, with one lot (22 A), where the greatest influence on the final germination was shown, a slightly more rapid rate was maintained from the start. With another lot (22 B), which was only moderately affected in its final germination, a most unusual and surprising performance resulted from the kiln-drying of the seed, more than eight-tenths of all the germination occurring before the expiration of 10 days, a status reached by the normal seed of this lot in 20 days. On the other hand, most of the lots of kiln-dried seed whose total germination is curtailed at the same time show stimulation in the early rate, as is illustrated by the group of averages given in Figure 10. This suggests that drying at 170° F. may have a stimulating effect on some of the seeds while killing outright others of the same lot. The E lots as a whole show the highest degree of stimulation, although their final germination is not increased.

The Gunnison seeds display quite as marked a stimulation of early germination as do the Medicine Bow seeds, although final germination was not increased as much. In the 170° F. and air-dried lots there is a very decided stimulating effect, while only the 200° lots, on the average, show a suppressing effect from the kiln drying of the seed. The arbitrary groups in Figure 13 show no appreciable difference in effect as between the two sources.

Although the individual variations are large, owing in part to the single test of kiln-dried seed, it may be said with considerable certainty that kiln drying improves the quality of the seed, which the ordinary extracting operation has not been adequate to ripen thoroughly. As has already been pointed out, normal seeds from Medicine Bow cones, germinated at 21 months, gave comparatively low values and evidence of reduced energy, owing almost certainly to their having had too much moisture during storage. With such seed the kiln-dried lots on the whole compare favorably, whereas the better ripened and less moist Gunnison seeds gained less by the additional drying. That kiln drying of the seeds, like the higher extracting temperatures, tends to produce a slight disintegration after long periods is indicated by the fact that in both the 7-year and 11-year tests a single composite sample of the kiln-dried seeds germinated about 2 per cent less than the average of all normal lots.

The above discussion is not intended to suggest that the extra kiln drying of seeds should be a common practice. It merely serves to emphasize the point that for prompt germination of comparatively fresh lodgepole pine seeds something in the nature of artificial ripening is needed. The regular extracting process should be designed to accomplish this, but if after a short period of storage the seeds show a tendency to sweat or become sticky or moldy, a treatment, perhaps at a temperature somewhat lower than 170° F., could doubtless be given with much benefit.

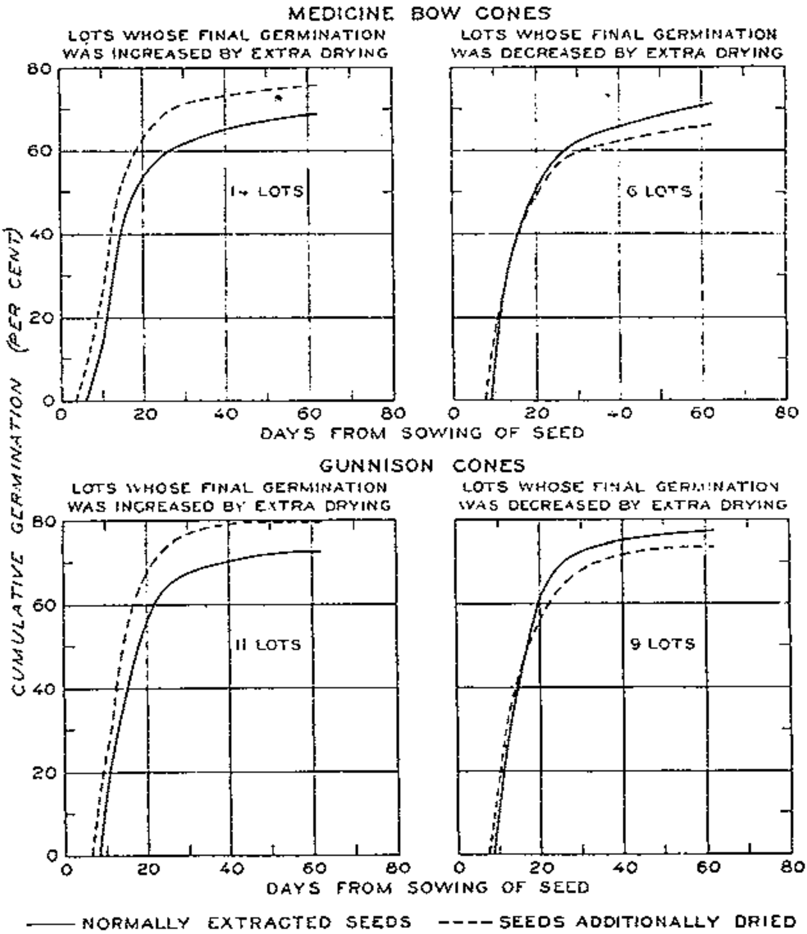


FIGURE 13.—Stimulation of rate of germination by kiln drying of lodgepole pine seed at 170° F. in addition to normal extracting treatment

EFFECT OF LONG STORAGE OF THE SEED

There can be little doubt that lodgepole pine seeds properly ripened and properly stored have an almost limitless life. The fragmentary results obtained with the Medicine Bow and Gunnison seed, of the 1914 crop, when tested 85 months after collection, show merely the possibilities in this line, but they seem to prove that there is no need for the rapid deterioration of tree seed that so often occurs when they are carelessly stored. The conditions of storage in this experiment were those of a cool moist cellar, with an approximate temperature range from 30° to 50° F. annually. Under these conditions seed lots adequately sealed to prevent absorption of moisture showed, for the most part, no loss of germinative capacity at the end of seven years, though there was a general falling off of about 10 per cent in the succeeding four years. Both Zederbauer (*17*) and Wiebecke (*14*) have said that European experience points to conditions for seed storage approximately equivalent to those under which vegetable products as a whole are preserved; that is, a constant temperature close to the freezing point. The seed must, of course, be shielded from a damp atmosphere.

It goes almost without saying that the first requirement is that the seed to be stored should not have been injured, since the deterioration of injured seed is almost certain to be progressive.

NET VALUE OF THE YIELDS AT VARIOUS TIMES AND TEMPERATURES

If the value of the seed yields previously described is to be computed from the gross values and the germinative qualities, it is necessary first to decide what shall be considered the average germination of a given lot.

It has been pointed out that the first germination test on the various lots is very slightly questionable because all such tests were not made synchronously. A more important consideration is that seed slightly injured—by overheating, for example—may perhaps germinate if sown at once, but not if retained for what may be considered an average period of storage. It is believed, therefore, that in a balanced average this first test should not be given a weight of more than one-fourth. In computing values for test 21, allowances are made, as previously mentioned, because of the fact that the germination tests were cut off 10 days before the usual time.

Although the germination at 21 months was determined for only 1,000 seeds of each lot, the two distinct tests on 500 seeds each were generally very consistent, and it is believed best to give the results at this period a weight of one-half, because the seeds had been in storage for a good many months, under moisture conditions controlled by their respective initial moisture contents, and this should bring out most clearly the influence of each extracting method. The tests in triplicate at 24 months supply the final fourth of the balanced averages.

Table 10 and Figure 14 show the yields and computed values of each lot separately for the Medicine Bow and Gunnison crops.

The first extraction of Medicine Bow cones yielded the largest number of seed; and so it was with the Arapaho cones two years earlier. The germination percentages of the second and third extractions were, however, so much higher that these proved to be much better in net yield. One noteworthy point is the lightness and comparatively low value, at the second and third extractions, of the seed which was air-dried only, whereas, after this seed reaches the point of representing nearly a third of the yield, its quality is above the average of the kiln-extracted seeds.

The Gunnison extractions show essentially the same tendencies, although the second and third extractions were apparently somewhat more effective than the first, producing more and better seeds and consequently higher net yields, culminating in the third extraction. It is here noteworthy that the lots subjected to air drying only were above the average quality in the third, fourth, and fifth extractions, although the volume of this air-dried seed did not become large until the last. This fact seems to indicate rather an improvement in such

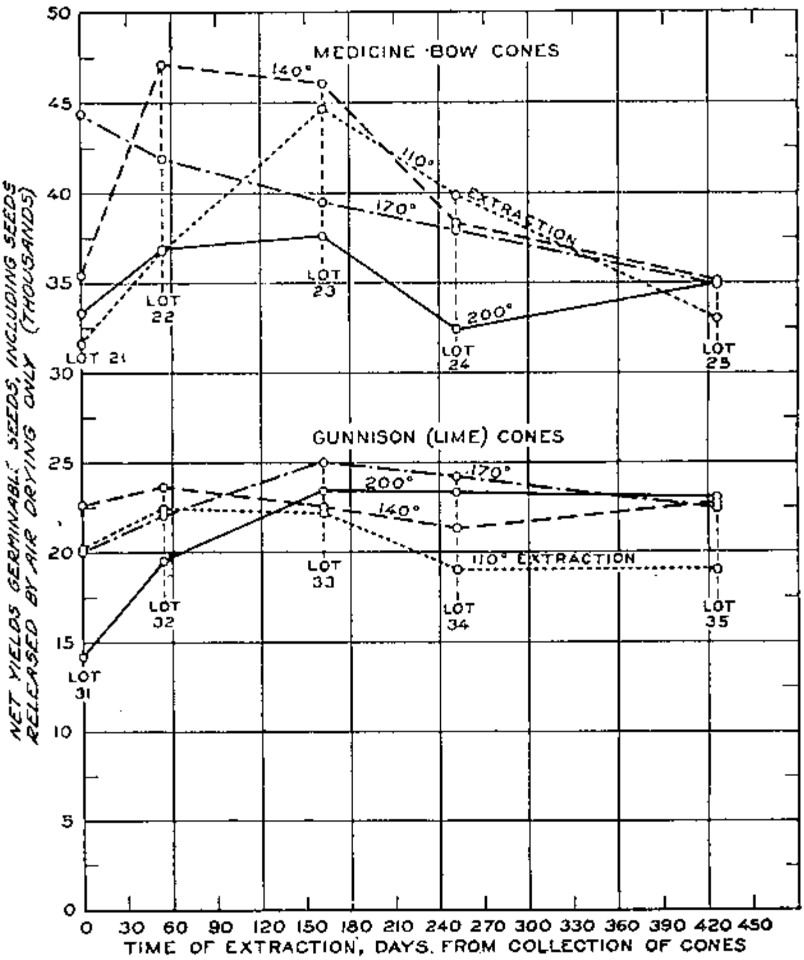


FIGURE 14.—Net yields of good seed per bushel of lodgepole pine cones stored for different periods, extracted at different temperatures, including also seed obtained through air drying. All values computed from balanced germination in tests up to end of 24 months

seed with continued drying than a proof that the first seed given up is of inferior quality.

The most striking point in Table 10 is the large seed yield of the Medicine Bow as compared with the Gunnison cones, the Gunnison cones yielding about the same number of good seeds as the Arapaho cones of 1912. The size of the Medicine Bow seed, as shown by the number of seeds per pound, is 10 to 20 per cent greater and the total number of seeds extracted nearly twice as great. As the germination percentages are very similar, the net yield of germinable seeds is 76 per cent greater per bushel of Medicine Bow cones than of Gunnison limestone cones. In the section on seed production, where Gunnison cones from a granitic soil were considered, it was shown that Gunnison cones produced a good many more seeds than Medicine Bow cones. When the data are reduced to a comparable basis it is found that the Medicine Bow cones in this experiment yield nearly twice as many seed as in the seed-production study (considering the 10-year average) and that the Gunnison limestone cones are fully as fruitful as Gunnison granitic cones. This difference, then, must be due to obtaining very superior cones on the Medicine Bow for these extraction experiments.

TABLE 10.—*Yields of Medicine Bow and Gunnison lodgepole pine cones in total and germinable seeds after varied air-drying and kiln-drying treatment*

[Lots of 1 bushel treated at each temperature; untreated seeds represent yields of 4 bushels from air drying only]

Period of air drying (days)	Kiln temperature	Seeds per pound extracted		Total quantity extracted		Balanced average of final germination			
		Medicine Bow	Gunnison	Medicine Bow	Gunnison	Medicine Bow		Gunnison	
	°F.	No.	No.	No.	No.	P. ct.	No.	P. ct.	No.
None	110	102,150	104,550	61,975	24,312	[1] 51.05	31,638	83.01	29,182
	140	91,713	111,050	58,745	27,691	60.20	35,364	81.78	22,846
	170	103,708	118,190	67,512	33,385	65.62	44,301	60.05	20,048
	200	101,105	113,740	56,787	29,510	58.68	33,323	47.98	14,159
Total or average	--------	[2] 99,034	[2] 112,096	245,019	114,898	59.03	144,626	67.05	77,035
55	110	100,574	120,943	52,417	28,917	61.08	32,016	73.08	21,133
	140	100,798	117,816	5[illegible],677	28,556	75.98	42,303	78.38	22,382
	170	96,509	110,362	52,[illegible]9	27,533	70.38	37,181	75.32	20,738
	200	101,022	109,209	54,092	26,798	59.35	32,104	68.12	18,255
	None.	112,833	128,496	28,000	7,731	68.05	19,054	63.92	4,942
Total or average	--------	101,067	117,191	243,015	119,535	66.93	162,658	73.16	87,450
161	110	97,128	125,648	40,012	26,731	83.58	38,457	74.28	19,850
	140	94,803	116,305	48,029	28,138	82.00	39,875	71.88	20,226
	170	95,694	137,451	45,008	33,342	74.25	33,418	67.98	22,666
	200	97,968	119,681	45,009	28,950	68.58	31,484	72.78	21,070
	None.	125,648	108,255	38,715	12,162	63.10	24,429	75.51	9,184
Total or average	--------	100,427	122,054	224,273	129,323	74.70	167,603	71.91	93,002
252	110	91,634	110,902	35,297	20,166	81.75	28,855	80.85	16,320
	140	92,381	113,967	33,691	25,168	80.95	27,273	73.85	18,586
	170	93,150	113,833	35,419	27,258	70.02	20,925	79.02	21,539
	200	93,331	116,305	35,432	27,844	60.30	21,365	74.00	20,005
	None.	109,552	103,755	61,119	13,383	72.08	44,055	80.21	10,735
Total or average	--------	97,194	113,003	200,958	113,839	73.88	148,473	77.11	87,785
425	110	98,607	119,097	15,183	18,159	71.22	10,813	70.12	13,823
	140	101,022	122,262	17,408	23,391	74.18	12,913	74.80	17,496
	170	101,022	138,290	17,053	27,460	70.42	12,643	62.48	17,157
	200	103,323	120,316	18,572	24,101	68.62	12,744	73.60	17,738
	None.	94,498	116,604	120,071	27,054	74.00	88,852	76.92	20,810
Total or average	--------	96,586	123,420	189,187	120,165	72.93	137,065	72.42	87,024
All	110	[2] 98,586	[2] 118,057	210,684	118,305	[2] 67.23	141,779	[2] 77.19	91,314
	140	95,304	115,997	214,150	132,944	73.65	157,728	76.22	101,336
	170	98,882	123,021	218,721	148,978	70.02	154,468	68.57	102,148
	200	99,236	115,637	210,792	137,203	62.16	131,020	66.93	91,827
	None.	103,804	113,338	247,005	60,330	71.15	176,310	75.70	45,671

[1] Allowances are made as described in the text for the short germinating period in the first test.
[2] Algebraic means.

From a comparison of the results at different temperatures, it is seen that the best net yield of Medicine Bow cones was obtained by using temperatures of about 140° F., owing both to high gross yields and the superior quality of the seed. The net, however, at 140° is considerably exceeded by that at 170° in the first extraction, as it appears that with green cones the higher temperature improved the quantity and quality of the seed.

For the Gunnison cones, it is evident, somewhat higher temperatures are necessary for the best results. A temperature of 170° F. here produces considerably more than 140°, after the second extraction, and in spite of generally poor germination the 170° extraction makes a slightly better showing in the average.

