

CARDINAL TEMPERATURES FOR GERMINATION OF WHITE, RED AND JACK PINE SEED

by
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**PETAWAWA FOREST EXPERIMENT STATION
CHALK RIVER, ONTARIO
INFORMATION REPORT PS-X-15**

**CANADIAN FORESTRY SERVICE
DEPARTMENT OF FISHERIES AND FORESTRY
FEBRUARY, 1970**

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INTRODUCTION

The objective of the study reported here was to determine and demonstrate cardinal temperatures for germination of two provenances of white, red, and jack pine (Pinus strobus L., P. resinosa Ait., P. banksiana Lamb.)^{2/} seed. Cardinal temperatures (Daubenmire, 1959) for germination are the temperature below which seeds do not germinate, the temperature above which seeds do not germinate, and the temperature or temperature range at, or within which maximum germination occurs in a stipulated period of time.

Temperature is one of the most important factors governing germination of all seeds (Baldwin, 1942), hence its influence on germination of seeds from different species of trees, and from different provenances of the same species is of practical interest and importance to those concerned with the production of seedling stock for operations or research.

1/

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2/

Lower cardinal temperature (LCT)
Upper cardinal temperature (UCT)
Optimum cardinal temperature (OCT)

ABSTRACT

Experiments with two provenances of white, red, and jack pine seed were conducted, 1) to determine if constant temperature had a significant effect on germination of these species, 2) to establish cardinal germination temperatures for each species, 3) to determine if provenance of the seed influenced germination responses to temperature, and 4) to explore the effect of alternated temperatures on germination responses.

The significant effect of constant temperature on germination was apparent within 7 days from seeding. Cardinal germination temperatures were established for each species and were not influenced by provenance of the seed.

The cardinal temperatures for maximum germination 28 days after seeding were 65F to 75F (18.3C to 23.9C) for white pine seed, and 60F to 95F (15.6C to 35.0C) for both red, and jack pine seed.

Maximum germination responses to alternated periods of temperature were always inferior to maximum responses at the demonstrated optimum cardinal temperatures.

Silviculturists and nurserymen working under field conditions can seldom manipulate temperatures precisely or at will, but awareness of cardinal germination temperatures for different species and provenances should help them avoid costly mistakes and delays in broadcast-seeding and seed-spotting programs. To those who can manipulate and control temperature and whose objective is rapid, economical production of homogeneous seedling stock for research or for specialized operations such as container planting, cardinal germination temperatures, by species and provenance, are of the utmost importance.

Studies of the influence on germination of a complex of environmental factors which occur in nature (Farrar and Fraser, 1953; Fraser and Farrar, 1953a; 1953b; 1955) revealed that germination appeared to be related to such features as shading, seeding depth, medium, etc., but was really governed by moisture-temperature conditions associated with them. Moisture is a major factor influencing germination of seeds, but it was so difficult to manipulate and control at prescribed, reproducible values at different temperatures that the two-factor approach was abandoned and efforts were directed to studying the influence of temperature on germination.

Although germination is a plant function that sometimes manifests a type of thermoperiodism (Daubenmire, 1959) and sometimes does not, daily alterations of temperature are generally considered more favourable (Baldwin, 1942) because they simulate conditions found in nature. However,

a study involving alternating temperatures would have introduced variables (Haasis and Thrupp, 1931) which could not have been adequately controlled. Therefore, to obtain consistent results the main study of germination responses was confined to maintained or constant temperatures, and the effect of alternating temperatures was explored very briefly.

MATERIALS AND METHODS

Seeds

Seeds used in these experiments were collected on the Petawawa Forest Experiment Station in the Great Lakes - St. Lawrence Forest Region and in the vicinity of Sioux Lookout in the Boreal Forest Region (Rowe, 1959). Annual averages of daily temperatures and mean annual precipitation (Table 1) indicate that the Sioux Lookout seed collection area had a cooler, drier, climate than the Chalk River area.

Table 1. Location and climate of seed collection areas.

Provenance	Zone*	Latitude	Longitude	Mean Annual Air Temperature (F)			Mean Annual Precipitation(inches)	Observations (years)
				Min.	Max.	Mean		
Petawawa	5E	46°N	77°W	29	51	40	29.21	7
Sioux Lookout	4S	50°N	92°W	24	42	33	24.52	23

* Ontario Department of Lands and Forests Seed Collection Zones.

Storage and pre-treatment

Seeds from both provenances were stored dry in sealed jars at 37F.

Immediately prior to seeding white pine seeds were cold-soaked in a weak acid solution for 36 hours at 37F as an alternative to the conventional 3-, 6-day stratification in moist sand (Anon, 1968). Preliminary work demonstrated that white pine seeds so treated began to germinate within 10 days; it also indicated that the concentration of the solution was not critical -- results were equally good from 80 ppm to 800 ppm concentrated (93.1%) H_2SO_4 in distilled water.

Red and jack pine seeds do not require stratification but they were treated the same as the white pine seeds to give them equal opportunity to absorb water before being seeded at different temperatures. Immediately following cold-soaking, all seeds were washed in running distilled water, and surface-dried between blotting papers.

Germination media

Vermiculite, which holds water well and provides adequate aeration (Allen and Bientjes, 1954; Mahlstedt and Haber, 1957), was the germination medium for Petawawa seed. It was sterilized at 248F then brought to field capacity for the experiment. The moisture content remained well above the 15%, by weight, which Heinrich (1921) as cited by Baldwin (1942) considered adequate for germination.

Short grain, black germination paper, a more satisfactory germination medium, was available for tests of Sioux Lookout seeds. It was saturated with distilled water at the beginning of the experiments and carefully rewetted if it showed signs of drying during the tests.

Germination Criterion

Definitions of germination are also numerous (Holmes, 1951; Mahlestedt and Haber, 1957; Baldwin, 1942) and are usually related to the end purpose of the work. It was impossible for the same individual to tally the germinates each day so the arbitrary criterion in each experiment was intentionally simple. Seeds were tallied as germinates when the radicles were plainly visible.

Germination was recorded daily. Additional samples of seed from each provenance were selected at random for cutting tests to observe the proportion of full seed, and resultant correction factors were applied to germination data.

Germination Period

The time element in germination studies varies greatly and is usually chosen with reference to the objective. As preliminary tests showed that these species germinated almost completely within 30 days, a 28-day germination period was arbitrarily selected for convenience.

Seeding Method

One and a half inches of fine silica sand at field capacity was placed at the bottom of 6-ounce glass containers to act as ballast, and covered by 1 inch of #2 vermiculite, also at field capacity. For each of the three Petawawa species separately, 25 seeds, taken at random, were spread on the vermiculite. Watch glasses were placed over seeded containers to retard evaporation. One block of 10 containers of each species was assigned at

random to each temperature treatment (water bath) and to one of three positions in each bath. Light-weight Cell-O-Glass lids were placed over each bath.