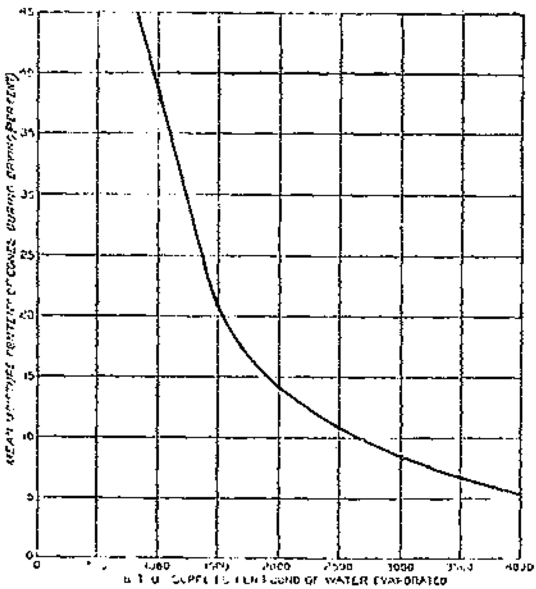


FIGURE 15.—Heat required for drying lodgepole pine cones at different moisture contents

As was indicated in the study of the germination results alone, Figure 11 shows that the longer air drying is continued the greater is the need and justification for the use of high temperatures. For the Gunnison cones even a temperature of 200° F. may in extreme circumstances be justified. The highest temperatures did not bring the late extractions of the Medicine Bow cones up to the status of earlier ones.

THE ECONOMY OF STORAGE AND AIR DRYING

It has been clearly indicated by both the 1912 and 1914 tests that the highest yields of germinable seeds may be expected after several months of storage and air drying of the cones. After possibly six months, however, the cones become casehardened and do not yield readily to artificial drying because of the relatively small amount of moisture available for removal, and as a result seed yields steadily decrease as the air drying is prolonged.

Since the evaporation of water by artificial heat necessarily involves expense, even though the necessary fuel be available in the opened cones, it follows that air drying of the cones may mean a considerable economy in the extracting process. It is conceivable that since at least temporary storage facilities must be provided air drying may be continued as long as desired without any material increase in cost on account of such facilities.

In the present study the unit of drying cost must be the heat actually utilized, with a small allowance for the fact that in cold weather a little more heat must be generated than in warm weather to produce the same kiln conditions. That the heat actually utilized is a fair basis, even though in these tests the percentage of utilization drops steadily as drier cones are treated, will be indicated by considering that in a practical operation this decrease might readily be balanced by treating larger masses of the dry cones. The limitation in efficiency of a hot air current is really decided by the amount of moisture which it accumulates. The heat actually utilized has been most carefully measured in these tests, which is an additional reason for adopting this measure.

The kiln-drying process is ordinarily thought of merely as a process of extracting water from the cones. This is undoubtedly the main consideration. But an examination of Table 11 will readily show that the amount of heat required in various extractions is not proportionate to the amount of drying done but rather increases markedly for each unit of water evaporated as the number of such units become less. (Fig. 15.) It is also greater in the 110° F. extractions of Gunnison cones than elsewhere. These phenomena are so striking and have given rise to so much speculation on the part of the writer and so great an effort to find an explanation that it would be desirable to discuss the matter thoroughly from a theoretical standpoint in order that the reader might have more confidence in the practical bearing of the results. This, however, is precluded by lack of space, and there will be mentioned, therefore, but three points which in the writer's opinion can have any material bearing on the results presented.

TABLE 11.—*Detailed record of extractions of lodgepole pine seed* [1]

MEDICINE BOW CONES

Test	Kiln temperature	Kiln data: Length of treatment	Kiln data: Mean air movement	Kiln data: Mean hot-air temperature	Kiln data: Mean exhaust temperature	Kiln data: Mean inside temperature	Kiln data: Mean room temperature	Heat computations: Total heat generated	Heat computations: Heat radiated	Heat computations: Heat used by cones	Heat computations: Proportion utilized	Dry weight of cones	Initial temperature of cones	Amount of water lost	Heat used in warming cones	Net heat use to evaporation	Heat use per pound of water evaporated [2]
	° F.	*Hours*	*Cubic feet per minute*	*° F.*	*° F.*	*° F.*	*° F.*	*B. t. u.*	*B. t. u.*	*B. t. u.*	*Per cent*	*Pounds*	*° F.*	*Pounds*	*B. t. u.*	*B. t. u.*	*B. t. u.*
21	110	19	65.3	115.52	85.82	100.67	65.77	54,960	18,577	12,467	22.7	27.5000	59.0	13.7656	867	11,600	843
	140	13	65.2	141.37	98.79	120.08	79.64	46,956	15,247	15,116	32.2	27.1997	60.0	14.0859	1,254	13,862	984
	170	9	78.4	166.95	109.27	138.11	96.40	49,556	10,926	23,579	47.6	25.9766	60.0	14.2265	1,581	21,998	1,546
	200	8	86.2	178.14	114.28	146.21	89.24	50,160	14,977	19,956	39.8	25.6484	55.6	14.5313	1,862	18,094	[3] 1,245
Average or total	------	--------	73.8	150.50	--------	--------	--------	201,632	59,727	71,118	[4] 35.3	106.3247	58.65	56.6093	5,564	65,554	[4] 1,158
22	110	10	91.6	112.23	86.31	99.27	58.21	40,980	11,221	9,307	22.7	23.8594	39.0	4.6484	844	8,463	1,821
	140	6	108.8	139.17	103.21	121.19	69.09	40,632	9,704	10,072	24.8	23.3516	49.0	5.0156	1,004	9,068	1,808
	170	4	110.8	165.66	112.93	139.30	65.53	38,244	10,363	9,557	25.0	23.1484	43.0	5.3516	1,342	8,215	1,535
	200	3	117.6	198.30	132.49	165.40	82.93	34,332	9,029	10,670	31.1	22.7344	44.0	5.6172	1,695	8,975	1,598
Average or total	------	--------	107.2	153.84	--------	--------	--------	154,188	40,317	39,606	[4] 25.7	93.0938	43.75	20.6328	4,885	34,721	[4] 1,683
23	110	7	99.5	111.84	85.57	98.70	49.14	35,712	10,648	4,904	13.7	23.5469	26.0	2.6093	1,294	3,610	1,384
	140	4	110.8	136.74	96.17	116.46	54.16	29,100	8,237	7,034	24.2	23.9297	35.9	3.1013	1,024	6,010	1,938
	170	2	119.8	168.24	111.96	140.10	64.10	18,342	5,374	5,605	30.6	23.2109	48.8	2.8594	1,100	4,505	[5] 1,576
	200	2	111.8	194.42	122.48	158.45	61.12	21,138	7,471	6,137	29.0	22.4844	45.0	3.3672	1,366	4,771	1,417
Average or total	------	--------	110.5	152.81	--------	--------	--------	104,292	31,730	23,680	[4] 22.7	93.1719	38.92	11.9372	4,784	18,896	[4] 1,583
24	110	6	101.4	112.48	93.92	103.20	70.00	23,280	5,524	4,150	17.8	23.0078	50.5	1.8281	605	3,545	1,939
	140	3	101.8	144.08	101.07	122.58	70.16	21,024	4,893	6,319	30.1	22.7812	56.5	1.9062	738	5,581	2,928
	170	2	99.1	166.24	111.60	138.92	78.80	15,582	3,937	5,266	33.8	22.4609	59.2	2.1172	887	4,379	2,068
	200	1½	115.4	203.77	128.88	166.32	81.58	17,475	4,682	6,102	34.9	22.0547	57.0	2.3672	1,216	4,886	2,064
Average or total	------	--------	104.4	156.64	--------	--------	--------	77,361	19,036	21,837	[4] 28.2	90.3046	55.80	8.2187	3,446	18,391	[4] 2,238
25	110	7	114.7	110.11	92.31	101.21	61.73	33,480	7,918	4,217	12.6	22.0000	52.0	1.1407	516	3,701	3,244
	140	3	119.6	140.11	105.16	122.64	62.86	23,388	5,825	4,825	20.6	22.4219	47.5	1.3437	809	4,016	2,989
	170	2	126.2	167.61	121.80	144.70	72.96	19,104	4,985	4,803	25.1	21.7891	45.8	1.5664	1,064	3,739	2,387
	200	1½	141.3	199.65	134.34	167.00	78.92	19,860	4,927	6,619	33.3	22.0703	54.0	1.8281	1,229	5,390	2,948
Average or total	------	--------	125.4	154.37	--------	--------	--------	95,832	23,655	20,464	[4] 21.4	88.2813	49.82	5.8789	3,618	16,846	[4] 2,866

All	110	9.8	94.5	111.66	88.79	100.61	60.97	188,412	53,888	35,045	[4] 18.6	119.9141	45.30	23.9921	4,126	30,919	[4] 1,289
	140	5.8	101.2	140.02	100.88	120.59	67.18	161,100	43,906	43,366	[4] 26.9	119.6841	49.78	25.4527	4,829	38,537	[4] 1,514
	170	3.8	106.9	166.94	113.51	140.23	75.56	140.828	35,585	48,810	[4] 34.7	116.5859	51.36	26.1211	5,974	42,836	[4] 1,640
	200	3.2	114.5	199.04	126.49	160.68	78.76	142,965	41,086	49,484	[4] 34.6	114.9922	51.12	27.7110	7,368	42,116	[4] 1,520
GUNNISON CONES																	
31	110	20	95.1	110.98	86.99	98.98	68.75	68,640	16,471	21,180	30.9	27.4141	53.2	8.9687	847	20,333	2,267
	140	9	117.8	130.49	101.89	120.69	70.06	59,010	14,014	19,780	33.5	26.9766	54.5	9.0547	1,204	18,576	2,052
	170	6	113.6	168.31	115.92	142.12	80.24	53,130	12,252	18,100	34.1	26.1953	54.0	9.6250	1,597	16,512	1,716
	200	4	113.4	203.44	123.92	163.68	73.80	45,300	13,483	17,165	37.9	26.5703	52.5	9.2734	1,944	15,221	1,641
Average or total	----	----	110.0	155.56	----	----	----	226,080	56,220	76,234	[4] 33.7	107.1563	----	36.9218	5,592	70,642	[4] 1,913
32	110	14	99.5	112.95	94.10	103.52	76.09	44,100	10,270	11,618	26.3	26.3203	44.0	4.3519	898	10,720	2,463
	140	5	96.6	139.25	103.12	121.18	71.96	28,200	7,507	7,225	25.6	27.1797	39.0	4.0078	1,227	5,998	1,497
	170	4	108.2	163.66	111.30	137.48	71.41	32,088	8,905	10,172	31.7	26.1172	49.0	4.6249	1,291	8,881	1,920
	200	3	119.5	191.36	125.64	158.50	82.01	32,880	8,162	11,909	36.2	25.9844	50.0	5.0453	1,605	10,304	2,042
Average or total	----	----	106.0	151.80	----	----	----	137,268	34,844	40,924	[4] 29.8	105.6016	----	18.0299	5,021	35,903	[4] 1,991
33	110	15	104.6	111.88	89.19	100.54	47.59	79,590	24,736	5,133	6.4	26.7656	31.1	2.4453	1,301	3,832	1,567
	140	5	111.4	139.72	101.16	120.44	51.67	39.840	11,754	6,502	16.3	26.1641	25.0	2.6328	1,673	4,829	1,834
	170	3	124.0	159.19	113.42	136.30	58.22	30,060	8,393	6,050	20.1	25.6406	39.0	2.9610	1,303	4,747	1,603
	200	2	116.0	200.94	121.68	161.31	60.48	23,970	7,324	8,339	34.8	26.0234	35.6	3.2422	1,699	6,640	2,048
Average or total	----	----	114.0	152.93	----	----	----	173,460	52,207	26,024	[4] 15.0	104.5937	----	11.2813	5,976	20,048	[4] 1,777
34	110	12	106.3	110.28	94.05	102.16	68.26	49,140	11,253	6,069	12.4	26.3594	55.0	2.0703	620	5,449	2,632
	140	5	93.3	139.56	106.12	122.84	73.13	26,646	7,606	5,026	18.9	25.8672	55.0	2.3750	883	4,143	1,744
	170	3½	125.5	162.00	119.18	140.59	74.30	30.708	7,183	7,103	23.1	25.6406	54.1	2.6014	1,132	5,971	2,295
	200	2½	123.2	190.86	129.35	160.10	77.14	32,276	7,564	9,334	28.9	26.7578	59.0	2.8750	1,376	7,958	2,768
Average or total	----	----	112.1	150.68	----	----	----	138,770	33,606	27,532	[4] 19.8	104.6250	----	9.9217	4,011	23,521	[4] 2,371
35	110	14	107.8	111.18	93.99	102.58	61.05	65,160	16,916	5,084	7.8	26.7734	40.5	1.3985	796	4,288	3,066
	140	4	114.8	139.22	105.77	122.50	64.88	29,418	7,390	5,631	19.1	26.2891	47.5	1.5218	945	4,686	3,079
	170	2½	132.5	171.95	126.73	149.34	76.91	26,640	6,331	6,479	24.3	25.2344	52.0	1.7421	1,196	5,283	3,033
	200	1½	136.6	199.50	128.83	164.16	77.73	19.656	4,802	7,515	38.2	26.5000	52.4	1.7500	1,419	6,096	3,483
Average or total	----	----	122.9	155.46	----	----	----	140,874	35,439	24,709	[4] 17.5	104.7969	----	6.4124	4,356	20.353	[4] 3,174
All	110	15.0	102.7	111.45	91.66	101.56	64.35	306,630	79,646	49,084	[4] 16.0	133.6328	----	19.2347	4,462	44,622	[4] 2,320
	140	5.6	106.8	139.45	103.61	121.53	66.34	183,114	48,271	44,164	[4] 24.1	132.4767	----	19.5921	5,932	38,232	[4] 1,951
	170	3.7	120.8	165.02	117.31	141.17	72.22	172,626	43,064	47,913	[4] 27.8	128.8281	----	21.5544	6,519	41,394	[4] 1,920
	200	2.6	121.7	197.22	125.88	161.55	74.23	154,082	41,335	54,262	[4] 35.2	131.8359	----	22.1859	8,043	46,219	[4] 2,083

[1] Unit for Medicine Bow cones is 0.9062 bushel except in test 21. In this test and in all Gunnison tests the unit is 1 bushel.
[2] After allowing for warming the water, it may be assumed that the amount of heat required per pound of water, if in a free state, is only 966 B. t. u.
[3] Low figure due in part to an irregular treatment for one hour after cones mostly open.
[4] Algebraic means.
[5] Low figure due in part to drying not being very thorough.

(1) The water to be extracted from the cones is not entirely free water. After a certain degree of dryness is reached—say, at about 15 per cent moisture content—the remaining water is held in a very strong bondage and behaves unlike liquid water, just as does the residue of soil water when the soil approaches complete dryness. If the drying process is reversed, very dry cone material being immersed in water, it is found that considerable heat is generated, which may be called "heat of imbibition or absorption." The amount so generated, in rough tests made without a calorimeter, is perhaps 15 B. t. u. per pound of dry cone material wet, and this is only a small fraction of the amount needed to explain the high heat use in some of the extractions. Nevertheless, the existence of such a factor is an important item in explaining why there is much greater heat use when cones are dried to a low moisture content.

(2) The second point concerns the allowance for radiation from the walls of the kiln between the points where the temperatures of the hot-air current and of the exhaust-air current are recorded. Every effort has been made to determine precisely what loss of heat occurs with the current of air passing through the kiln, but with no drying being done. The main difficulty is to duplicate the conditions which exist when there are cones in the kiln. Therefore, while it is believed that a radiation table has been prepared which is well balanced for different temperature conditions, still is must be recognized that the radiation is a large factor in the entire heat loss and that very slight changes in the allowances for radiation would greatly affect the apparent use of heat in the drying process.

(3) It may be assumed that some of the heat is used in obscure chemical changes in the cone cells and in the seeds. The facts deduced from germination data, indicating ripening changes in the seeds, both when the cones are air-dried, and occasionally when they are kiln dried, point strongly in this direction. The various lots of test 21 showed original germination almost directly proportionate to the excess heat used in extracting the seed, and in test 31, although the higher temperature treatments did not show the greater excesses, the same relation of heat use to germinative vigor is evident. While this relation can not be followed into subsequent tests without involving other factors, it is quite evident that there is a close relation between heat use and seed quality in green cones.

What quantities of heat may be involved in these possible chemical changes is entirely problematical, though it does not seem that they could be consequential unless the entire cone mass were affected.

PRACTICAL RESULTS OF THE DRYING PROCESSES

The calorimetric results obtained with the first kiln and the Arapaho cones of 1912 are not considered sufficiently reliable to warrant their presentation in tabular form, although the values obtained fall mainly within the range of values established later by more careful methods. A brief résumé will suffice to show the situation existing when the tests of 1914 were begun.

The quantity of heat required to open the cones, as determined by the cooling of the air in passing through the cone trays, with an allowance for the radiation loss from the kiln walls, was 6,651 B. t. u. in the first extraction at 110° F., and 18,289 for the entire bushel treated at three different temperatures. This total value decreased promptly but irregularly in later tests to less than 10,000 B. t. u. per bushel of cones and reached a low point of 5,500 B. t. u. in test 13 made January 15, 1914, 13 months after the first extraction. Considered by groups of five tests each, the first group had an average requirement of 11,993 B. t. u. per bushel, the second 8,206, and the last extractions 7,193 B. t. u. It is thus seen that after air drying the cones are opened with a much smaller utilization of heat, and this, in a practical operation, would mean that a greater volume of cones could be treated at one time.

Individual extractions vary widely in the amount of water evaporated in the artificial drying processes. Considering groups of results large enough to obscure individual variations, the first five tests required on the average[a] 2,655±107 B. t. u. per pound of water evaporated, the next five, 2,230±94, and the last, 2,516±89. One explanation of this low heat use in the second group is the fact that from the time of test 5 to that of test 10 the cones were at times being wet by rains, and in so far as this moisture remained in the superficial layers it is conceivable that it would be evaporated more readily than that deep within the tissues.

The practical results obtained in the various extractions of Medicine Bow and Gunnison cones may now be considered.

In Table 11 the conditions and heat computations for the numerous extractions in the 1914 tests have been given. Table 12 sums up the heat use in relation to seed yields.

It is to be expected that there will be a gradual diminution in the heat required to open cones as they become more and more affected by air-drying. Referring to Table 7, which shows the moisture condition of the cones as treated at different periods, it is seen that for Medicine Bow cones between tests 21 and 23 there was a loss of moisture by air-drying from 71.6 to 20.4 per cent; this is accompanied by a decrease of more than one-half in heat utilization. Beyond the third extraction, however, the decrease in heat use is far less than the decrease in the amount of water to be evaporated, and is just about equal to the decrease in total seed yield, including that obtained by air-drying.

Table 12 clearly shows that the 110° F. extractions of Medicine Bow cones are most saving of heat; but in view of the much higher yields of good seeds at 140°, it is felt that 140° is actually the more economical, if the original cost of the cones be properly weighed.

Extractions of Gunnison cones at 110° F. utilized a greater amount of heat than any except those at 200° and produced the highest quality seed; but as nearly one-fifth of the limestone cones do not open at this temperature, the net yield is low, and the heat required to produce 1,000 seeds is 20 per cent greater than at 140°, where practically the highest yields are obtained.

The most economical period for extracting both types of seed is that which produces the greatest seed yield, or, as represented by tests 23 and 33, in March, about 160 days after the end of September, when cones may be considered ripe. This is not marked enough,

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[a] Arithmetic means of the results of all of the extractions in these tests after eliminating from first and second groups one high figure whose deviation exceeds three times the probable error. In the second group results in test 9 are not included.

however, to warrant undertaking extracting operations in March if that month should happen to be very cold and undue expense would be involved in generating the total amount of heat required. It must also be kept in mind that the low heat use at this period in the tests has not been clearly explained.

TABLE 12.—*Heat required to open lodgepole pine cones in 1914 tests in relation to net seed yields at various times and temperatures*

Medicine Bow cones					Gunnison cones				
Test No.	Kiln temperature	Heat units used [1]	Good seeds obtained [2]	Heat units per M good seeds	Test No.	Kiln temperature	Heat units used	Good seeds obtained [2]	Heat units per M good seeds
	°F.	*B. t. u.*	*Number*	*B. t. u.*		*°F.*	*B. t. u.*	*Number*	*B. t. u.*
21	110	12,467	31,638	304	31	110	21,180	20,182	1,049
	140	15,116	35,364	427		140	19,780	22,646	873
	170	23,579	44,301	532		170	18,109	20,048	903
	200	19,956	33,323	599		200	17,165	14,159	1,212
Total or average		71,118	144,626	[3] 492	Total or average		76,234	77,035	[3] 900
22	110	10,270	36,779	279	32	110	11,618	22,369	519
	140	11,115	47,067	236		140	7,225	23,617	306
	170	10,546	41,944	251		170	10,172	21,974	463
	200	11,774	36,868	199		200	11,909	19,490	611
Total or average		43,705	162,658	[3] 209	Total or average		40,924	87,450	[3] 468
23	110	5,412	44,565	121	33	110	5,133	22,152	232
	140	7,762	45,982	169		140	6,502	22,522	289
	170	6,185	39,525	156		170	6,050	24,962	242
	200	6,772	37,591	180		200	8,339	23,366	357
Total or average		26,131	167,663	[3] 156	Total or average		26,024	93,002	[3] 280
24	110	4,580	39,868	115	34	110	6,069	19,004	319
	140	6,973	38,287	182		140	5,026	21,270	236
	170	5,811	37,939	153		170	7,103	24,222	293
	200	6,734	32,379	208		200	9,334	23,289	401
Total or average		24,098	148,473	[3] 162	Total or average		27,532	87,785	[3] 314
25	110	4,653	33,026	141	35	110	5,084	19,025	267
	140	5,324	35,126	152		140	5,631	22,600	248
	170	5,300	34,856	152		170	6,479	22,359	290
	200	7,304	34,957	209		200	7,515	22,941	328
Total or average		22,581	137,965	[3] 164	Total or average		24,709	87,924	[3] 284
All	110	37,382	185,876	[3] 201	All	110	40,084	102,732	[3] 478
	140	46,290	201,826	[3] 229		140	44,164	112,754	[3] 392
	170	51,421	198,565	[3] 259		170	47,913	113,565	[3] 422
	200	52,540	175,118	[3] 300		200	54,262	103,245	[3] 526

[1] For tests 22 to 25, figures from Table 11 were increased to a whole-bushel basis by dividing by 0.9062.
[2] Including seeds released by air-drying only.
[3] Algebraic means.

It is noteworthy that although test 23 represents the lowest average heat utilization by the Medicine Bow cones, extractions at 140° and 170° F. produced slightly better utilization in test 25. This is in line with the fact previously pointed out that the higher temperatures become increasingly effective as the cones become drier. Extractions of Gunnison cones at 140° took the least heat in test 34; at 170° the low level was reached in test 33. Test 33, at 170°, produced the highest individual seed yield for the Gunnison cones.

The practical results of these tests may, then, be summed up as follows:

Air drying under ideal storage conditions may in the course of six months reduce the moisture content of the choicest fresh cones by about 70 per cent of the original amount and thereby reduce by fully one-half the heat required to complete their opening. A maximum temperature in the kiln of about 140° F. is all that is required while the cones contain good "life." Beyond this period drying of fresh cones goes on much more slowly. The cones become hardened and soon do not contain enough moisture to show a sharp reaction when the moisture is removed, so that higher temperatures have to be used. It may well be said that the best temperature is the lowest that will open the cones effectively, time being a consideration. Medicine Bow and Gunnison cones were very different in this respect, in that the former never failed to respond quite well to the low temperatures.

Everything considered, storage for six to nine months produces the largest yields of seed, of the best quality, and at the least expense of artificial heat. The amount of artificial heat required may be taken as an index of the speed of operation as well as of the total expense.

Cones that are for any reason more poorly developed, like those grown on limestone soil on the Gunnison Forest, differ mainly in requiring higher temperatures for their effective opening, except possibly while fairly fresh.

GERMINATION OF LODGEPOLE PINE SEED

THE METHOD OF GERMINATION TESTS

SOIL, TEMPERATURE, AND WATER

Since a test of the viability of the seed is necessary for any conclusion as to the real value of a seed crop or method of treatment of the crop, germination tests must be frequent in such a study as this, and the manner in which they are made is of no small importance. The subject is extremely large and complex, and various seed-testing methods have been widely discussed. In defense of the method applied in this work it may be said that it has the justification of being natural and practical; natural in the sense that the medium, sand, is the natural habitat[7] for seed, and that the daily range of temperatures and the absolute temperatures are similar to those occurring in lodgepole pine sites; practical, in that the manipulation of the tests is much simpler in sand flats than under more artificial conditions, and also because the results are perhaps indicative of the seed values for nursery or field use. By this method germination is more than a mere showing of life in the seed—the seedling must at least have vigor enough to push to the surface.

The main features of the method chiefly used in connection with this study were described by the writer in 1913 (*1*), but since then some refinements and additional data make it desirable to describe anew the entire process so far as it relates to tests with lodgepole pine.

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[7] In considering the difference between sand and blotting paper, for example, the chemical reactions of the two mediums may be of some small moment. The sand medium will usually show an acid reaction, to which the pines are partial, at least in their later growth, while it is to be expected that blotting paper will be alkaline or nearly neutral. No doubt the reaction of the water (or solution) will have appreciable effect on its rate of absorption by the seed.

As the small greenhouse designed for these tests was not equipped with artificial heat until November, 1911, the preliminary work for the first year was done under a natural or practically uncontrolled range of temperatures. It was not difficult to keep the minimum temperatures above freezing, although at times they went below 40° F., but there was less control of the maximum air temperatures, which in August averaged 100°. A daily range of air temperatures from 50° to 85° was soon decided upon, to be controlled as needed by means of artificial heat at night and curtains in the daytime.

After a period of observations in which the extremes of air temperature, 50° and 85° F., had been compared with the maxima and minima in the soil, the temperature range was controlled according to the soil temperatures, beginning in November, 1913. It was found that at a depth of 1 inch in the sand the daily range was about 15° less than that of the air in the greenhouse. Consequently, the new standard adopted permitted a maximum each day of 77.5°, and a minimum, usually occurring in the early morning, of 57.5°. It was thought that in this manner the actual temperatures experienced by the germinating seed would be made more closely comparable for days when sunlight supplied the heat, and days in which the entire warming process must be through warming of the air, and thence the soil, by artificial heat. However, because of the more sustained effect of artificial heat, it is more equable that when sunlight is not available the maximum should fall somewhat short of 77.5°, and this not infrequently happens because of physical limitations of the greenhouse equipment.

Later observation over a period of 80 days showed that when a maximum temperature of 77.5° F. is attained at a depth of 1 inch, the corresponding temperature 0.25 inch below the surface, where the seeds lie, is 5.7° higher on the average. The minimum at 0.25 inch depth, however, is only 0.5° lower than that of the deeper soil. The actual range of temperatures experienced by the seed under the standard air temperatures is, therefore, 57° to 83.2°.

Most of the space in the greenhouse was occupied until 1918 by a bench partitioned into tills, each approximately 1 foot square and 4 inches deep. (Pl. 1, C.) This gave fairly uniform conditions for conducting 165 synchronous tests, with some variations, which will be mentioned later. A movable bench of 25 square feet capacity was then constructed, separate tills instead of built-in sections being used thereon.

The material used in all recent soil tests has been a granitic sand fairly free of both humus and clay, obtained by passing the native granitic gravel of the region through ¼-inch-mesh hardware cloth. The sand was taken from a deep excavation, where it was thought few spores or mycelia of parasitic fungi would have penetrated. That this idea was sound is shown by the fact that in 10 years there have been not over half a dozen outbreaks of damping-off in the testing tills, and these were confined to single seed lots, the spores probably having been brought in with the seed. Probably because of this factor the sand medium was found generally to induce higher germination than a loamy soil. The slightly acid reaction of the granitic and (pH about 6.0) probably has a stimulating effect on lodgepole pine germination, as it does later on growth.

At first one-half of an inch covering of sand was used for all seeds, but this was quickly changed on evidence that it materially retarded germination, especially of the small seeds of spruce and lodgepole pine. The standard covering of one-fourth of an inch was adopted, with this provision—that where the thickness of the seed is itself a large proportion of this depth the seed will be pressed in flush with the surface before the covering soil is applied.

The exact control of watering has never been considered either feasible or necessary. It has seemed best to compensate for variations in weather conditions merely by varying the morning watering according to the prospective weather, and if this fails to keep the soil surface appreciably moist to supplement it by a watering later in the day. Considerable faith is pinned to this method because of the loose character of the soil, the freedom of drainage both through the soil and the bench floor, and the lack of any tendency toward sourness or moldiness. Only in 1915 was there discovered any evidence of bad effects from overwatering.

During a temperature test, described later, samples of the sand in the tills were taken daily to determine moisture content. Moisture was found to vary by slow changes from 6 to 12 per cent. The higher figure is possibly a little too much moisture for the best results. Any value between 6 and 10 per cent would probably insure highly available moisture and complete aeration. Variations within this range would only have a negligible influence.

PREPARATION AND TESTING OF THE SAMPLE

The lots of seed obtained in experiments such as those described rarely exceed 0.5 to 1 pound in weight. These lots are first freed of long needles, seed wings, or other foreign matter which would tend to bind the seeds together. In this condition the total roughly cleaned weight is determined.

A small sample of 500 seed is counted and accurately weighed, all foreign matter being carefully removed, as well as broken and hollow seeds when it appears certain that these can not germinate. From the weights thus taken it is possible to determine the number of clean seed per pound, as well as the purity percentage of the seed lot, and the total number of seeds therein.

The 500 seeds are then ready to be sown. A section or till is somewhat loosely but evenly filled with slightly moist sand, which is pressed down one-fourth of an inch below the top of the till with a specially constructed block, leaving the soil surface smooth and slightly compacted. The 500 seeds are distributed evenly over this surface or, if they are large (more than about 2 millimeters thick), embedded with the pressing block. Loose, dry sand is then placed over them, level with the top of the till. By this means, unless erosion of the surface occurs, a uniform covering of the seeds is assured even though the sand in the till should settle somewhat unevenly from repeated watering.

The tills are immediately watered. Thereafter they are observed and watered each morning. When seedlings begin to appear, after 7 to 15 days, the sand is watered and eruptions on the surface are "melted down" before the seedlings are counted and removed. The tally of each till is made from day to day.

This method is designed to give the total number and germinable number of seeds in the entire sample or per pound. Because of the difficulty of obtaining a perfectly true sample either for weight or germinability, and because these two things usually vary in the same direction, a short-cut method is possible which promises less variable results. Instead of a fixed number of cleaned seed, a known weight of uncleaned seed may be sown, the result being stated as so many germinable seeds per gram. This figure will probably be found less variable in successive samples than any other measure of germinability. At least the method guarantees numerous samplings for weight as well as for germinability, and is recommended for use in investigations in which it is possible to get away from the stereotyped expressions of "germination percentage." When there is a time element, with opportunity for the entire seed lot to gain or lose weight through moisture changes, it is, of course, necessary to keep track of such changes.

THE GERMINATION PERIOD

For practical purposes seed which germinates promptly has much greater value than that which responds slowly to favorable heat and moisture. Nature being quite relentless in such matters, especially in a region with a dry atmosphere which quickly desiccates the soil surface, it follows that seeds whose vigor permits them to germinate on the moisture of a single rain have a much greater chance of success and a much greater value in reproduction than those which perhaps have only begun to swell when their seed bed becomes dry.

It is recognized that the seed of each species has its characteristic germinating time and rate, and the differences between climatic varieties of the same species are equally marked. Therefore, there is a tendency in seed testing to set aside a limited period for a showing of energetic germination and to consider the germination occurring after that period as of little or no practical value.

Wiebecke (*14*) writing in 1910 of experience with Scotch pine (*Pinus sylvestris*) in Europe, and referring to germination upon strips of moist flannel or blotting paper, which is, of course, more rapid than in soil, says:

> The practical working out of several thousand germination experiments at Eberswalde has confirmed the opinion of Haack that in the case of fresh seed from good cones all the really useful seeds have germinated in seven days.

The relative "germinative energy" of any particular lot of seed, or the period required for the germination of the more vigorous and prompt portion, may be expressed in several ways with reference to other seeds. Perhaps the commonest and least arbitrary method is to give the number of days required by the seed to produce one-half of its possible germination. This number is called the "rapidity factor." The objectionable feature in the use of this term is that the rapidity factor can not be given until a very long period has elapsed to bring out the complete germination.