Twenty-five seeds taken at random from each of the three Sioux Lookout species separately, were spread on double layers of saturated germination paper in covered, sterile petri dishes. One tray of each species, containing 12 petri dishes positioned at random, was assigned, also at random, to each temperature treatment (incubator) and to one of three shelves in each incubator. The same methods were used in a limited exploration of thermo-periodism and germination of Sioux Lookout pine seed. Temperature alterations were achieved by moving seeds from one incubator to another at scheduled times.

Water baths with hydraulically or mechanically controlled heating and magnetic or power stirring maintained scheduled temperatures for testing Petawawa seed. Forced air incubation cabinets with hydraulic or pneumatic control on heating and cooling systems provided temperature treatments for Sioux Lookout seed. Sensitivity of both systems was $\pm 1F$ ($\pm \frac{1}{2}C$).

Temperatures of baths and incubators were assigned at random, checked for stability before the experiments and monitored during the test periods by means of mercury-actuated recording thermometers (Petawawa) and 24-gauge thermocouples and potentiometric recorders (Sioux Lookout).

Temperature treatment

Temperature was the main treatment. Exploratory work established that red, white, and jack pine seeds germinated at 75F but not at 40F or at

115F. Germination was then tested at 14 5-degree intervals from 45F to 110F. As there were too few water baths and too few incubators to test the effect of all levels of temperature at once the different temperatures were tested at random in time.

Germination of Sioux Lookout seed only was tested at temperatures of 100F and 105F for 8 hours alternated with 50F and 60F for 16 hours daily for 28 days.

Moisture treatment

Moisture was eliminated as an experimental variable by maintaining it at or near field capacity during the tests.

Light treatment

There are opposing views and findings concerning the role of light in germination. Crocker and Barton (1935) stated that although lack of light might inhibit germination of some seeds, light might actually cause some others to remain dormant, and Baldwin (1942) considered light to be essential for germination of comparatively few species of seeds. Nordstrom (1964) found that sunlight stimulated germination of dry pine seed, but Fraser^{3/} germinated jack pine seed successfully in total darkness in both sand and humus at field capacity and concluded that light, beyond that received during normal extraction, storage, and seeding procedures, was not essential for germination.

^{3/} Unpublished report, file P-366, P.F.E.S., Chalk River, Ontario.

Because of these conflicting views all tests of both provenances of seed were conducted under uniform, low light conditions.

DESIGN AND ANALYSIS

Design

Details of the completely randomized experiments (Freese, 1967; Finney, 1960), conducted under conditions of adequate moisture and constant low intensity illumination for 28 days, are tabulated below:

Provenance:	Petawawa	Sioux Lookout
Species:	---White pine, Red pine, Jack pine---	
Experiments:*	2	2
Temperatures:	---14: 45F to 110F at intervals of 5F---	
Sensitivity:	<u>+1F</u>	<u>+1F</u>
Population:	10 x 25 = 250	12 x 25 = 300

*When the series of 14 temperatures were completed, they were tested again in a second experiment. Elapsed times from the start of the 1st to the end of the 2nd experiment were 18, and 12 months for Petawawa and Sioux Lookout respectively.

Statistical Analysis

Germination percentages corrected for percent full seed and transformed to degrees (Bliss 1937) by the arc sine method were subjected to analyses of variance as completely randomized experiments, and Duncan's (1955) multiple range test was used to test the significance of treatment-mean comparisons.

The results of the exploratory study of germination responses to periods of alternated temperature were too limited in scope to support a statistical analysis and too definite to require analysis.

RESULTS AND DISCUSSION

Constant temperature

Figures 1 and 2, 4 and 5, 7 and 8, illustrate germination responses (hereafter referred to only as "responses") to temperature of both provenances of white, red, and jack pine seed respectively^{4/}. Analysis of variance confirmed what is apparent from these graphs, that temperature had a significant^{5/} effect on germination of the three species of pine seeds.

White pine. The LCT and UCT for germination of both provenances of white pine seed are clearly established as 50F and 100F respectively (Figures 1, 2, and 3). The extremely poor germination (15% or less) eliminates both 50F and 100F from further consideration, and interest is confined to the 55F to 95F range within which the OCT, occurred, i.e. 65F and 75F for Petawawa seed and 65F to 75F inclusive for Sioux Lookout seed.

^{4/} Treatments where no germination occurred, i.e. 45F and 110F are omitted except in Figures 1 and 2 where there was no germination at 105F but the treatment is included to balance the presentation.

^{5/} p = 0.01 unless otherwise specified.

Germination of seed from both provenances began within one week of seeding at and above 65F. Each 5F decrease in temperature below 65F resulted in a corresponding delay in the onset of germination.

At temperatures below 65F a few Petawawa seeds were still germinating by the 28th day. Above 65F germination was 90% complete^{6/} in the second or third week.

Unlike Petawawa seeds which achieved a plateau of near maximum germination at all but the three lowest temperatures, Sioux Lookout seeds were still germinating within the cardinal temperatures at the end of the experiment. It is therefore more difficult to determine the rate of germination for this provenance of seed, but in general terms of germination Sioux Lookout seed only reached 90% of the 28-day value sometime in the third and fourth weeks - approximately 1 week longer than it took Petawawa seed to achieve the same level.

There were obvious differences in the time from seeding to onset of germination between the two Petawawa experiments (Figure 1) but practically none between the Sioux Lookout experiments (Figure 2). When the differences did not exceed one or two days, i.e. 65F to 100F they were probably due to the relatively more difficult task of applying the germination criterion, consistently, to seeds germinating in vermiculite (Petawawa) compared to seeds germinating on black paper (Sioux Lookout).

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Based on maximum germination as 100%.