Other means of expressing the energy or real value of the seed require that the percentage of germination in some limited period shall itself delimit the quality of the seed, or that this amount in a limited period, expressed as a ratio to the germinative capacity, shall show the proportion of vigorous seeds. The period of energetic germination must then be decided upon. In the present study an analytical method of determining this period was used with lodgepole pine, as with other species, with a certain arbitrary basis. The records of a number of tests were analyzed on the premise that the energetic germination should be considered to have ceased when, in the test of 500 seeds, the number of seedlings appearing was less than 4 in two consecutive days, or less than an average of 0.4 per cent per day for two consecutive days.

From 40 tests of lodgepole pine which were available for analysis in 1913, it was found that the period in which the germination rate exceeded 0.4 per cent per day varied from 20 to 45 days, with an average of about 31 days. This period was therefore adopted at that time as the standard period for testing seed lots which had no research value and as a basis for comparing seed lots of an experimental nature. At the same time it was recognized that to approach a measure of germinative capacity at least twice the energy period should be allowed, or 62 days.

More complete information shows that the germinating rate has not commonly dropped to 0.4 per cent per day until 40 to 50 days after sowing; that the germination of lodgepole pine may sometimes continue for 100 days or more under the greenhouse conditions and may be spread over two growing seasons in the field.

From the data to be presented in the following pages it will be seen that the actual value of seed for sowing depends as much upon the field conditions as upon the quality of the seed, so that any attempt to define seed quality except in the simplest terms is futile. For contrasting the energy of lodgepole pine seed from different localities, or for investigating the effect of a treatment upon the energy of the seed, the germination occurring in a period of 31 days will serve as well as any other criterion, but for most other purposes at present the final germination is best used.

CRITICAL STUDY OF THE TEMPERATURE FACTOR

In the present study, since relative germination rates and amounts have such an important bearing on the conclusions, it is desirable to know whether the standard temperature conditions described in earlier paragraphs are natural for lodgepole pine in the sense of being nearly optimum and capable of bringing out a large proportion of the possibly viable seed within the time allowed. The question arises naturally from the fact that throughout the tests final germination values of about 70 per cent are the rule. If other germination conditions might have produced markedly higher germination, then it may be questioned whether even the comparative values for different seed lots are to be relied upon.

The first test of the arbitrarily selected greenhouse temperatures was made in the spring of 1917, while the large area of tills was still in use, and included Douglas fir and western yellow pine, as well as lodgepole pine. Each test covered an entire cross section of the bench, or five tills, 500 seeds being sown, as usual, in each of these. The entire space used, comprising 75 tills, was centrally located in the greenhouse, so that local temperature variations should not have had any appreciable influence on the results.

TABLE 13.—*Summary of temperature-germination tests of tree seeds in 1917, the daily range of temperatures being stepped up 10° F. each 10 days when a new test was started*[1]

Test No.	10-day average temperature range at start of test	Mean relative growth value of temperatures [2]	Germination of lodgepole pine: Starting time	Germination of lodgepole pine: Total	Germination of lodgepole pine: Total, 35 days	Germination of lodgepole pine: Value of x [2]	Germination of Douglas fir: Starting time	Germination of Douglas fir: Total germination		Germination of western yellow pine: Starting time	Germination of western yellow pine: Total germination	
	° F.		Days	P. ct.	P. ct.	P. ct.	Days	P. ct.	Days	Days	P. ct.	Days
1	37.1-40.7	1.17	23	74.84	60.8	0.41	23	84.32	53	24	34.04	47
2	42.1-63.4	1.77	17	70.32	71.9	6.59	16	83.08	43	18	37.12	38
3	52.6-72.8	2.58	10	80.64	75.8	5.17	8	77.88	[3] 33	10	34.01	35
4	62.0-82.8	3.80	6	78.72	72.5	4.11	6	79.44	39	6	36.40	37
5	71.9-92.8	5.53	5	75.40	67.0	3.40	5	73.12	32	5	38.16	[4] 37

[1] A total of 2,500 seeds were used in each test.
[2] See reference in text to Van't Hoff-Arrhenius principle. The growth value of 40° F. is considered unity.
[3] Between 27 and 32 days no germination, followed by 2 stragglers.
[4] 1 additional seed germinated on the fifty-third day.

The plan followed was to sow five lots of each species simultaneously, maintaining a given range of temperatures for 10 days, a period in which, at the ordinary temperatures, germination of lodgepole pine is almost invariably begun. Following this, another set of samples for each species was sown, with the daily maximum and minimum temperatures of the greenhouse each increased by 10° F.

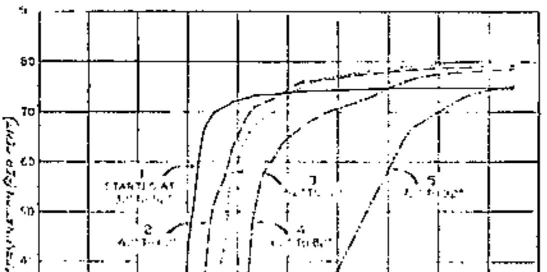

FIGURE 16.—Germination of lodgepole pine seed in 1917 from successive sowings with temperatures increasing first 40 days

In all, five sets of samples for each species were sown successively at 10-day intervals, and the temperatures changed from an initial daily range of 32° to 52° up to 72° to 92°. The first seed sown thus experienced total temperature ranges of 60° or more within 40 days of sowing; the second lot 50°; the third, 40°; and the last only slightly more than 20°. The actual mean maxima and minima are shown in Table 13. These were not quite as planned; the temperature of 32° was attained only once in the first 10 days, and the maxima were accordingly reduced to give a mean of about 43°.

To determine an optimum temperature for germination, one would naturally carry through individual tests at fixed temperatures or at temperatures within a given, narrow range, but this plan was not practicable in 1917, if even partially synchronous tests were to be made. Nevertheless, the 1917 tests brought out facts of value. In Table 13 is presented a brief summary of these tests and in Figure 16 the progress of germination for lodgepole pine may be seen in detail. The results will be considered in connection with those obtained later in 1922, when an incubator and a cool cellar made it possible to conduct tests at fairly even temperatures of 50°, 60°, 70°,

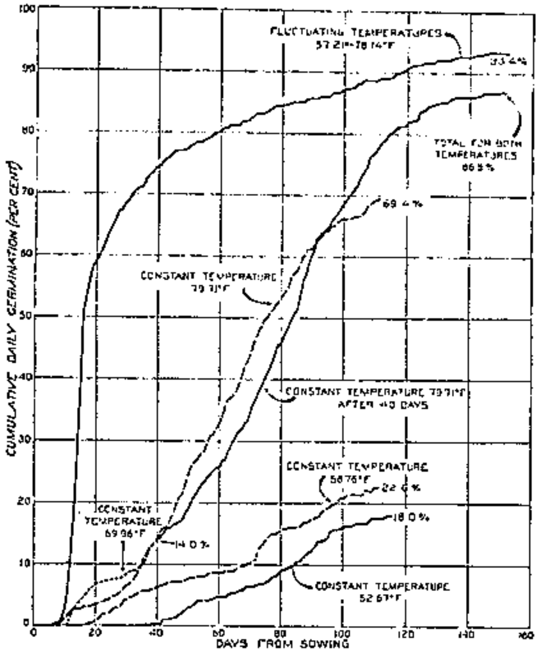

FIGURE 17.—Cumulative germination of lodgepole pine seed at various temperatures based upon 500 seeds sown in each test

and 80° F., or at least with only minor fluctuations from these standards.

Each of the four 1922 tests was made with 500 carefully selected seeds of each species, in small iron pans filled with sand and brought daily to a 10 per cent moisture content, or about the average maintained in the greenhouse. At the same time a test was made in the greenhouse under the standard conditions. In Table 14 is given a summary of these even-temperature and regular greenhouse tests. Figure 17 shows the cumulative germination, departing from the usual practice of showing current daily amounts because of the importance of the final totals. In both series of tests it seems desirable to compare lodgepole with other species in the tabular data.

TABLE 14.—*Summary of temperature-germination tests of tree seeds in 1922 under varied temperature conditions* [1]

Test No.	Temperature conditions	Lodgepole pine: Start	Lodgepole pine: Total germination		Lodgepole pine: Energy ([2])	Western yellow pine: Start	Western yellow pine: Total germination		Western yellow pine: Energy ([2])
		Days	*Days*	*Per cent*	*Per cent*	*Days*	*Days*	*Per cent*	*Per cent*
1	Daily range 57.2° to 78.1°, 1 inch in soil	7	152	93.4	69.3	6	131	99.0	84.6
2	79.7° steady temperature. Dropped few minutes each day	8	171	[4] 69.4	8.8	5	100	98.4	92.1
3	70°, increased to 80° after 40 days [3]	11	151	[4] 86.8	8.8	8	40	99.4	97.4
4	58.8°. Steady rise from 53.6° to 63.2°	17	111	22.6	4.6	14	111	50.8	19.8
5	52.7°. Steady rise from 43.2° to 55.8°	34	115	18.0	0.0	25	115	61.4	0.2

Test No.	Temperature conditions	Douglas fir: Start	Douglas fir: Total germination		Douglas fir: Energy ([2])	Engelmann spruce: Start	Engelmann spruce: Total germination		Engelmann spruce: Energy ([2])
		Days	*Days*	*Per cent*	*Per cent*	*Days*	*Days*	*Per cent*	*Per cent*
1	Daily range 57.2° to 78.1°, 1 inch in soil	7	28	75.6	74.2	6	28	56.8	56.6
2	79.7° steady temperature. Dropped few minutes each day	6	28	63.0	62.8	6	30	54.2	54.0
3	70°, increased to 80° after 40 days [3]	9	33	73.0	72.4	7	40	51.4	51.2
4	58.8°. Steady rise from 53.6° to 63.2°	13	106	69.4	47.0	11	95	43.2	36.4
5	52.7°. Steady rise from 43.2° to 55.8°	20	114	36.8	0.0	27	112	26.2	0.0

[1] A total of 500 seeds were used in each test; moisture standardized.
[2] Amount in usual period for species.
[3] Only lodgepole pine was carried past 40 days, the other species having completed germination.
[4] The germination in 40 days was 14.2 per cent in test 2 and 14 per cent in test 3.

In 1917 the lodgepole seed germinated best, considering both promptness and final germination, in test 3 starting at temperatures 52° to 72° F., increasing in 10 days to 62°–82° and at 20 days to 72—92°. Vigorous germination started just at the time of the first increase in temperature, showing as in tests 1 and 2 that the temperature 52°–72° causes a good deal of activity.

Tests 1 and 2, starting at lower temperatures, show hardly less spontaneity once germination was started. but the lower final figures suggest the loss of a small percentage during the period of low temperatures. Test 4, starting at 62°–82° F., is also vigorous at the outset, but appears to be somewhat depressed by the highest temperatures attained. Test 5 started at 72°–92°, and experiencing only slight variations from this standard, is sluggish, the more rapid germination being spread over a period of nearly 30 days. Evidently this temperature scale is a little too high.

Since it is fairly evident that lodgepole pine germination is benefited by a wide range of temperatures, the thought might occur that a part of the seeds find one temperature just right, another quota prefer a higher temperature, and so on, in much the same way that some of the cones are opened at air temperatures, others at 120° F., and still others only at 160° or 200°. This may be true to some extent, but hardly describes the situation fully, although in the tests of 1922 the aggregate germination at the two constant temperatures of 58.8° and 79.7° was just about equal to that of seeds which experienced the daily range from 57.2° to 78.1°. It may better be said, however, that lodgepole pine seeds in general demand more or less heating and cooling for the rapid absorption of moisture and the chemical changes which precede germination, and this apparent requirement is no doubt linked up with the habit of the species of reproducing in the open places, and at high altitudes where the daily range of temperature is extremely great.

In order further to show the importance of specific temperatures in the germinating process of lodgepole pine as contrasted with the effect of rapidly fluctuating temperatures, it is desirable to examine the germination records in a statistical manner. The Van't Hoff-Arrhenius principle, as described by Livingston and Livingston (*9*), which refers to chemical reactions and is sometimes applied to the reactions which control vegetative growth, suggests that the vegetative activity of plants should double in rate for each increase of 10° C., or 18° F., above a starting point of 40° F. If in the present instance the unit rate of growth, x, is considered to be the percentage of germination which might result from 10 days' exposure in a moist soil at 40° F., then for a similar period at 58° a germination amounting to $2x$ may be expected, at 76°, $4x$, etc. By means of a graph the expected rates corresponding to any of the maximum and minimum temperatures in these tests may be found, and without too great an error the rate of germination may be assumed to be the mean of the maximum and minimum possible rates for each 10-day period. Although in the 1917 tests no germination appeared above ground until the twenty-third day, when the temperatures had risen to 52°–72°, it must be assumed that the lower temperatures preceding had had an influence on the vigorous germination appearing after the twenty-third day. The sum of the influences affecting the germination of the first test, for the first 35 days, may be expressed by the equation—

$$1.17x + 1.77x + 2.58x + \frac{3.80x}{2} = 69.8 \text{ per cent}$$

$$x = 9.41 \text{ per cent}$$

In other words, if the principle of doubled activity for each 18° increase is properly applied to this form of vegetative growth, then in 10 days at a temperature of 40° F. there have really been accomplished changes equivalent to the germination of over 9 per cent of the seed. The value of x should also be found the same by considering the conditions and results of each of the tests. The important thing is not the absolute value of x but the fact that as computed for Table 13, using for each test the germination occurring in 35 days, the value of x is highest in the test started at a low temperature and steadily decreases as the low temperatures are departed from. This does not in itself give proof of the point on which information is desired, since, considering only the first 35 days of the tests, Nos. 1 and 2 each experienced a total temperature range of about 50°, while the later tests went through smaller and smaller total ranges. Only the comparison of the first and second tests is valid, therefore, as to the relative values of different temperatures, but this comparison seems to prove that, at least relative to the assumptions of the Van't Hoff-Arrhenius principle, the response of lodgepole pine seed is more vigorous to the lower scale of temperatures. There is scarcely any doubt, both from this and the direct consideration of the curves of Figure 16, that maximum temperatures beyond 82° are somewhat inhibitory.

For further clarification of this subject the data obtained in 1922 with fluctuating temperatures and several constant temperatures may now be considered.

Although the tests were made in 1917 with lodgepole pine seeds from a Wyoming forest, and those in 1922 with seeds obtained near Gunnison, Colo., the germination quantities are evidently of about the same magnitude in the two periods. Under the regular seed-testing conditions, in 1922, with a mean daily range from 57.2° to 78.1° F., as in test 1, the value of x for lodgepole pine was 6.44 for the first 35 days. This, it will be seen, corresponds closely to that in test 2 in 1917, in which the range of temperatures in 35 days was from 42.1° to 92.8°. The mean temperature of the latter was about 2° lower than the temperature of the test in 1922, but the range in 1917 was much greater.

To compare all of the tests in 1922, a period of 35 days is quite inadequate, because in the low-temperature tests germination is just getting well started in this time and the total effect of the 35-day exposure is in no sense expressed. (Fig. 16.) While the period of 100 days goes well beyond the crest of germination in the fluctuating-temperature test, it is designed to bring out about the highest average rates in the others.

The values of x given in Table 15, on the same basis as in Table 13, are thus obtained:

TABLE 15.—*Value of x in five tests of lodgepole pine seed*

Test No.	Type of test	Temperature	Germination	Value of x
		°F.	*Per cent*	
1	Fluctuating	57.2–78.1	87.2	2.79
2	Constant	79.7	66.2	1.44
3	do	[1] 70.0 [2] 79.7	68.7	1.70
4	do	58.8	20.8	1.01
5	do	52.7	16.0	.98

[1] For 40 days. [2] For 60 days.

The above values for the 70° F. test are somewhat clouded by the effect of the change in temperatures at the end of 40 days. If this test is compared with the 80° test for the 40-day period alone, a higher value of x for the lower temperature is indicated. At 70° the value is 1.11 and at 79.7°, 0.77.

It is thus quite evident that none of the approximately constant temperatures have the value of regularly fluctuating temperatures in stimulating lodgepole pine germination, and that a constant temperature in the vicinity of 70° F. is more effective than temperatures higher or lower. Furthermore, the possible conclusion from the 1917 tests that the low temperatures are relatively important is not borne out when low temperatures are considered alone, and this places the emphasis on the inhibitory effects of very high temperatures. A daily range of temperatures is the important thing, and, apparently, a range centering around 65° or 70° represents the optimum.

This result does not fully agree with the results of laboratory tests in Washington (*13*), where it was found that the fullest and most prompt germination of one lot of lodgepole pine seed was obtained with temperatures ranging between 68° and 95°, or even as high as 77°–95°. With another lot of seed 59° to 86° gave the best results. The results there shown were somewhat erratic, however, and as the temperatures reported were probably those of the air rather than of the soil it is difficult to make comparisons.

Boerker's findings (*4*) may be considered as corroborating the above conclusions. He shows that with fairly optimum greenhouse temperatures lodgepole pine seed germinated 22 per cent in half light, 7.5 per cent in light of 16 per cent intensity, and 3.5 per cent in light of 2 per cent intensity. It is believed that these results reflect to some extent the effect of a greater range of temperatures in the stronger light.

Harrington (*7*) has recently shown that some kinds of seed germinate best with alternating and some with constant temperatures, and that of the latter varieties some lots are favorably affected by alternating temperatures, which he thinks may be due to incomplete after ripening. He discards most of the theories as to the effects produced by alternating temperatures, being convinced that these are due to changing conditions rather than to the specific temperatures reached.

From the facts which have been stated it is readily concluded that the standard daily temperature range from 57.5° to 77.5°, with such fluctuations from this as commonly occur, forms almost ideal conditions for lodgepole pine germination. It is no doubt because of fluctuations which occur in the greenhouse at infrequent intervals that even after 60 or 70 days the ungerminated lodgepole pine seed sometimes receive stimulation.

Douglas fir seeds in the 1917 tests (Table 13), with only one exception, gave decreasingly poor results as the temperatures were raised. The first lot, started at 32°–52° F., had practically completed its vigorous germination before the stage of 52°–72° was passed. The next three tests germinated rapidly, but with some evident curtailment as a result of the higher temperatures. This leaves little doubt that heat injury of Douglas fir seeds may occur somewhat sooner than with lodgepole pine. In 1922 (Table 14) a steady temperature of 70° gave results practically equal to those attained in the greenhouse at 57°–78°. Even the 58.8° steady temperature was effective, if slow; whereas the 80° test was prompt, but the total germination was evidently curtailed. Probably 70° may be taken as nearly an optimum temperature for Douglas fir, and wide fluctuations as not necessary. These facts are in agreement with the habit of the species of germinating in shaded places.

The western yellow pine test (Table 13) that started at the highest temperature must be taken as the best, both from the standpoint of promptness and completeness of germination. Although there was irregularity in the successive tests, in 1922 (Table 14) there is scarcely any difference between the results for 70°, 80°, and 57°–78° F. The total germinations occurring at 50° and 60°,[8] though accruing slowly, are much higher than was expected with this heat-demanding species.

[8] The poor and irregular performance at 60° F. is due to depredations of mice about 18 days after a promising start. It was not thought at the time that an appreciable number of seeds had been taken, but only a considerable loss of germinable seeds from this cause can account for the sudden falling off in germination.

It is, therefore, evident, that while western yellow pine does not require large temperature variations it is also not injured by high temperatures, which may be counted on to produce prompt germination. Probably its optimum temperature is nearer 80° than 70°.

Engelmann spruce was not considered in 1917. Seeds of this species from the Uncompahgre National Forest, Colo., were used in the tests of 1922. (Table 14.) Spruce seeds may be counted upon more than those of any other Rocky Mountain species except *Pinus aristata*, a companion of spruce at high elevations, to complete germination in a very short period. In this test, although they did not make a good showing at a temperature of about 50° F., at 60° germination was nearly completed in a short time. The surprising fact is that spruce germination shows no signs of curtailment by temperatures as high as 80° or by the extremes which may be experienced in the greenhouse with an average range from 57° to 77° F.

In a broad comparison with the other species mentioned, the striking thing about lodgepole pine is the impossibility of bringing out spontaneous germination of a large part of the seeds by any means so far tried. Fluctuating and reasonably high temperatures seem to be the necessary means for approaching even remotely this desideratum.

PROBABLE ERRORS IN SEED TESTS

In considering the germination data reported in this bulletin it is well to keep in mind the fact that the mathematical accuracy of seed tests is not very high. Under the methods which have been described, the sources of error may be roughly grouped into three classes, as follows: (1) The sampling error, (2) the time error due to variations from the standard heat and moisture conditions, and (3) the space error due to differences between various parts of the greenhouse. It is not a simple matter to segregate these factors, nor is it particularly important to do so. A single term which will show the probable compensated error from all causes is of greatest interest in the present study.

The sampling error may best be approximated by considering the weights of samples of seeds, each of which is supposed to be representative of the same large lot. While variations in weight are not necessarily followed by corresponding variations in germination, still the weights show clearly how difficult a matter is true sampling. Thus 14 samples of 500 lodgepole pine seeds each, counted out with ordinary care, showed a standard deviation [9] of 3.45 per cent from the mean weight, 7 samples showed a standard deviation of 2.95 per cent, and another group of 7 samples, a standard deviation of 3.32 per cent. The extreme individual variation among the 28 samples was 8.2 per cent. On the basis of the 3.32 per cent deviation of the last group, the probable error of any single sample of the lot is 2.2 per cent. This means that the individual sample is just as likely to exceed this error as to show a smaller error. The mean of 3 samples

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[9] The formulas used (*15*) are, respectively—

Standard deviation, $s=\sqrt{\frac{\Sigma d^2}{n-1}}$

Standard or probable error of the individual, $e=0.6745\, s$

Probable error of mean, $E=\frac{e}{\sqrt{n}}$

of this lot should not be in error by more than 1.29 per cent; that of 5 samples, by more than 1 per cent; and that of 8 samples, by more than 0.79 per cent.

The time factor is that which may result from inability to maintain constant conditions of moisture and heat in the greenhouse. Without doubt, the variation in the latter is particularly influenced by the occasional need for using artificial heat.

A test made with three related lots of seed, each sown repeatedly at intervals of about five weeks, from January, 1913, to August, 1914—in all, 14 times—gives some basis for estimating the time factor. The space factor also enters into this result, however, owing to lack of care in selecting the greenhouse space, for 4 of the tests in the east end of the greenhouse averaged 62.25 per cent, 2 in the center 68.95 per cent, and 8 in the west half 58.98 per cent, with a high of 63.6 per cent and a low of 53.1 per cent. Considering only the last group, and taking the average of the three lots tested at each period, the standard deviation for each period is 3.83 per cent absolute, or 6.5 per cent of the mean germinative capacity, giving a probable error of about 4.4 per cent in any single test. This error is due mainly to the time factor, though the sampling error and the space error are only in part compensated.

The space factor is due both to unequal lighting of the different parts of the greenhouse, creating a maximum variation of possibly 10 per cent, and to unequal heating of the tills on the north and south edges of the bench, as compared with those in the center. Possibly this latitudinal difference is not so much a matter of excess heat as of greater diurnal fluctuations on the edges of the bench, these being likely, as has been shown, to stimulate the germination of lodgepole pine. It will be recalled that the bench space is five tills wide. The following average germination was obtained in the temperature tests of 1917, which have already been described. Two thousand five hundred lodgepole pine seed were used in each position. The figures represent percentage of final germination.

Location:	Per cent
North-edge till	79.72
Intermediate till	75.24
Center till	76.80
Intermediate till	75.52
South-edge till	81.68
Average	77.79
Standard deviation due to position (absolute)	2.81
Percentage of average variation	3.61
Probable error due to position	2.43

By eliminating a single test affecting the second row from the north, and thus making the average for that row 79.4 per cent, these percentages are reduced about one-seventh.

The variables affecting any individual seed test are likely to be in part compensating. In the above-described attempts to define these three factors separately the intention has been to eliminate others in part by considering only group averages.

Fourteen lots of seed from different sources were sampled eight times each and sown three of them on April 17, 1914, and the remaining five, because of lack of space, 42 days later. The earlier sowing was in the easterly part of the greenhouse, while the later sowing was more generally distributed. In neither period was any systematic effort made to obtain compensating distribution for the samples representing each lot. There were at work, then, the sampling factor, the space factor, and a small time factor. In Table 16 the variations are shown for 5 of the 14 lots, namely the 2 of highest germination, 1 as near average as possible, and the 2 of lowest final germination.

TABLE 16.—*Variations in final germination percentage, single tests of 500 lodgepole pine seeds each, 1924*

Tests of eight samplings	High germination		Intermediate germination, lot 237	Low germination		Average ratio
	Lot 247	Lot 240		Lot 238	Lot 246	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Sown Apr. 17:						
Test A	77.6	68.2	63.4	39.2	[1] 15.0	
Test B	81.8	71.0	62.6	43.8	39.2	
Test C	86.0	75.0	66.2	38.0	41.0	
Sown May 29:						
Test D	80.8	78.8	61.8	40.6	42.0	
Test E	80.0	75.8	62.8	36.8	36.0	
Test F	82.6	73.8	59.8	39.8	37.2	
Test G	79.4	69.8	59.0	36.2	41.4	
Test H	77.6	65.2	54.6	35.4	35.0	
Average	81.85	72.20	61.35	38.70	38.83	
Sum of deviations	24.10	29.20	20.10	17.20	16.57	
Standard deviation	4.00	4.46	3.44	2.75	2.79	
Ratio standard deviation to average	4.89	6.18	5.61	7.11	7.19	6.20
Ratio of probable error to the average	3.30	4.17	3.78	4.78	4.84	4.18

[1] This test eliminated from final calculations since its deviation is more than three times the probable error computed before its exclusion.

There is some indication from the data presented that the probable error in any single germination test is a larger percentage of the total germination for seed of poor quality than for seed of good quality, and it might well be assumed that seed of poor quality is more difficult to sample correctly. However, examination of the entire 14 tests from which these 5 have been selected does not give much evidence of such a difference.

Considering, then, the average probable error, it may be said that the chances are even that in a single test of 500 seeds the final germination at 62 days will be influenced more than 4.2 per cent of its own correct value by variable factors such as have commonly occurred in this work. An average obtained by testing 3 samples should not be in error more than 2.41 per cent; one of 5 samples, not more than 1.87 per cent; and one of 8 samples, not more than 1.48 per cent.

It should be pointed out, however, that the time element in these errors represents the sum of compensating errors over a period of 62 days, so that even larger errors are to be expected if shorter periods are considered, such, for example, as the germination in 31 days or the time of the first or the most rapid germination.

CHARACTERISTICS OF GREENHOUSE GERMINATION

THE AVERAGE OR NORMAL RATE OF GERMINATION

As has been pointed out in the discussion of the effect of various temperatures, the germination of lodgepole pine is comparatively sluggish. The first germination occurs almost as promptly as with other species; that is, within 9 to 10 days of the time of sowing, and frequently as early as the seventh day. The peak of the germination, also, comes within a few days after the beginning. The striking difference between lodgepole pine and its associates lies in the fact that with lodgepole pine a small residue of the germinable seeds spreads its activity over many weeks.

However, for any practical purpose it will certainly be safe to consider as final or capacity germination that which has occurred up to the end of a 62-day period. The great majority of the experimental tests have been carried for this period. In considering what may be the full potentialities of germination, Figure 17 should be referred to, the test there represented being comparable with others that have been run for long periods.

There are found to be 413 tests from which the characteristic behavior of lodgepole pine seed may be derived, not considering the late tests in the seed-extraction experiments, of which the results have already been given, and which it is preferable to omit because they are not needed here and might introduce the factor of age of the seed.

These 413 germination tests are taken mainly from the extraction experiments with Medicine Bow, Arapaho, and Gunnison cones, but also from a number of ordinary extractions on scattered forests, as brought together for the field tests of 1914. It is safe to say that as a whole they present a good average of seed conditions as affected by extracting processes.

The general average germination in Table 17 shows 205,270 seeds tested and 130,040 germinated in 62 days, or 63.4 per cent average germination. Of this total germination, 76.6 per cent occurred in the first 20 days and 90.1 per cent in the first 30 days, and about 10 per cent were scattered over the last 32 days, with a very gradual decrease in rate.

TABLE 17.—*Characteristics of lodgepole pine seed germination as shown by tests in the greenhouse from 1912 to 1914*

Quality group	Tests	Seeds tested	Seeds germinated	Mean germinative capacity	Average time of start	Peak	Rate at peak [1]	Total at peak [1]	March of germination [1]— In 20 days	In 30 days	In 40 days
	Number	*Number*	*Number*	*Per cent*	*Days*	*Day*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Final germination, 75 per cent and over	80	43,953	35,275	80.3	8.87	11	11.33	25.4	84.8	94.2	97.4
Final germination, 60-75 per cent	179	89,500	60,213	67.3	9.37	12	9.57	30.0	77.9	90.8	95.2
Final germination, 45-60 per cent	91	44,817	24,410	54.5	9.81	12	8.29	24.7	68.0	86.6	94.3
Final germination, under 45 per cent	54	27,000	10,142	37.6	10.30	12	7.23	16.8	58.7	80.8	91.6
Total or average	413	205,270	130,040	63.4	9.48	12	9.56	30.2	76.6	90.1	95.3

[1] For more ready comparison of the different grades the percentages of the whole germination are given rather than the absolute percentages based on number of seed sown.

EFFECT OF QUALITY OF THE SEED ON THE GERMINATION RATE

If it is true that the amount of germination occurring in a limited period is a better index of practical values than the capacity germination, then it will be worth while to observe whether the amount of germination in a period of 30 days, for example, bears any constant ratio to the final germination. It is obvious that for individual tests this ratio might be considerably affected by germination conditions, since these can not be kept absolutely uniform from day to day. Hence the need for considering group averages.

The 413 tests which have just been considered for a general average have been divided into four groups showing final germination percentages of over 75, of 60 to 75, of 45 to 60, and of less than 45, respectively. (Table 17.) By expressing the periodic germination as a proportion of the whole or final germination, comparison is greatly facilitated. These comparisons are brought out also in Figure 18.

The relations between different grades of seed, it will be seen, are very simple and fairly regular. The lower the percentage of final germination, the slower the beginning, the later the peak of germination reached, the lower the peak, and the greater the residue to be

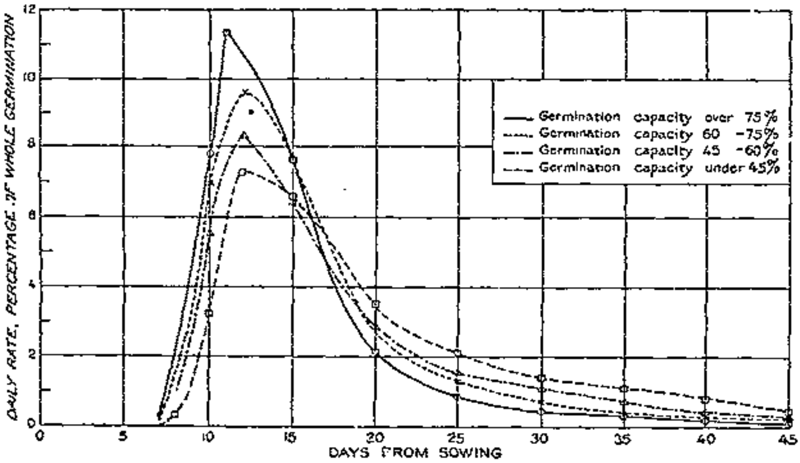

FIGURE 18.—Characteristic germination of different grades of lodgepole pine seed

distributed over the remainder of the period. The last-named fact suggests that if the total period were greatly extended the differences between grades might be reduced; but if the current rates of germination at 50 or 60 days are considered it will be seen that a longer period would probably add nearly equal numbers of germinable seeds to each group, and hence would not materially alter the relations of the groups.