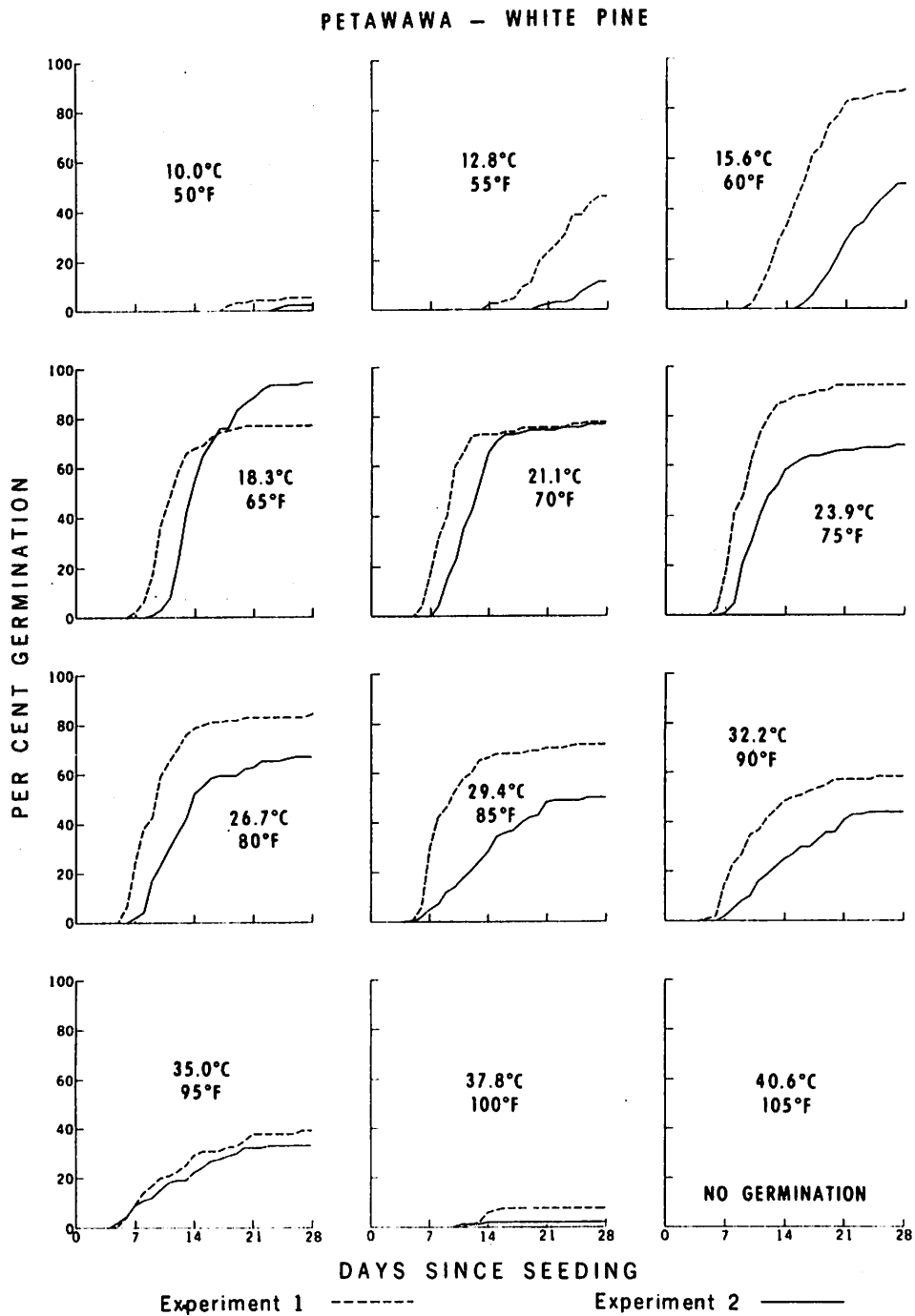


Figure 1. Per cent germination of Petawawa white pine seed at different temperature.

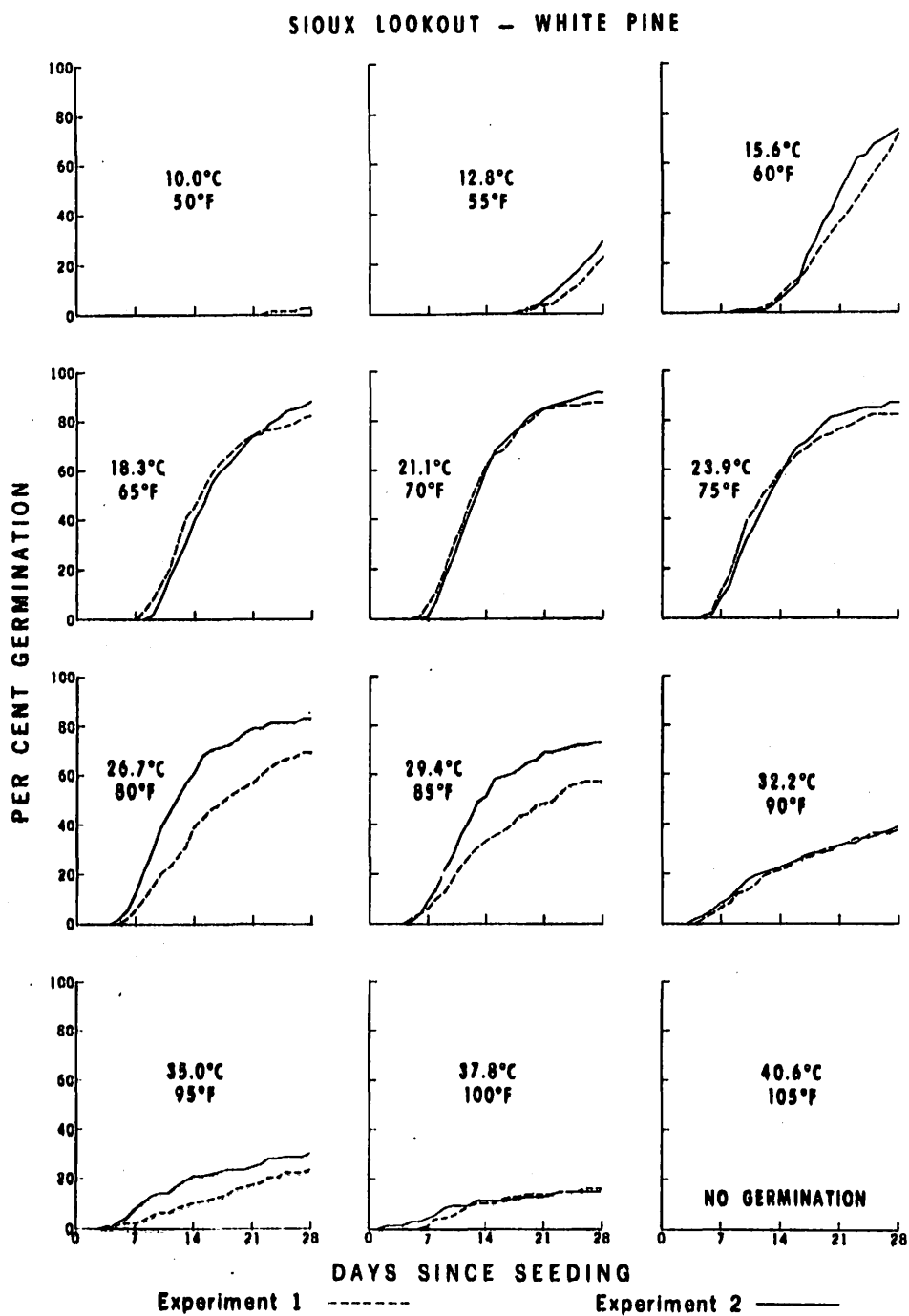


Figure 2. Per cent germination of Sioux Lookout white pine seed at different temperatures.