Another suggestion from these parallel relations of the groups is that possibly certain greenhouse conditions may tend to delay the beginning of germination and thereby cause a low final germination. While this may occasionally be the cause of a poor showing, comparison of identical seed lots shows that a delay of several days in the starting does not necessarily lead to poor final results, and that, generally speaking, by the end of the 62-day period each seed lot will have experienced nearly average conditions.

From the relations shown to exist between final germination percentage and intermediate rates, it must be fairly apparent that a low final germination percentage not only means that some of the seeds have completely lost their vitality and viability but that nearly all of the seeds have had their vitality reduced. Hence, if absolute vigor of the individual seeds is an important element in their success under natural conditions, it may be said that the value of a seed lot decreases geometrically as the final germination decreases. However, it will be seen that under certain circumstances, at least, this suggested valuation does not work out.

EFFECT OF SEED SOURCE ON THE GERMINATION RATE

Early experience in the testing of Douglas fir seeds brought out a sharp contrast in behavior between seeds from Wyoming and seeds from Colorado. Wyoming seedlings when planted in the field proved to be so poorly adapted to existing local climatic conditions as to lead to the presumption that the Wyoming form represented a fairly distinct climatic variety of Douglas fir and that such adaptations as it had developed were reflected in its seed behavior.

It was expected that similar differences would be found with lodgepole pine seed, although it was early noted and reported by the writer (*2*) that apparently the Wyoming and Colorado seed of lodgepole pine differed little in initial vigor of germination.

The most careful study of this subject that it has been possible to make brings out no significant differences between lodgepole pine seeds from Medicine Bow, Arapaho, and Gunnison National Forests that can be considered characteristic regional differences. It is, therefore, necessary to leave conclusions on this point to be derived indirectly from the study, in the following section, of the comparative field and greenhouse behavior of an assortment of seeds studied in 1914.

STUDIES OF FIELD AND NURSERY GERMINATION

Before attempting to determine finally what characteristic of germination may give the best indication of the practical value of a lot of seed it will be desirable to observe the results of parallel tests of seed in the greenhouse, nursery, and field.

In the spring of 1912, 10 lots of seed of various sources and grades, which had previously been tested for other purposes, were selected for field tests. All of the seed lots were from cones of 1911 collection, and most of them had received kiln treatments of about average character. Because of the lack of a sufficient number of greenhouse tests to establish fully the germination characters of these seed lots, it is impossible to interpret the results of nursery and field sowings except in a very broad way, and it is, therefore, useless to report any of the original data. These tests may be said to show merely that under adverse field conditions seed of low germinative capacity is almost worthless, while under more moderate conditions, such as may obtain in a nursery, the best seed gives results only slightly better in proportion. More satisfactory tests were made two years later.

FIELD AND NURSERY TESTS IN 1914–15

NURSERY TESTS AT FREMONT

Nursery tests conducted at Fremont, beginning with a sowing in May, 1914, involved 14 lots of seed, 1,000 seeds of each lot being sown, the germination being carefully recorded through both the current and following growing seasons.

The seed was tested eight times in the greenhouse, three of these tests being made in one group and five about a month later. There is, therefore, assurance of very good average germination figures. While the seed for greenhouse tests was being obtained, the seed for the nursery sowing, as well as that for the field tests described later, was counted out at intermediate stages, thereby greatly reducing the probability of material differences between the seed used in the field and that tested in the greenhouse.

There seems to be no basis for questioning the results of the work during 1914–15, except for the discovery, after the work was well started, that seed lot No. 241 contained a considerable portion of Engelmann spruce seed. This was probably responsible for the rapid rate of germination of this lot in the greenhouse, but it is not seen that the presence of the spruce seed should otherwise affect the results appreciably.

The second section of Table 18 shows the germination of the seed in the nursery by major stages. Any further analysis of the progress of germination would probably be useless. The table also brings out the important comparisons between nursery and greenhouse germination.

TABLE 18.—*Comparative study of greenhouse, nursery, and field germination of lodgepole pine seed, 1914–15*[1]

GREENHOUSE GERMINATION

Lot No.	Source of seed	Average capacity (62 days)	Average energy (31 days)	Ratio of energy to capacity	Average energy first 15 days
	Northern Wyoming:	*Per cent*	*Per cent*	*Per cent*	*Per cent*
233	Bridger	69.4	59.2	0.853	42.0
239	Washakie	66.6	61.3	.920	37.6
240	Washakie	72.2	68.2	.945	50.1
	Average	69.4	62.9	.906	43.2
	Southern Wyoming:				
234	Hayden	70.8	65.4	.924	46.4
235	Hayden	54.0	49.6	.919	36.8
237	Medicine Bow	61.4	57.8	.941	38.3
238	Medicine Bow	38.7	32.9	.850	15.3
	Average	56.2	51.4	.915	34.2
	Northern Colorado:				
241	Colorado [2]	65.8	62.5	.950	47.5
245	Arapaho	62.4	58.2	.933	37.5
244	Arapaho	61.5	57.8	.940	41.2
	Average	63.2	59.5	.941	42.0
	Central Colorado:				
242	Leadville	56.2	53.2	.947	33.2
243	Leadville	63.7	61.6	.967	42.2
246	Gunnison	38.8	35.7	.920	20.9
247	Gunnison	81.8	78.6	.961	58.2
	Average	60.1	57.3	.953	38.6
	All Wyoming	61.9	56.3	.916	38.1
	All Colorado	61.5	58.2	.946	40.1
	Average	61.7	57.3	.929	39.1

[1] 1,000 seeds sown in each nursery and field test. [2] Partly Engelmann spruce seed.

TABLE 18.—*Comparative study of greenhouse, nursery, and field germination of lodgepole pine seed, 1913–15*—Continued

NURSERY GERMINATION

Lot No.	Germination of first 60 days		First season's germination		Two years' total germination	Ratio of total germination—	
						To capacity	To energy
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Per cent*
233	61	21.3	141	37.1	390	0.548	0.642
239	91	25.1	168	46.3	363	.545	.592
240	102	24.5	175	42.0	417	.578	.612
Average	91	23.6	161	41.8	387	.557	.615
234	94	22.0	139	32.6	427	.603	.653
235	70	26.7	133	50.8	262	.485	.528
237	84	24.0	161	46.0	349	.568	.605
238	45	21.8	130	63.1	206	.532	.626
Average	73	23.6	141	43.1	311	.553	.605
241 [1]	128	35.6	209	58.1	360	.547	.576
245	84	28.8	159	54.5	292	.408	.502
244	119	35.0	205	60.3	340	.553	.587
Average	110	33.1	191	57.6	331	.523	.555
242	135	38.8	231	66.4	348	.613	.654
243	140	40.8	236	68.8	343	.538	.557
246	131	50.6	202	78.3	258	.604	.722
247	275	50.3	416	76.1	547	.608	.696
Average	170	45.2	271	72.4	374	.622	.657
All Wyoming	81	[3] 23.5	150	[3] 43.6	343	.555	[3] .610
All Colorado	145	[3] 40.7	237	[3] 66.6	355	.580	[3] .610

FIELD GERMINATION AT SOURCE

Lot No.	Germination of seed sown—			Ratio of total germination to capacity germination—		
	First 60 days	First season	Two years' total	First 60 days	First season	Two years' total
	Per cent	*Per cent*	*Per cent*			
233	57.2	59.7	62.2	0.824	0.860	0.896
239	0.2	0.3	25.2	.003	.005	.378
240	2.1	2.2	[4] 2.2	.029	.030	.030
Average	19.8	20.7	29.9	.285	.298	.431
234	18.0	20.0	35.8	.267	.282	.506
235	4.5	4.5	9.2	.083	.083	.170
237	0.1	0.2	37.2	.002	.003	.606
238	0.0	0.0	19.9	.000	.000	.514
Average	5.9	6.2	25.5	.105	.110	.454
241 [1]	49.0	53.8	55.8	.745	.818	.848
245	7.6	11.0	32.3	.122	.176	.516
244	9.9	13.7	33.3	.161	.223	.541
Average	22.2	26.2	40.5	.351	.414	.640
242	10.1	10.4	13.0	.180	.185	.231
243	20.5	20.8	27.5	.322	.327	.432
246	0.2	4.3	4.6	.005	.111	.118
247	3.9	4.5	20.7	.048	.055	.253
Average	8.7	10.0	16.4	.145	.166	.273
All Wyoming	11.9	12.4	27.4	.192±.077	.201±.081	.443±.073
All Colorado	14.5	16.9	26.7	.235±.064	.275±.060	.435±.063

[1] Partly Engelmann spruce seed.

[3] The percentages here given are not the arithmetical means of the percentages given above, but are computed from the whole numbers representing averages.

[4] Data not properly obtained. Casual observation showed no germination early in 1915, hence same figure is used as at end of first year.

The ratios of total nursery germination to greenhouse average capacity, shown in the second section of Table 18, exhibit so little variation between the quality groups that where a mixture of Colorado and Wyoming lots is involved the ratio for any group might safely be placed at about 0.575. However, the ratio for Wyoming seed alone can not be placed quite so high, and it is apparent that on the whole the Wyoming seed is not quite so well adapted to field germination, at least under the conditions provided in these tests.

The ratios of nursery germination to the greenhouse energy or germination in 31 days show about the same degree of variation, but it is a little more difficult to reconcile the quality groups. (Fig. 19.) It must be remembered that in this comparison there is greater opportunity for unexplainable variations in greenhouse germination.

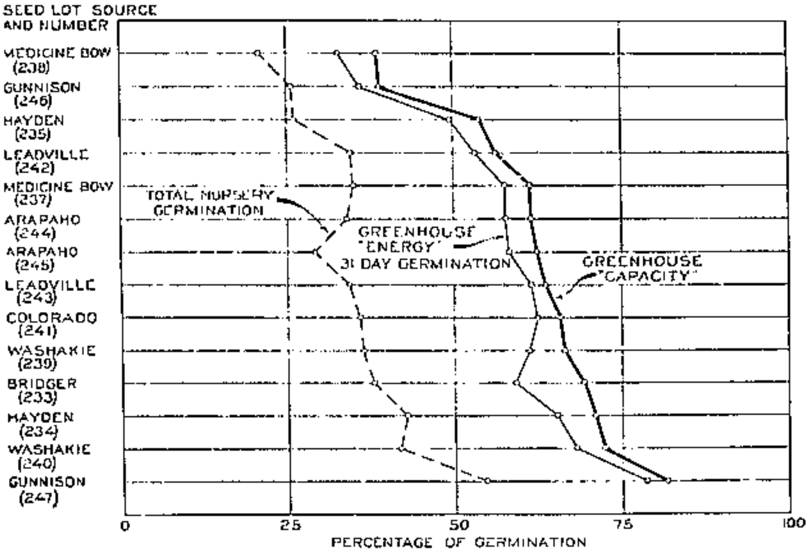

FIGURE 19.—Relation of nursery to greenhouse germination of lodgepole pine seed, 1914–15

But the probable reason for the high ratio of nursery to greenhouse energy germination in the poorest group of seed lots lies in the fact, already demonstrated for lodgepole pine seed in a broad way, that the poorer seed lots do not adequately express their potentialities in a short period. In other words, these data make it fairly clear that where favorable conditions for germination can be maintained for a long time (in the present tests two years) the nursery germination to be expected will be more nearly proportionate to the total capacity of the seed than to any other criterion.

While, in general, the total germination occurring in the two years is closely proportionate to the capacity of the seed, the percentage of this germination occurring at any stage is very variable with the different lots and does not seem to decrease or increase regularly with change in the quality of the seed. The striking similarity between the percentages at different stages of the 2 lots of Gunnison seed, representing the best and poorest seed of the 14 lots, leads at once to the presumption that the source of the seed may have more bearing on its rate of germination in the nursery than does quality. This similarity is apparent, though not so consistent, in other groups of seed from common sources. (See lots 242 and 243, 239 and 240, 244 and 245.)

Thus all of the seed lots from Colorado forests produced more than 50 per cent of their nursery germination during the first season, averaging 66.6 per cent, the 4 lots from central Colorado especially showing high proportions. The 7 Wyoming lots produced on the average only 43.6 per cent of their whole germination the first season. Only 2 of the 7 lots of Wyoming seed produced more than 50 per cent. Since these exceptions were from the southern part of Wyoming and represented poor grades of seed, it may readily be assumed that the high percentage is due to deterioration of the seed and low second-year germination.

If a period is considered in which roughly the same amount of germination occurred in the greenhouse, say 15 days, it is found that in this period the Colorado seed attains a considerable lead, amounting to 4 per cent of the whole germination—a lead well maintained until after the middle of the greenhouse period.

When this short-period germination is compared with that occurring in the nursery in the first year, wide variations in the ratios appear, as might be expected in view of the much greater time element in the one set of data than in the other. There is an unmistakable tendency toward higher nursery germination of the poorer seed lots because of this time factor. Lot 238, for example, shows a very high ratio for a Wyoming seed lot, but on examining its record, in Table 18, it is seen that lot 238 did not accomplish the better half of its germination until the second half of the first season, while all of the other lots accomplished more in the first half.

The important item, however, is that the consideration of a shorter period brings out clearly the contrast between Wyoming and Colorado seeds, the Wyoming seed showing a slight sluggishness under the very favorable greenhouse conditions and a more marked sluggishness in the nursery, leading to the supposition that under less favorable field conditions they might suffer a considerable net loss through delay.

FIELD TESTS AT THE SOURCES OF SEED LOTS

The behavior of these seeds lots when sown at a common point makes it possible to interpret more intelligently their behavior when sown at their respective points of origin.

The sowings in the field were executed with the greatest uniformity possible, in a manner very similar to that of the 1912 field sowings at Fremont, and were all made at approximately the same time climatologically. (Pl. 3, C.) Even if absolute uniformity of sowing were possible at a number of points great variations might be expected in germination due to the time of occurrence of precipitation, variations in soil, etc., so that only the final germination can be of much interest. In the third section of Table 18 these data are divided by stages as far as seems justified by an examination of the detailed records, which, with one exception, were posted approximately once each week through both the first and second seasons.

Examination of these figures in Table 18 shows that even at the end of the second season correlation between the actual capacity of the seed and its performance in the field seems to be lacking. For example, seed lots of practically the same greenhouse value, sown in two contiguous northern Wyoming forests, germinated 62, 25, and 2 per cent, respectively. A point worthy of note in the early germination is that where two seed lots were sown side by side (the Arapaho, Medicine Bow, and Leadville (pl. 3, B) sowings being of this kind), the behavior of the two lots is somewhat similar. Where two seed lots were sown very close together, but in different soil conditions, as on the Washakie, Hayden, and Gunnison National Forests, there is much less similarity within the pairs. This naturally leads to the supposition that soil must play a very important part in germination. On this point all attempts have failed to correlate the germination of the individual lots with soil qualities, except to establish a very broad relation between poor germination and heavy soil, as measured by the soil's capillarity or moisture equivalent. The two Gunnison sowings are striking exceptions and serve to show the extent to which climatic, as well as soil factors, must influence the results.

Because of the large number of factors which must have affected the field germination, the use of group averages must be resorted to or the possibility of correlation entirely abandoned. Considering first, in Table 18, the broad comparison in field germination between all Wyoming and all Colorado seed lots, it is to be noted that the former show considerably less germination throughout the first season, although at the end of the second season the Wyoming sowings are slightly in the lead. Irregular as are the individual results, this broad relationship can not be overlooked because it signifies the same quality that was exhibited in the nursery, namely, a tendency of the more sluggish Wyoming seed as defined by early greenhouse germination, to delay germination to a much greater extent in the field. The result is not, however, what was expected, in that the total germination of the Wyoming seed is not decreased by reason of this sluggish quality.

Two rather obvious conclusions may be drawn.

It must be admitted that the Wyoming field conditions are in some sense more favorable for the lying over of the seed without deterioration or destruction in the lying-over period. This advantage may possibly arise from somewhat more equable temperatures, which, while failing to stimulate germination, at the same time result in more equable moisture conditions over long periods. Be that as it may, the conclusion can now hardly be avoided that the four regions represented in Table 18 are differentiated, and that their climatic conditions have differentiated the lodgepole pine seeds which are produced within their confines. On the basis of the final results in field germination, no line can be drawn between northern and southern Wyoming, but it can be quite confidently said that northern Colorado presents the best field conditions and central Colorado the least favorable conditions. The seed from central Colorado shows a tendency in the greenhouse to respond quickly to favorable conditions, but since it is probable that this adaptation has not fully developed to meet the unfavorable field conditions it is readily seen that this, the southernmost extension of lodgepole pine in the Rocky Mountains, presents the most difficult situation for natural reproduction.

On the other hand, if all of the Colorado field tests are compared with all of the Wyoming tests, the results are essentially the same, about 44 per cent of the possible germination. This leads to the second important conclusion, namely, that for rating the value of the seed for use within the region of its source the germinative capacity in the greenhouse is the best criterion, unless prompt germination in the field can be shown to be very necessary to success, as, for example, where rodents are very numerous. It is not, however, believed to be feasible to make allowance for such factors except on the ground when the seed is sown.

SUMMARY

This bulletin deals with the general qualities of lodgepole pine cones and seed; with two studies of the mass production of seed over a period of 10 years; with characteristics affecting the opening of cones by air drying and artificial heat; with the quality, quantity, and comparative costs of seed obtained by different methods; and, finally, with the germination behavior of lodgepole pine seed under both greenhouse and field conditions.

PRODUCTION

Lodgepole pine seeds average about 100,000 to the pound, but vary in size, dryness, and weight between 85,000 and 160,000. Seeds of good quality are denoted by a black or slightly grayish color, brown being an indication of low vitality due to incomplete development. The size of the seed does not seem to be important.

The seed production of lodgepole pine in two localities from 1912 to 1921, inclusive, averaged 320,000 germinable seed per acre-year for the central Colorado area and 73,000 for the southern Wyoming area, although the Wyoming stand is larger, more open, and better adapted to seed production. The difference is probably due to climatic factors which destroy more young cone flowers in the Wyoming area, and particularly to freezing in the early summer.

The production of seed by lodgepole pine is apparently greater than the production of seed by western yellow pine and Douglas fir in the Rocky Mountain region, and complete crop failures are fewer, but the numbers are of the same order of magnitude for all species. One area of Engelmann spruce has exceeded the better figure for lodgepole pine.

One of the greatest aids to the natural reproduction of lodgepole pine is the retention on the tree of unopened cones equivalent to three or four average yearly crops, which, in the event of fire, release an accumulated supply of seeds to fall on ground cleared of other vegetation. Old cones should, however, never be gathered unless in prime condition, for they are difficult to open and give very low yields of seeds in various stages of deterioration. The retention of cones by trees apparently results in part from crowding in the stand and to some extent from the poorer quality of the soil.

When trees growing in the open show a decided tendency to retain their cones it may in all probability be ascribed to an unfavorable soil. (*12.*)

The production of seeds by lodgepole pine in a given locality is not periodic in the sense that a good crop weakens the tree and is therefore followed by one or more poor crops. The production in any year appears to depend largely on the occurrence or absence of low temperatures in the previous year when the cone flowers emerged. Also, other climatic factors may affect the crop in its later development. In general the species may be expected to decrease in fecundity at high elevations where freezes occur throughout the year, but there is yet no direct evidence on this.

As is common in the forest, dominant large-crowned trees produce the largest seed crops, but not necessarily any better seed than that from smaller trees. In a comparatively open stand like that on the Medicine Bow National Forest there are usually fairly full-crowned trees which rank only as intermediate or oppressed in height but which are capable of bearing some seed and probably of improving materially after the stand is opened up by cutting. These are the trees which may be left, both from the standpoint of seed production and growth potentialities.

The application of these facts is more important in seed collecting for reforestation purposes than in forest management. In the cutting of lodgepole pine by any system the aim must be not to encourage too much reproduction, as this would give stagnated stands at an early age. It is difficult to conceive of conditions in which there will not be ample seed for the necessary reproduction, if both old cones and possible future crops are intelligently utilized.

EXTRACTION

Experiments in seed extracting started in 1912 and in 1914 employed kilns in the form of a hollow column. The cones were placed in single layers on trays within the kiln, through which a steady current of hot air rose by natural forces. The rapid opening of cones by this treatment showed that the essential requirement of extracting is to bring a supply of dry air steadily to each cone through free movement of the air current. High temperature without sufficient air circulation for effective drying represents an entirely erroneous conception of the objectives of artificial treatment.

Every consideration points to the desirability of small and simple extracting plants rather than large ones complicated by much machinery.

In air drying a large part of the moisture in the cones is lost in the first few months, but slow drying may continue for 15 months. When permitted to air dry under moderate conditions many well-developed cones begin to open almost immediately. The failure of cones to open under such conditions must be taken as evidence of incomplete development.

Cones from a siliceous soil (Medicine Bow) dried more quickly, to a lower point, and with much wider opening of the scales than cones from a limestone soil which were less perfectly developed.

Analysis of volume expansion of the cones indicates that opening under artificial treatment is the direct result of loss of water. The amount of water lost is the important thing; the rate is of less importance. Cones which have air-dried for a long time without opening must, because of their low water content, be brought to a very dry condition to produce the necessary change; and it is in creating this dry condition, through low relative humidity of the surrounding atmosphere, that high temperatures are effective and necessary.

In the successive extractions of 1912–13 the best yields of seed were obtained from the freshest cones, and there is reason for believing that the cone opening is most complete at this stage. These cones, however, had had considerable opportunity for air drying before the first artificial treatment. Judged both by the quantity and quality of seed obtained, an extracting temperature not exceeding 140° F. is indicated for fresh cones, whereas, when the cones become decidedly dry, a temperature of 170° may be used safely and more effectively. In these tests about 40 per cent of the seed became available by air drying alone after about 19 months, but, except in the early stages, the seed so obtained were not superior in germinative capacity to the seed obtained after kiln drying the cones. Later, the free seed were probably affected slightly by molding.

In the successive extractions of 1914–15 the Medicine Bow cones, which were very green at the outset, yielded the poorest seed from the first extraction, and the Gunnison cones, although somewhat drier, also yielded poor seed at this stage, showing, with the qualified results for Arapaho cones, that extraction from very green cones is not at all desirable. When all the results are considered it is seen that four to six months of moderate air drying gives the best yields and quality.

On the basis of the averages of germination tests made immediately after extractions and up to two years after the cone collections, the seed from moderately air-dried Arapaho cones showed little difference in germination as a result of different extracting temperatures. Starting with very green cones from the Medicine Bow, in the first extraction a temperature of 170° F. was most effective and beneficial, apparently because the seeds needed to be dried, but, as a whole, the 140° extractions gave the best results. With drier cones from the Gunnison, which apparently give up their water less readily, a temperature of 170° gave by far the highest yields, slightly inferior germination, and slightly the best yields of germinable seeds. After prolonged air drying a temperature even of 200° gave very satisfactory results.

Much indirect and direct evidence points to the fact that lodgepole pine seeds are not mature at the end of their second season's growth, and hence are benefited by artificial heat and to some extent at least by the removal of moisture. The most direct evidence was obtained by drying seed for four hours at 170° F. after they had been removed from the cones by the regular treatments. The most marked benefit was noted with the seed from the extractions of green Medicine Bow cones, which without this drying apparently contained too much moisture to keep in the best of condition. With most seed, however, the heat required for ordinarily efficient extraction has an immediate effect in high germinative vigor; in only a few instances is any deterioration of the seed plainly traceable to the effects of high temperatures.

All of the evidence points to the conclusion that the best temperature for cone treatment, from the standpoint of net yields of germinable seed, is that temperature which, with free air circulation and after the seed has had four to six months of preliminary drying, will produce a complete opening of the cones in not more than six to eight hours. The drier the cones become before this treatment the higher must the temperature be. The two objectives in any treatment of lodgepole pine cones must be, first, to accomplish the drying and ripening of the seed, which apparently proceeds either in a naturally warm building through a period of several months or in an artificially heated kiln in a much shorter period; secondly, to apply such artificial treatment as will cause the reasonably rapid drying of the scales of those cones which are least perfectly developed and lack "life."

Theoretically, the process of opening cones by artificial heat is, first, one of evaporating the freer moisture and perhaps some volatile oils contained in them; then a process of extracting the unfree moisture which is held by the cell walls and cell contents; finally, the energy of artificial heat is almost certainly consumed in producing chemical changes in the seeds and probably also in the cones, corresponding to ripening processes which occur in fruits, twigs, etc., in sunlight. There is no direct basis for measuring the last item of consumption, but it appears to be a large one.

Because of the secondary uses described, the amount of heat required to open cones does not decrease in proportion to the duration of preliminary air drying. Nevertheless, air drying for several months, with a loss of perhaps one-half the original moisture of the cones, effects a very considerable saving in heat use. Beyond this point air drying does not have much effect, but should possibly be continued under certain circumstances because of other economies incident to conducting the extracting operations in warmer weather. By partially drying the cones before artificial treatment the effective capacity of any drying kilns should be increased, since the dry cones will less readily cool and saturate the air current. In addition, the fact that some of the cones are partially opened makes it possible to force an air current through larger masses of them.

A fact which is not easily comprehended by persons unfamiliar with physical principles is that the drying process really uses up the heat and by cooling the air decreases its capacity to take up moisture. It is for this reason that to produce prompt opening a fresh current of warm air must constantly come in contact with the cones. A bushel of fresh green cones may utilize about 20,000 B. t. u. of heat; after a year's air drying this requirement will be reduced to about 6,000 B. t. u., this unit being the amount of heat required to raise a pound of water 1° F. The larger amount will be represented by the heat given off in cooling about 28,000 cubic feet of air [10] by a change of 50°, or, if this is represented by an 8-hour process, about 60 cubic feet of air should be supplied each minute for each bushel of cones. In addition to the heat actually utilized, it may be expected that in any ordinary kiln as much or more will be lost by

[10] Computed for mountain conditions, barometer 22 inches.

radiation from the walls, so that the current of air will emerge from the kiln about 100° cooler than when it entered.

GERMINATION

The method of germination tests is considered to have an important bearing on the germination values of seed and on the statistical value of the information obtained for seed production, extracting methods, and comparative germination in the field. The essentials of the standard method attained are as follows: A medium of sand having a desirable acid reaction; seed covered with one-fourth of an inch of sand; moisture not closely controlled, but ranging between 6 and 10 per cent; temperatures controlled in an attempt to attain each day a minimum of 57° F. and a maximum of 83° at the depth of the seed.

Fluctuating temperatures are shown to be highly stimulating to lodgepole pine and to bring out the greatest germination. The optimum basic temperature is about 70° F. Other species considered also benefit by the fluctuating temperature, but are not so markedly dependent on it.

The relatively sluggish character of lodgepole pine germination is shown by the fact that under the best conditions obtained in a series of temperature tests 41 days were required to produce 80 per cent of the total germination of lodgepole pine seed, as compared with 11 days for western yellow pine seed, 11 days for Douglas fir seed, 10 days for Engelmann spruce seed, and 8 days for bristlecone pine seed, all from Colorado sources. This, however, is considerably slower than the usual germination of lodgepole pine seed.

It has not been possible to eliminate errors or variations to the extent that a single germination test can be relied upon for great accuracy. The sampling error alone is probably 2.2 per cent for any single sample, and factors which affect the final germination make the probable error of the result about 4 per cent of the true germination value. These errors are greatly reduced by using the average of a number of tests.

Considering the final or capacity germination, or that occurring in a period of 62 days, the averages of 413 greenhouse tests show that the various grades of seed may be distinguished not only by their total germinations but by their relative behavior at earlier periods. The better seed germinates more quickly, reaches a higher and earlier crest, and leaves a smaller proportional residue to be scattered over the later period. These qualities give the theoretical basis for differentiating the grades even more sharply by their germination in a limited period, on the theory that if germination in the field does not occur promptly it will not occur at all. But the field tests do not indicate that high germinative energy is particularly important except under decidedly adverse conditions. Elsewhere field germination is about proportionate to total capacity, except for seeds which have possibly been decisively injured and have a germinative capacity of less than 50 per cent. It is probable that sound lodgepole pine seed can lie on the ground or in the soil for long periods without serious deterioration, retaining the ability to germinate when it receives the proper stimulus. Scarcely more than 75 per cent of the capacity germination of lodgepole pine can be expected even under ideal nursery conditions.

Although in various other comparisons there have been indications that Gunnison seed germinates a little more vigorously in the early stages than seed of more northerly origin, a selected group from each of three regions whose extraction histories were well known and similar brings out no clear differences between any one group and the average or normal for seed of the same quality.

Nevertheless, preliminary to the field tests of 1914, each seed lot was so fully tested in the greenhouse as to bring out clearly its characteristics, and it was shown that Wyoming seed lots, which at 15 or 20 days in the greenhouse were 4 per cent behind an equal number of Colorado lots, at the end of the first season in the nursery showed a corresponding retardation. Wyoming lots completed but 44 per cent of their total germination the first year, while Colorado seed completed 67 per cent. This performance appears to be more definitely related to sources than to seed qualities, as indicated by total greenhouse germination.

Wyoming seed, when sown in its native habitat, made quite as good a showing after two years as Colorado seed sown at its source, indicating that lodgepole pine seed are to a slight extent adapted to certain conditions under which they have grown. Conditions prevailing in southern Wyoming in 1914 seem to have been especially conducive to lying over of the seed, yet the eventual germination was better than the average for all localities. Northern Colorado, best represented by the Arapaho National Forest, seems to have very favorable conditions for seed germination, while west-central Colorado, approaching the southern limit of lodgepole pine in the Rockies, has the least favorable field conditions, and the seed from this source shows the most spontaneous germination when conditions for germination are favorable.

The lesson to be taken from this study of germination is that no arbitrary basis for rating seed values is needed, for in any field work a great deal of judgment will be required to rate the conditions which will affect germination and seed loss, and precise measures will be useless. The most important item in seed use is to have seed fully adapted to local conditions in so far as nature has developed any adaptations. The seed should be taken from the locality in which it is expected the seeding will be done or the nursery stock planted.

APPENDIX

A MODEL SEED-EXTRACTING PLANT FOR LODGEPOLE PINE CONES

The ideal seed-extracting plant for most purposes is one of relatively small capacity, of very simple design, involving no mechanisms which can not be kept in order by the average workman, and embodying the principle of rapid drying by a current of hot air rising by natural draft through a fluelike kiln.

From experience with lodgepole pine seed extraction and the evidence from innumerable germination tests, it appears that certain principles should be followed in the construction of any seed-extracting plant using artificial heat. With proper adjustment of temperatures, these principles should apply equally well to cones of all species. They have already been applied successfully in the treatment of western yellow, Norway, and jack pine cones.

The basic principle of seed extraction by artificial heat is to dry the cones, rather than merely to heat them. This can only be accomplished where warm, dry air moves freely about each cone and is supplied in sufficient volume to carry off and replace the air so cooled or moisture laden as to be no longer effective for drying. Hence, the heating capacity of any given plant must be adjusted carefully to the volume of cones to be treated in any one charge.

For lodgepole pine cones the most efficient temperature is undoubtedly between 140° and 170° F. This is not a temperature which the cones will ordinarily attain to, but the temperature of the air where it is introduced into the kiln and first strikes the cones. The higher temperature—170°—is very effective; it causes no immediate injury, and only slight deterioration of the seed is perceptible through a period of several years' storage, except possibly when very green cones are treated. For other species, however, until more is known of them, somewhat lower maxima should be adhered to, forcing the drying rather by good ventilation than by excessive temperatures.

The process of removing water from the cones must be accomplished in a reasonably short time if the cones are to be opened satisfactorily. If more than eight hours are required for kiln drying the process is inefficient. Lodgepole pine cones may be dried so slowly that when they are later subjected to a high temperature they do not contain sufficient moisture to show any "life." Hence, preliminary air drying should not go too far. It is possible, however, that such cones as those of white pine, of which both the cones and seed appear to contain much water, must be dried more slowly than lodgepole pine. Little is known of the effect of artificial heat on the germination of seed of that class.

Since fresh green cones kiln dry more readily than cones already partly dried, they can be exposed first to air which has been partly cooled and moistened by passing over other, drier cones, and may later be moved toward the current coming directly from the furnace. This requirement calls for arrangements for moving the cones usually from the top toward the bottom of the kiln by regular stages.

Since degree of drying is the important thing in attaining the mechanical effect on the cone scales, the greatest efficiency will be attained only with a reasonably high temperature which causes a low relative humidity, but this must be combined with free and rapid movement of the air.