However, greater discrepancies of 5 to 7 days (55F and 60F) suggest that during storage of the seed there may have been changes that subsequently delayed germination, particularly at lower temperatures.

Differences in maximum germination in the two experiments suggest a loss of viability during storage but there is no evidence yet ^{7/} to support this.

The possibility that these differences were due to some error in procedure, or to equipment failure is refuted by the regular response of Petawawa red and jack pine seed (Figures 4 and 7) at the same treatments at the same time.

There was no such apparent, similar delay in germination or loss of viability associated with storage of Sioux Lookout seed.

The significant influence of temperature on germination in relation to time is more apparent when percent germination is plotted over the entire range of treatments 7, 14, and 28 days after seeding (Figure 3).

When the germination period was extended from 7, to 14, to 28 days the UCT established at 7 days remained unchanged for Sioux Lookout seed, and virtually so for Petawawa seed, but the LCTs were progressively lower. Although percent germination generally increased as the test was extended, the OCTs were established by the 14th day.

7/

Three years have been completed of a 10-year experiment with Petawawa white pine seed to test the effect of length of dry storage on the germination response to temperature.

WHITE PINE

PETAWAWA

SIOUX LOOKOUT

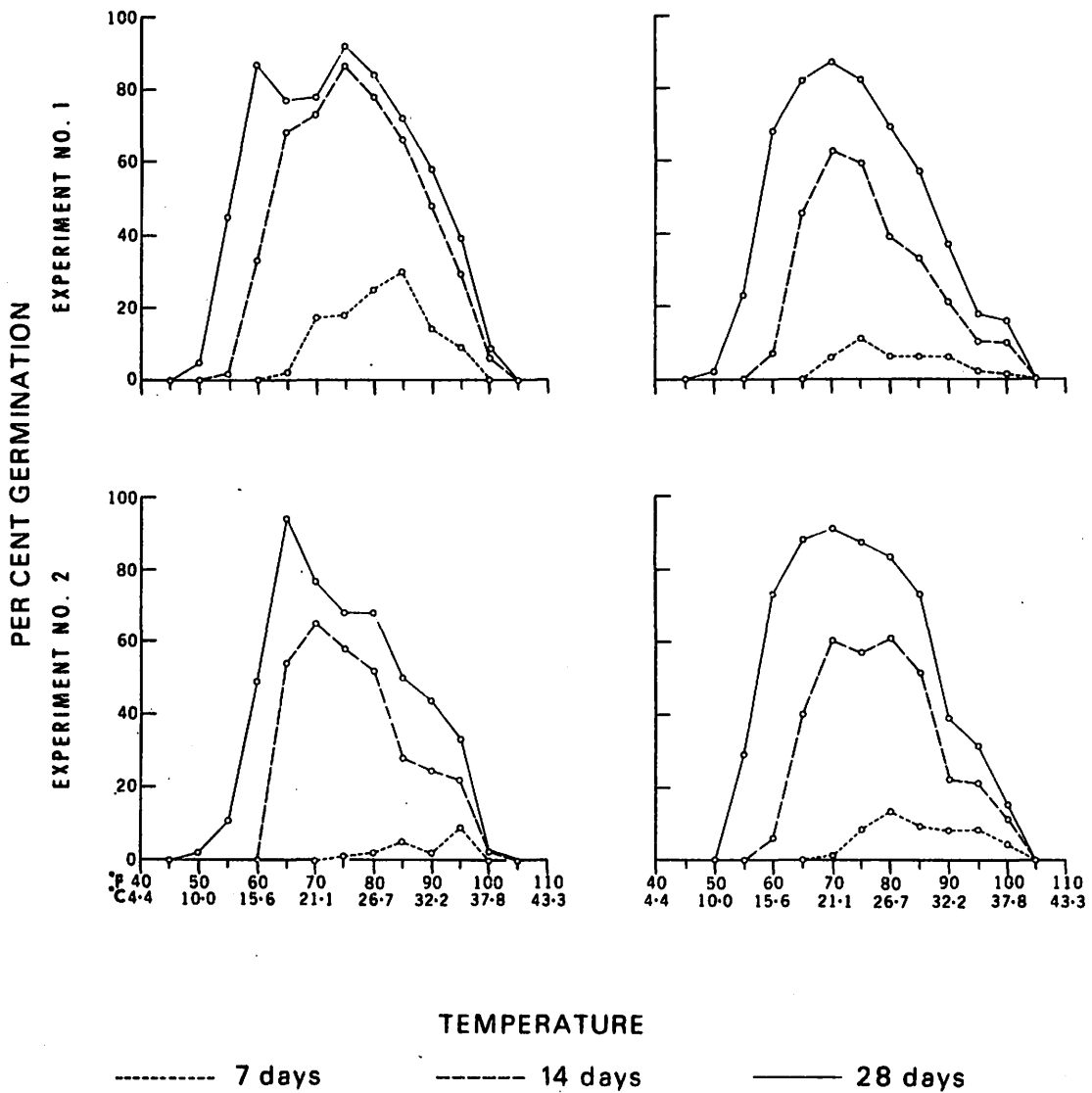


Figure 3. Percent germination of white pine seed from Petawawa, and from Sioux Lookout, 7, 14, and 28 days from seeding.

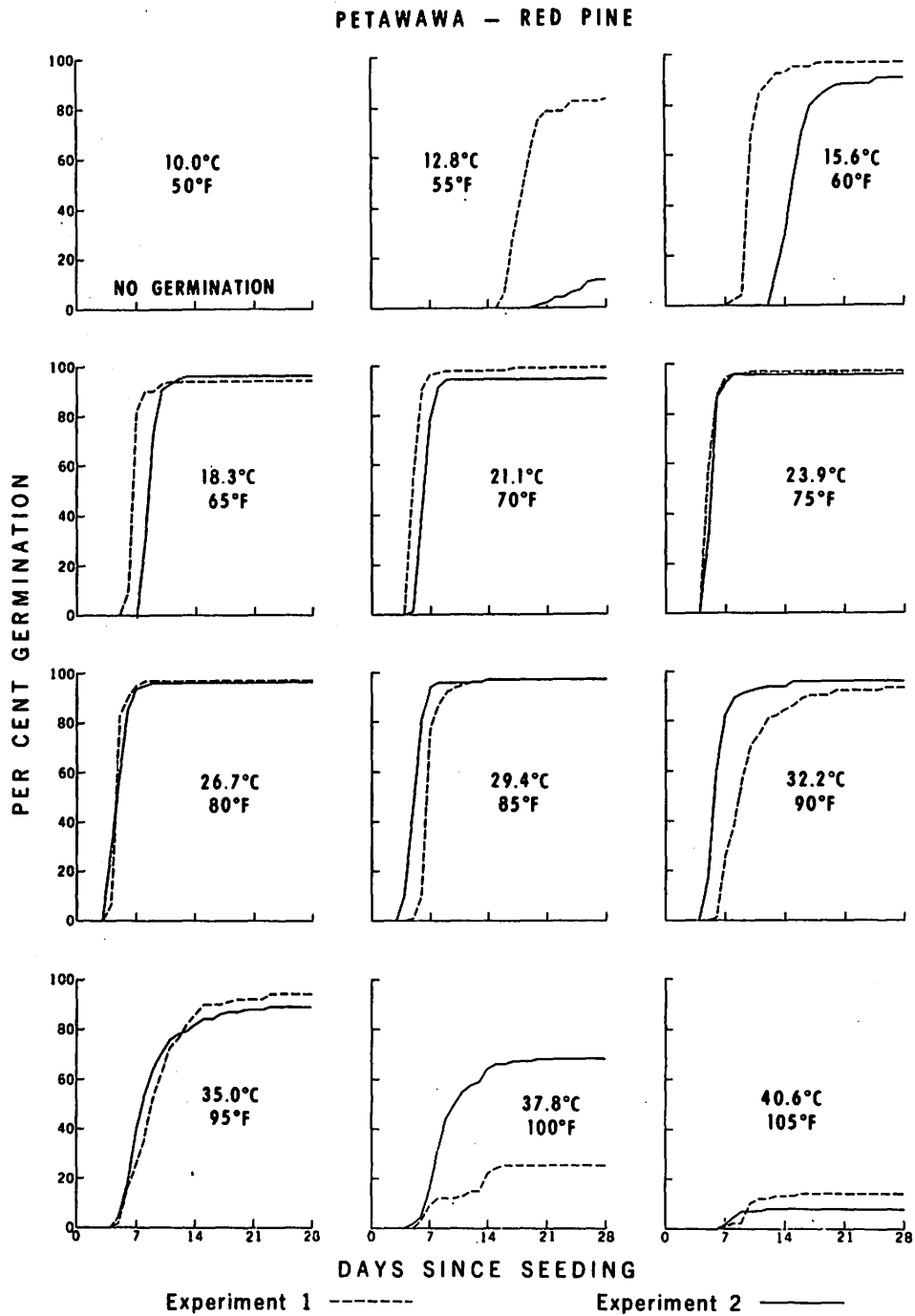


Figure 4. Per cent germination of Petawawa red pine seed at different temperatures.

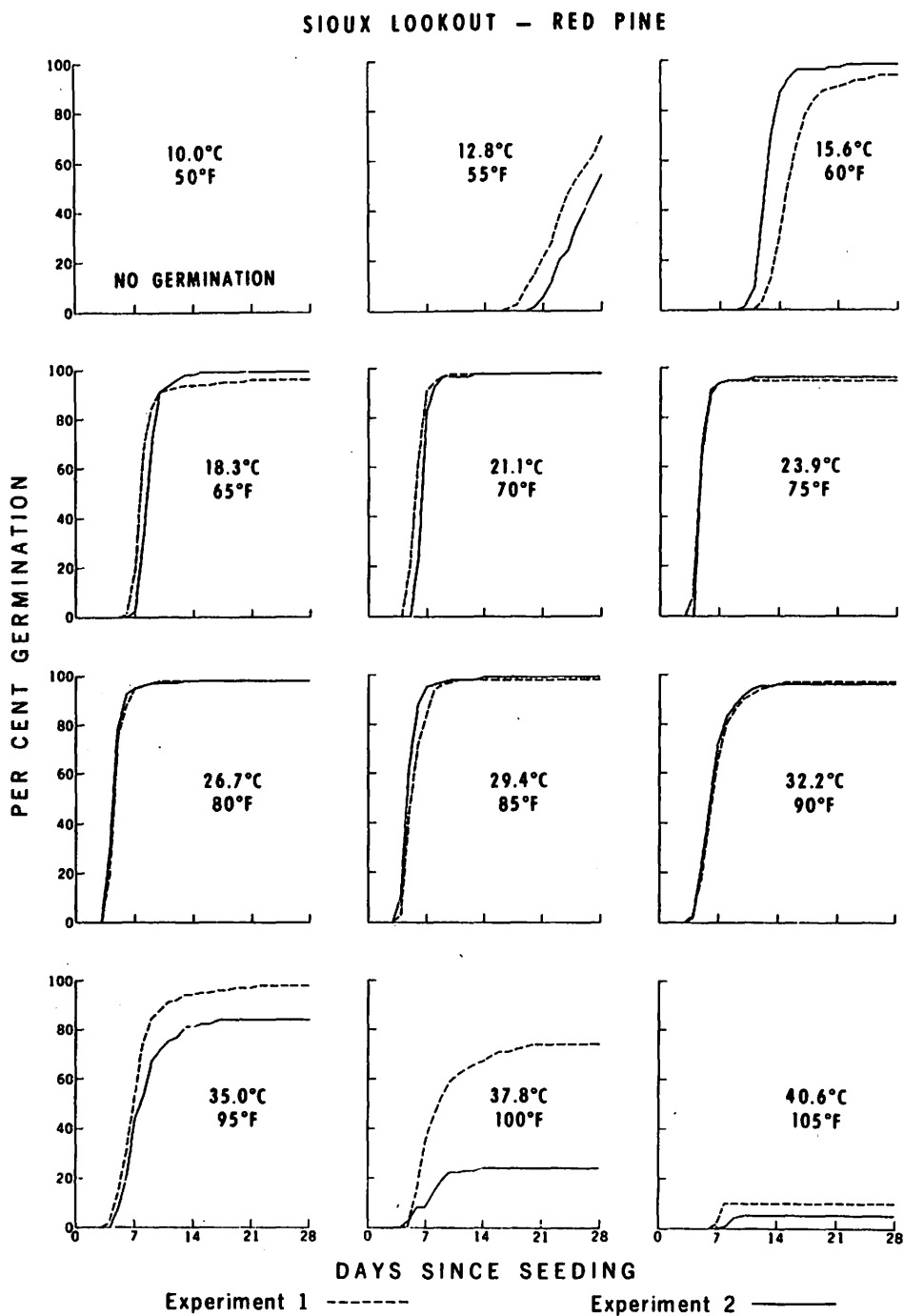


Figure 5. Per cent germination of Sioux Lookout red pine seed at different temperatures.