As drying proceeds and cone temperatures approach that of the air, there is increasing tendency for the seeds to become heated and to be dried. In order to avert excessive heating with species which are not benefitted by it[11] the seed should be shaken from the cones at frequent intervals as the cones open and removed to a cool container. If the larger part of the seed is removed from the kiln as soon as released, then one may with less hesitancy use a higher temperature on the rest of the cones.

ESSENTIALS OF THE KILN

The kiln walls should be well insulated so that the heat of the air current may be used up in evaporating water, not in radiating into the room.

[11] Seeds from fresh lodgepole pine cones are apparently benefited by considerable drying but after air seasoning of the cones this becomes unnecessary.

The air current must be compelled to move over and around each cone, not merely over a mass of cones, and must be given no opportunity to escape without coming into contact with them. At the same time the air current must not be too severely choked back by having little space between the cones, else it will move too slowly and become too moist to dry them effectively. All of these conditions are most simply and naturally met in a vertical kiln, in which the trays, covered on the bottom with coarse wire cloth, fit close inside the walls of the kiln. In each tray should be spread a single layer of cones. To remove the seed from the cones frequently enough to avoid any possible injury from the heat some form of agitation must be used.

A MANUALLY OPERATED KILN

The following specifications are for a simple, manual, 1-man equipment, very similar to that of the experimental kiln previously described. Such a kiln has a capacity of 15 bushels or more each 8-hour day, and may be built without any considerable initial outlay or operating expense.

The trays for the proposed kiln are 30 in number, set up in two stacks of 15 each, which are reached by opening the doors on the two opposite sides of the kiln. (Fig. 17.) As the stacks extend only 7 feet above the floor, the highest trays may be reached from a movable step 1 or 2 feet high.

Each tray is 4 feet long and 2 feet wide (these dimensions facilitating handling by one man), and is expected to hold approximately one-half bushel of cones. The sides and back end of the tray are 2 inches high, the front face 4 inches. The trays rest on cleats 2 inches high running through the kiln from side to side. The height or depth of these cleats may be diminished in order to permit thin strips to be nailed on the bottoms of the trays after the hardware cloth has been tacked on. The faces of the trays should fit together snugly, and a cleat should close the gap between the lowest tray and the doors. The outer doors will, of course, prevent the complete escape of such air as leaks out between the trays.

In operation, the fresher cones are placed on the top trays of the stack. Even if all trays are filled with fresh cones, those on the bottom trays will be opened first, and, after several hours, one or two of these trays may be removed, and the cones dumped on a screen. But first, working from the top down, each tray should be shaken moderately, the cones spread evenly again if they have bunched, and the tray pushed back in place. This process brings all the loose seed to the bottom of the kiln, where they will fall on the floor. As trays are removed from the bottom, each of those above may then be moved down accordingly. Finally, the empty trays should be replaced at the top and quickly filled with fresh cones.

After this, the process of shaking the trays to liberate the seeds, removing the bottom trays on which the cones are opened, and moving all the others down, becomes an intermittent one to be repeated at least once each hour. It goes without saying that at the initiation of one of these continuous kiln runs, before the cones on the lowest trays are ready to be removed, all of the trays should be shaken several times.

The two stacks of drawers in the kiln should be operated independently since they may not proceed evenly, particularly if, as in so many furnace-heated houses, there is a tendency for the air current to cling to one side or the other of the kiln.

Further details of construction and operation are not so much matters of principles as of practicability and convenience.

HEIGHT, DRAFT, AND GENERAL EFFICIENCY OF THE KILN

Leaving the top of the kiln wide open is a great convenience in filling the empty trays moved up from the bottom and in itself interferes in no way with the drying of the cones. Unless, however, the furnace has been arranged to draw cold air directly from out of doors, ventilation in the roof above the kiln should be provided to prevent the warm, moist air from reentering the kiln and to promote working comfort in the room.

Too small an air current passing upward through the kiln is apt to result in the ineffective use of the heating capacity of the furnace and a dangerous temperature in the bottom of the kiln. In the light of principles here established it may confidently be said that it is safer and better to draw much air through the kiln at a moderate temperature than little at a high temperature.

In this situation the full capacity of the furnace may best be utilized by increasing the height of the kiln sufficiently or capping it with a sufficiently large flue so that it will draw the hot air away from the furnace more powerfully, increase the current, and thus lower the temperature at the point of entrance. This is an important point in the efficiency of the plant.

The question as to whether the capacity of the kiln may be increased by adding more trays at the top need not be answered arbitrarily. In the initial construction of a kiln according to this plan it would seem the part of wisdom

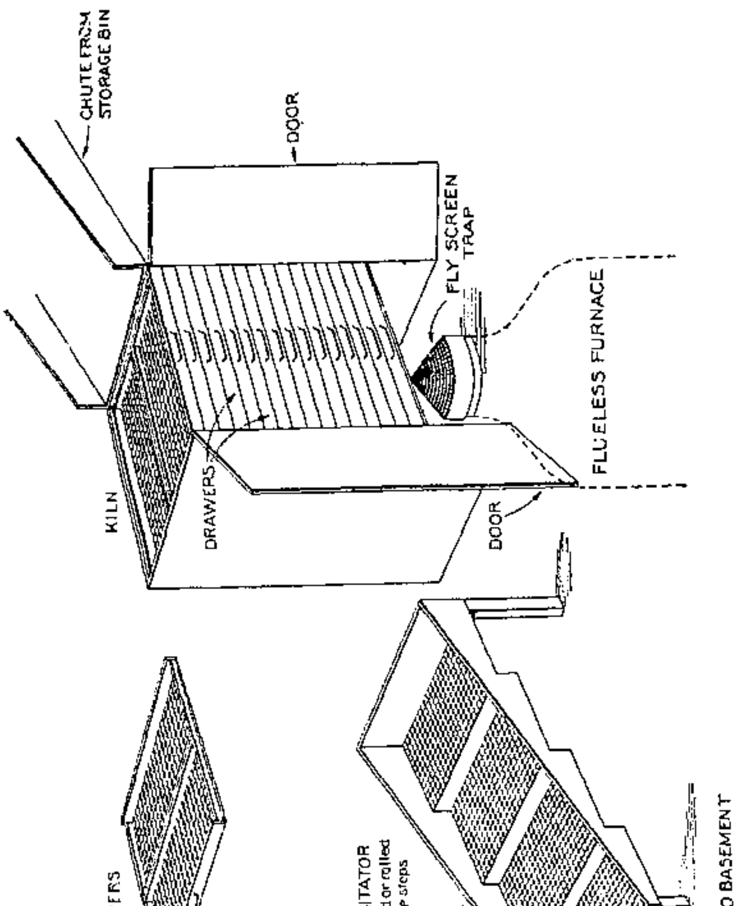

FIGURE 20.—Perspective view of manually operated seed kiln and cone agitator

to so build the walls that their height could be readily increased. Assuming that the kiln itself has been built high enough so that the air comes from the furnace with a strong draft and at a safe temperature, the air at the top of the kiln may be examined to determine whether its heat has been utilized to a reasonable degree. This, as has been pointed out, is not to be gauged by the temperature of the air so much as its moisture content or relative humidity. A wet-and-dry-bulb psychrometer held in the current of air above the cones (not in contact with them) for about five minutes should show a wet-bulb temperature at least 8°–10° F. below that of the dry bulb to indicate any further effectiveness. If there is not this much difference, it means that the air is already so nearly saturated with moisture that it can not be of much use for further drying.

If occasionally the draft from the furnace is unusually strong, so that the air is leaving the kiln still quite warm, the trays should be loaded more heavily; the additional cones will not only use more of the heat but will also choke down the draft. Thus it is seen that with the idea of full utilization of the heat always in mind the operator may to a considerable extent adjust the process to circumstances.

HOT-AIR INTAKE AND SEED SPACE

The kiln is shown in figure 17 as resting on the floor immediately above the furnace, with the hot air coming through the floor directly below the stack of trays. A metal flue rises 6 to 8 inches above the floor, and this is capped by a cone or hemisphere of fly screen, so that seeds dropping from the trays can not fall through to the furnace. There will, of course, be a strong tendency for the current of air to carry seeds and chaff away from the screen.

This arrangement directly over the furnace is obviously ideal in heating efficiency, but perhaps increases the fire danger and may overheat the seed chamber. If the floor over the furnace becomes very hot it must be well insulated from contact with the top of the furnace. Even then, frequent removal of the seeds may be necessary to prevent overheating. On the other hand, were the kiln farther removed from the furnace and the hot air brought to it in a duct which opened into the side wall of the kiln above the floor, the floor itself would be relatively cool and the seed would need be removed less frequently. Such a flue should have at least one-third of the cross section of the kiln itself, as should any flue placed at the top to carry off the moist air. The disadvantage of this arrangement may be that it sometimes makes one side of the kiln much hotter than the other.

GENERAL NEED OF INSULATION

Under ordinary conditions a kiln constructed of wood is far preferable to one of iron because less skill is required to do reasonably good fitting in the original construction, and repairs and changes are more readily made. The plan described is intended for a wooden kiln, but yet is entirely susceptible to adaptation to metal construction.

Wood is a fairly good nonconductor of heat, but for economy additional lining should be provided. No difficulty would be experienced, under the proposed plan, in lining the wood kiln with heavy sheet asbestos, which would be slightly effective against fire and would also prevent excessive drying of the wood. The tray cleats should be nailed on over the asbestos, and the latter should be protected from wear by the trays, by placing tin flashing in the angles formed by the upper surfaces of the cleats and the walls. This would also be worth while to reduce friction.

However, the most inflammable thing about the kiln is its content of dry cones, and no amount of care in construction can prevent a fire if the furnace becomes so seriously defective as to allow flame or sparks to enter the hot-air current of the furnace. The precautions to be taken are mainly those against fire in the furnace room. The fuel supply should be in a room separated from the furnace by a fireproof door which is always closed except when there is an attendant at the furnace. The ceiling above the furnace should, of course, be completely insulated with heavy sheet asbestos. If the furnace room is kept free of inflammable material and concrete construction is used in the floors and walls, ordinary care at all times should prevent fire.

FINAL TREATMENT OF CONES

Under a system in which the cones are agitated rather frequently while opening, there will be very little seed left in them when the drying process is completed, or at any rate not enough to require any long, or very thorough shaking of the cones. In Figure 20 is shown a wide, screened trough of sloping steps down which the cones may be brushed and beaten with any convenient tool. Probably the hand beating rather than the steps in the screen should be depended upon most to loosen the seed. Gradually, however, the cones should be worked down the screen to drop into a convenient receptacle or if possible directly into the fuel room. The need for additional shaking or beating could easily be determined after noting the amount of seed coming out of the cones in the fuel room.

A MECHANICAL KILN

The very simple mechanical plan suggested in Figure 21 is in every principle the same as the manual plan, but provides for moving screens to hold the cones, instead of trays to be shaken and lifted up and down. Once the cones have rolled or been shoveled onto the top screen, they are moved first in one direction and then tumbled to the next screen below and moved in the opposite direction, by means of a windlass-driven chain connected with gears on one roller of each pair. The rate of movement is determined by the complete opening of the cones on the lowest screen.

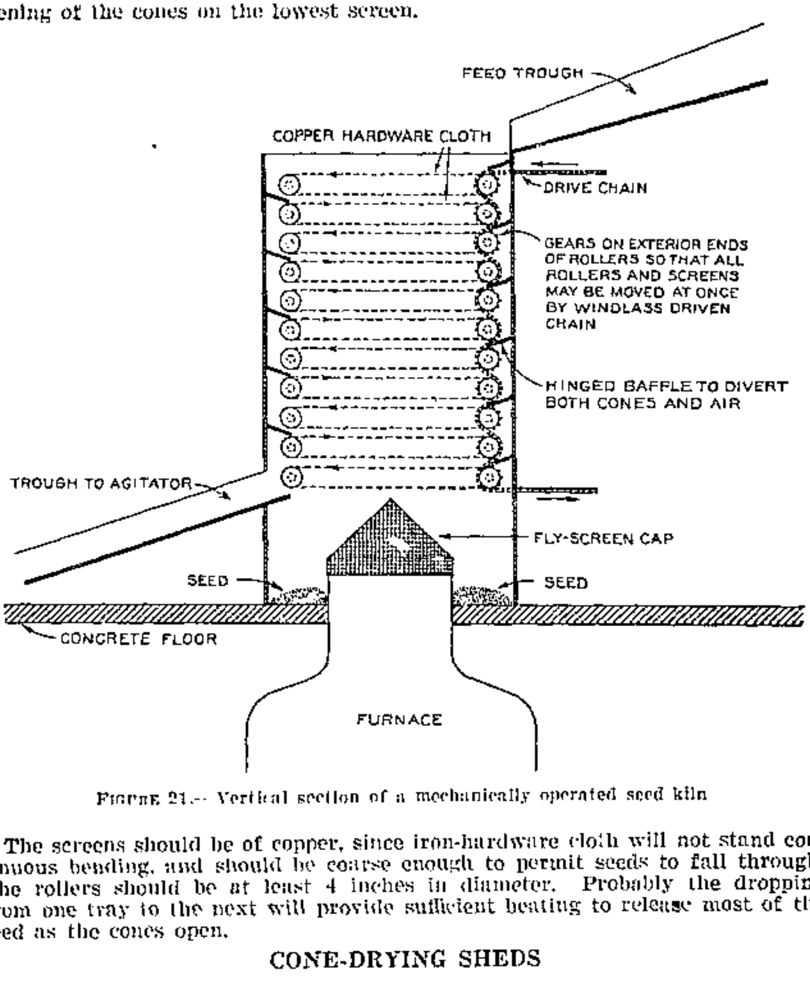

FIGURE 21.—Vertical section of a mechanically operated seed kiln

The screens should be of copper, since iron-hardware cloth will not stand continuous bending, and should be coarse enough to permit seeds to fall through. The rollers should be at least 4 inches in diameter. Probably the dropping from one tray to the next will provide sufficient beating to release most of the seed as the cones open.

CONE-DRYING SHEDS

The data reported in this bulletin indicate that with species which ordinarily open in the sun, and even with selected cones of lodgepole pine, the use of artificial heat is unnecessary, and by proper arrangements for air drying the need for extracting plants could largely be obviated. At least this should be the case where the fall and winter weather is characterized by dry atmosphere and a high percentage of sunshine.

Large cribs or bins such as that shown in Plate 3, A, although desirable for storage or preliminary drying, are not conducive to the opening of the cones except those in the topmost layer. The cone-drying shed should be built like an open cowshed, high at the south side, and with a comparatively low north wall. The question whether the south side should be closed by screen or left entirely open, as well as other features of the construction, should be decided by the prevalence of rodents and an estimate of the amount of damage they may do.

Within the shed the essential feature is tier after tier of trays. These may be constructed of 1 by 6 or 1 by 8 boards, with bottoms of hardware cloth for strength and coarse muslin to retain the seeds, or hardware cloth may be used alone and the seed allowed to drop through all the trays to a special tray near the floor. The advantage of the latter plan is that it permits the best possible ventilation through the cones. For large-seeded species fly screen supported by one or two longitudinal ribs would be preferable.

The trays will hold 1 bushel to each 3 square feet if spread 5 inches deep, which would permit nearly 100 per cent expansion without overflowing an 8-inch wall. Therefore a tray 3 by 6 feet will hold 6 bushels, and if six trays are placed one above another at intervals of a foot, leaving 4-inch spaces between them for ventilation, a floor space 3.2 by 6 feet will accommodate 36 bushels. The roof should project at the front 2 or 3 feet beyond the trays, so that they will not usually be wet during storms. A lateral space of 2 or 4 inches between trays should be allowed for the uprights, to which supporting cleats will be attached, and for ventilation around the trays.

On this basis a shed of 6 by 90 feet floor space and 10 by 90 feet roof should accommodate 1,000 bushels of cones. The simple construction possible, the elimination of a great deal of labor in repeated handling of the cones, and the possibility of leaving the threshing of the cones to the most convenient season should recommend drying sheds, where practicable, in preference to heating plants of greater initial cost and complexity, which also are all too frequently destroyed by fire.

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