Red Pine. Petawawa and Sioux Lookout red pine seed had the same cardinal germination temperatures, 55F(LCT), 105F(UCT) and 60F to 95F(OCT), (Figures 4, 5, and 6). The response at the UCT was too limited (15% or less) to be of any practical interest.

Both provenances of seed began germinating during the first week after seeding at 65F to 95F inclusive, and germination was at least 90% complete by the end of the second week; average time from seeding to onset of germination was 5 days. Within this range, from 70F to 85F inclusive, germination was complete only 7 days after seeding; or, on the average, 2 days after onset of germination.

Although 60F is the lower limit of the OCT for 28-day germination of seed from both provenances, germination began approximately one week later at this temperature and another week later at the LCT (55F). The different responses of the two experiments at 55F and at 100F suggest that responses of both provenances of seed to these temperatures may have been influenced by changes that took place during storage. In red pine seed unlike Petawawa white pine, there was no apparent effect of storage on responses outside the OCT range.

The significant effect of temperature on germination in relation to time was more clearly defined for red pine (Figure 6) than for white pine (Figure 3). The red pine responses paralleled those for white pine in that the UCTs at 7 days remained virtually unchanged and the LCTs became progressively lower as the test period was extended from 7, to 14, and then to 28 days. Additionally, as the period was extended from one, to two, to four weeks, maximum germination occurred over a progressively

RED PINE

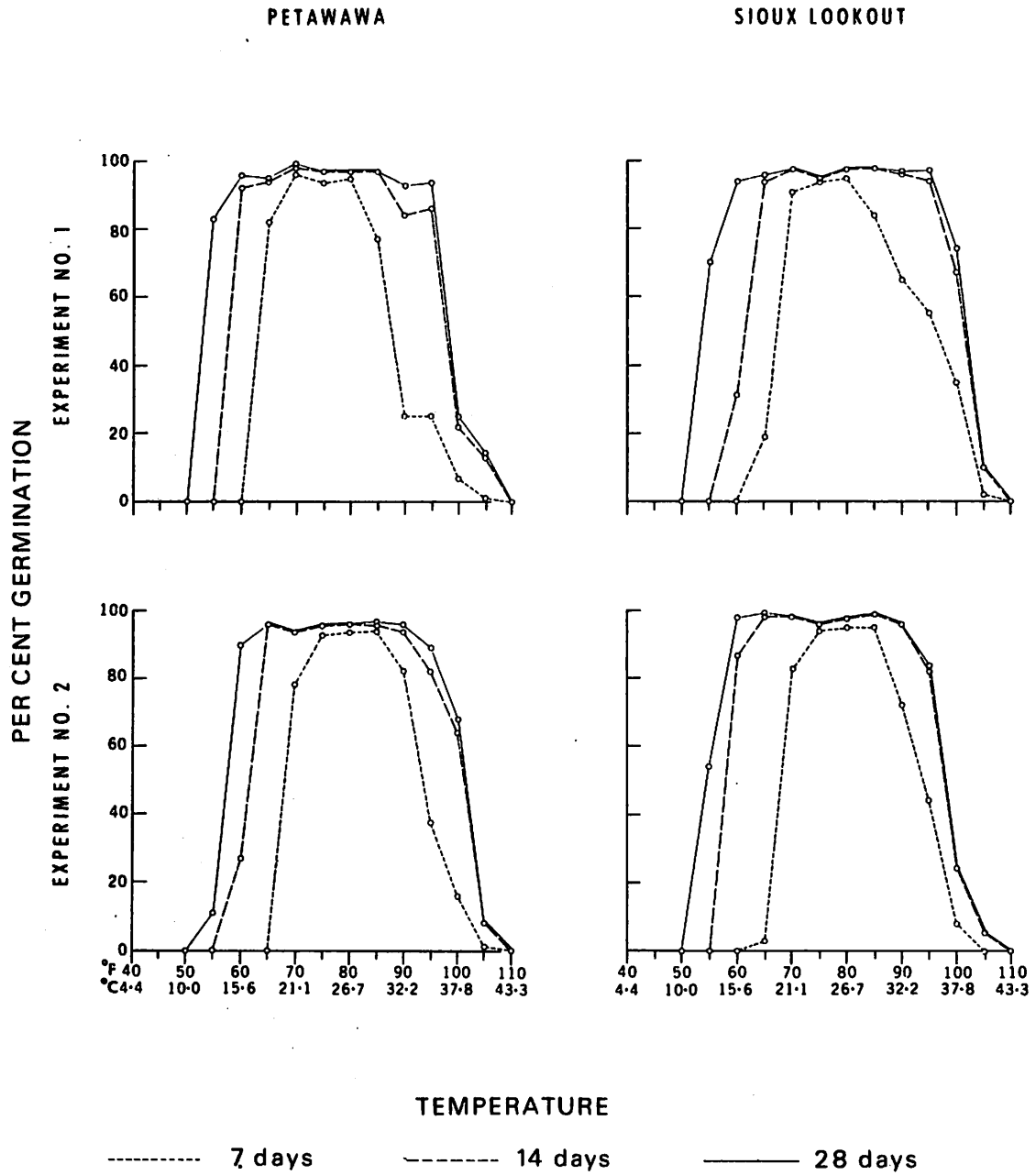


Figure 6. Per cent germination of red pine seed from Petawawa, and from Sioux Lookout 7, 14, and 20 days from seeding.

wider range of temperatures i.e. 70F to 85F (7 days), 65F to 90F (14 days), and 60F to 95F (28 days), but maximum germination of both provenances of seed occurred earlier and faster at the 7-day OCT (70F to 85F).

Jack pine. Both provenances of jack pine seed had the same LCT (50F), the same UCT (105F) and the same OCT (60F to 95F) (Figures 7, 8, 9). At the limiting temperatures, 105F and 50F, germination responses were too low (20% or less) or too slow and irregular to warrant further consideration.

Germination began within one week from seeding at and above 60F; each 5F decrease in treatment temperature delayed germination by approximately one week.

From 65F to 95F, the OCT for both provenances of seed, germination was at least 90% complete by the end of the first week, and 99% complete before the end of the second week. Outside this temperature range germination was progressively poorer, and occurred later and/or more slowly.

The average times tabulated for this treatment range suggest that at the OCT, at least, Sioux Lookout seed exhibited a slightly earlier, faster response to temperature than did Petawawa seed.

Temperature (treatment) range	65F to 95F inclusive	
Provenance	Petawawa	Sioux Lookout
From seeding to germination	4 days	2 days
To achieve 90% maximum germination	6 days	4 days
To achieve 99% maximum germination	10 days	9 days

PETAWAWA - JACK PINE

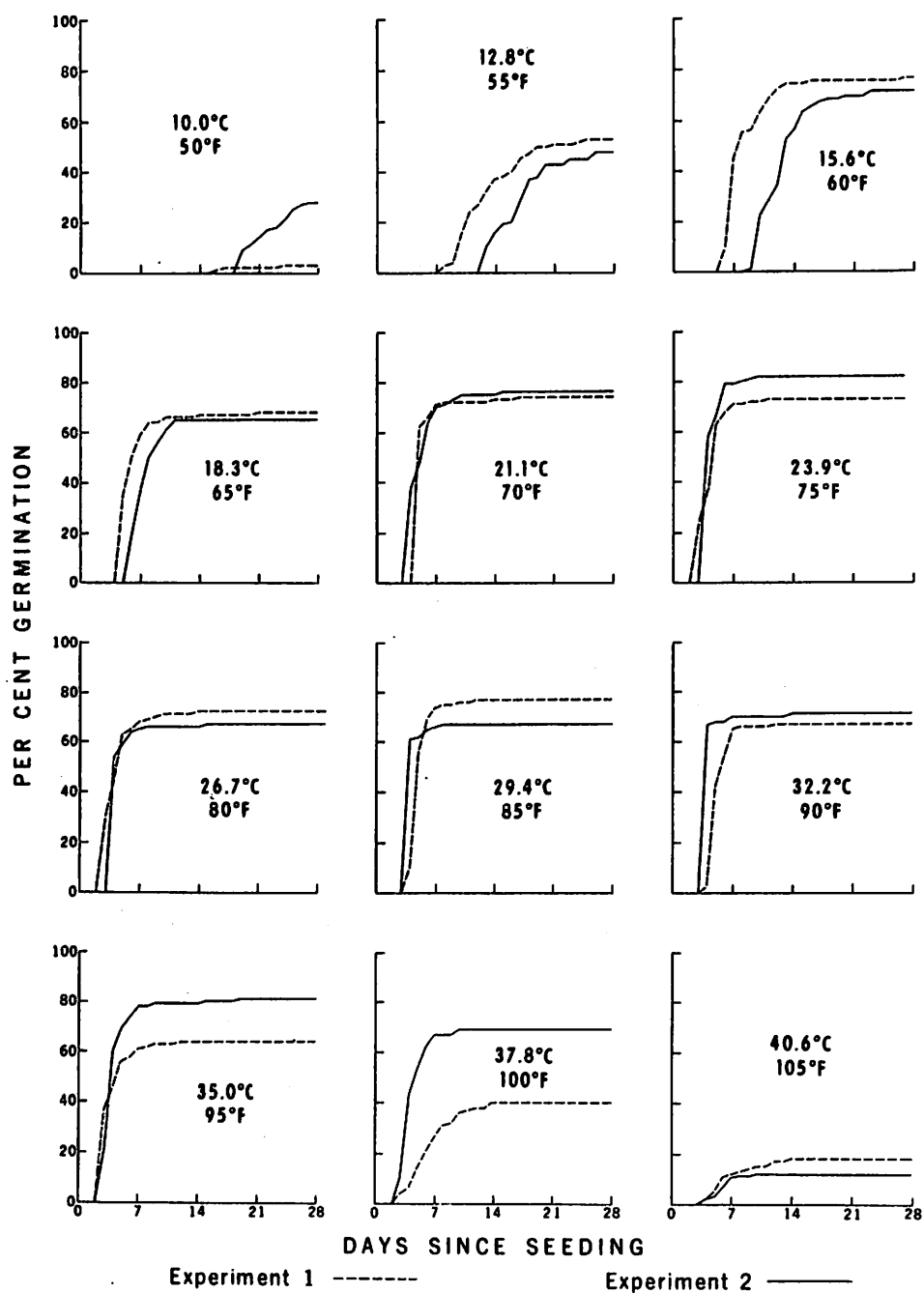


Figure 7. Per cent germination of Petawawa jack pine seed at different temperatures.

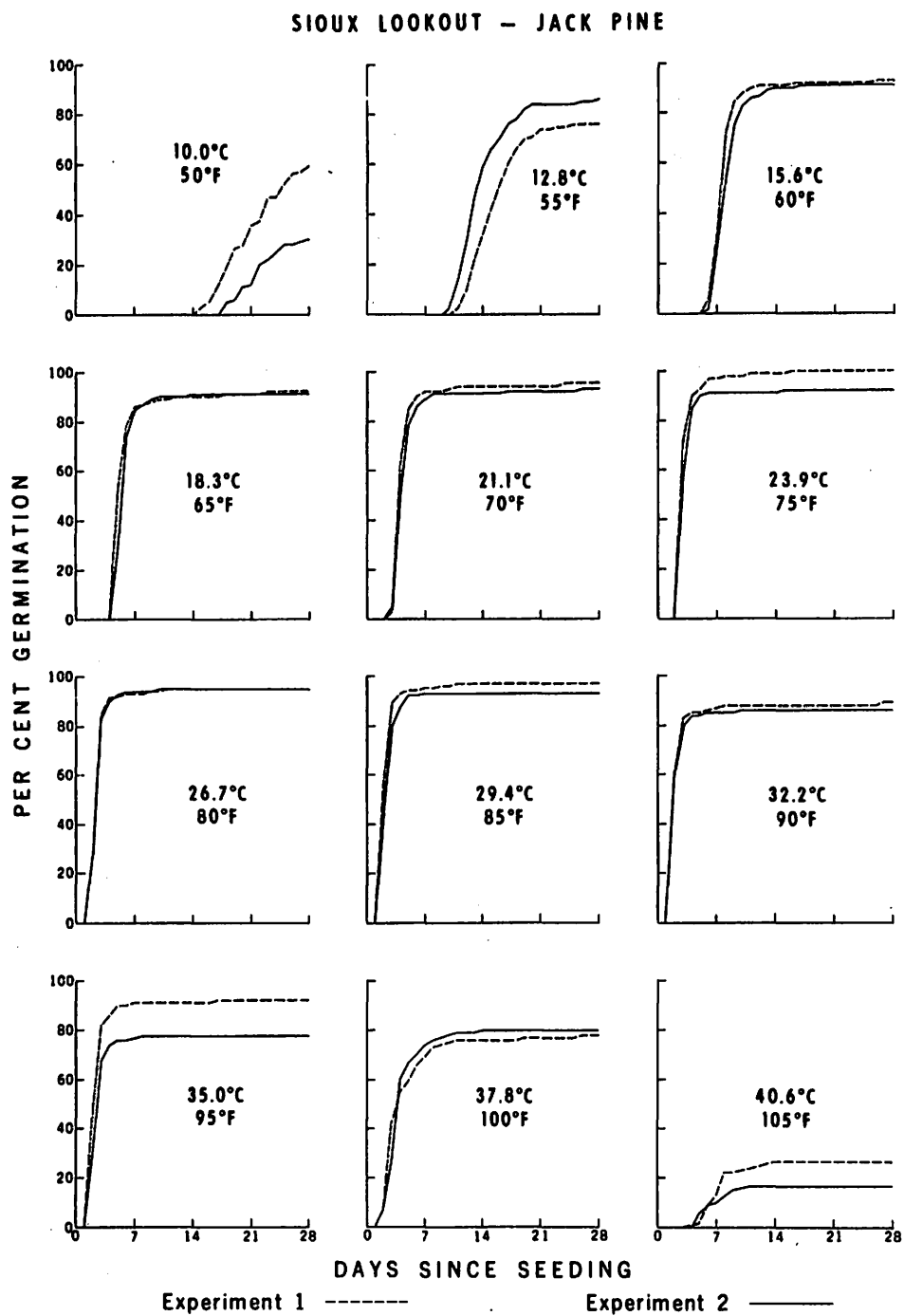


Figure 8. Per cent germination of Sioux Lookout jack pine seed at different temperatures.

JACK PINE

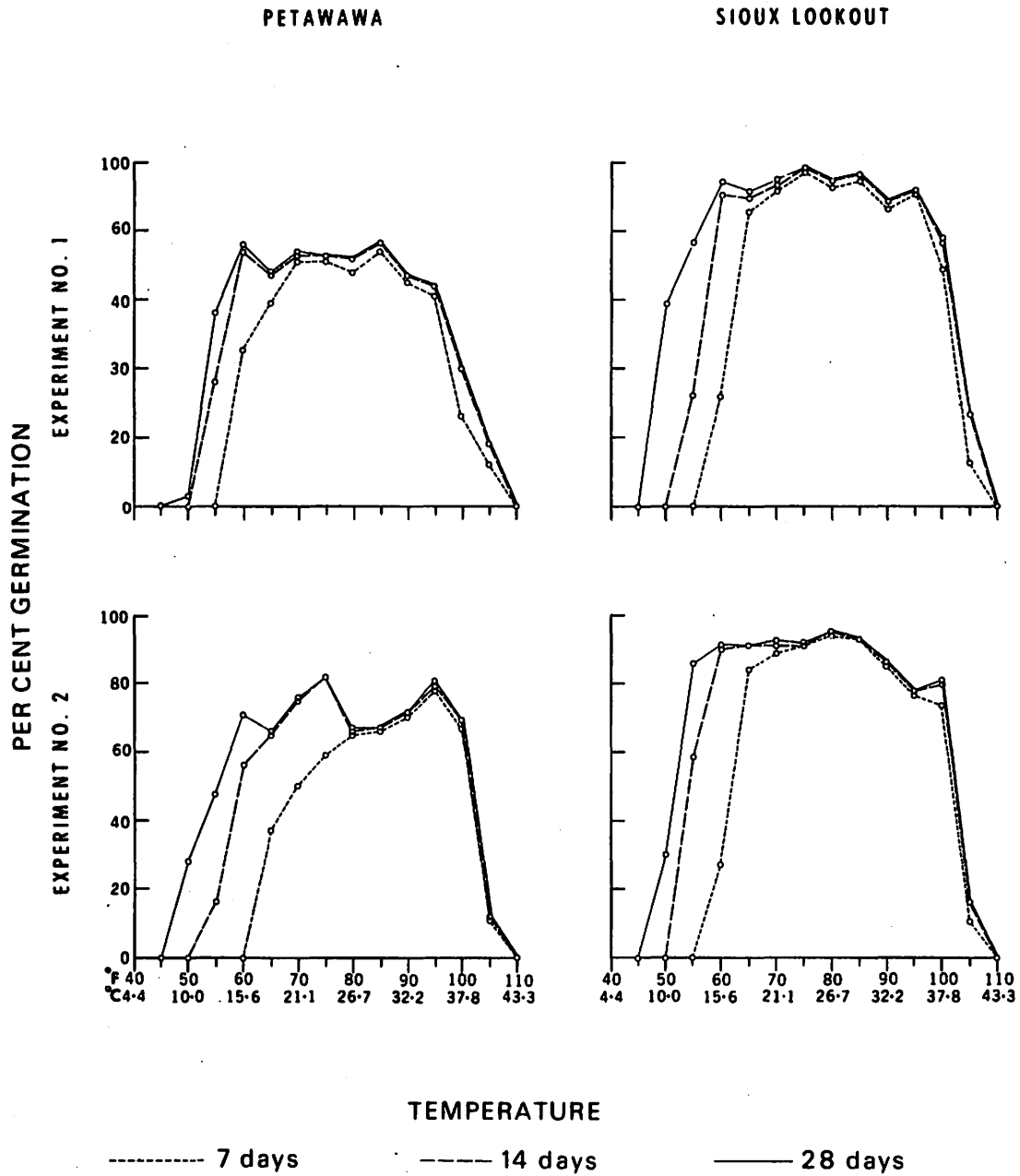


Figure 9. Per cent germination of jack pine seed from Petawawa and from Sioux Lookout, 7, 14, and 28 days from seeding.

With jack pine, as with red pine the responses above and below the OCT indicate the possibility of changes during storage having influenced the response to the higher and lower temperature.

UCTs were established 7 days after seeding and remained unchanged when the test was prolonged to 14 and then to 28 days (Figure 9) although the LCTs were progressively lower and the OCT was progressively broader with each extension of the germination period. Yet, maximum germination occurred earlier, and more quickly within the relatively narrow 7-day OCT, than at any higher or lower temperature.

Provenance. Averages of 28-day germination percentages from both experiments are plotted over temperature treatments for both provenances of each species in Figure 10.

The remarkably similar cardinal germination temperatures and response patterns for each species indicates that in this particular case provenance of the seed had little, if any, effect on the response to constant temperature of either white, red, or jack pine seed, although Sioux Lookout is considerably north of Petawawa (4°N), with a noticeably cooler, drier climate.

The obviously better germination of Sioux Lookout jack pine is attributed to greater viability rather than to any effect of provenance on its response to temperature.

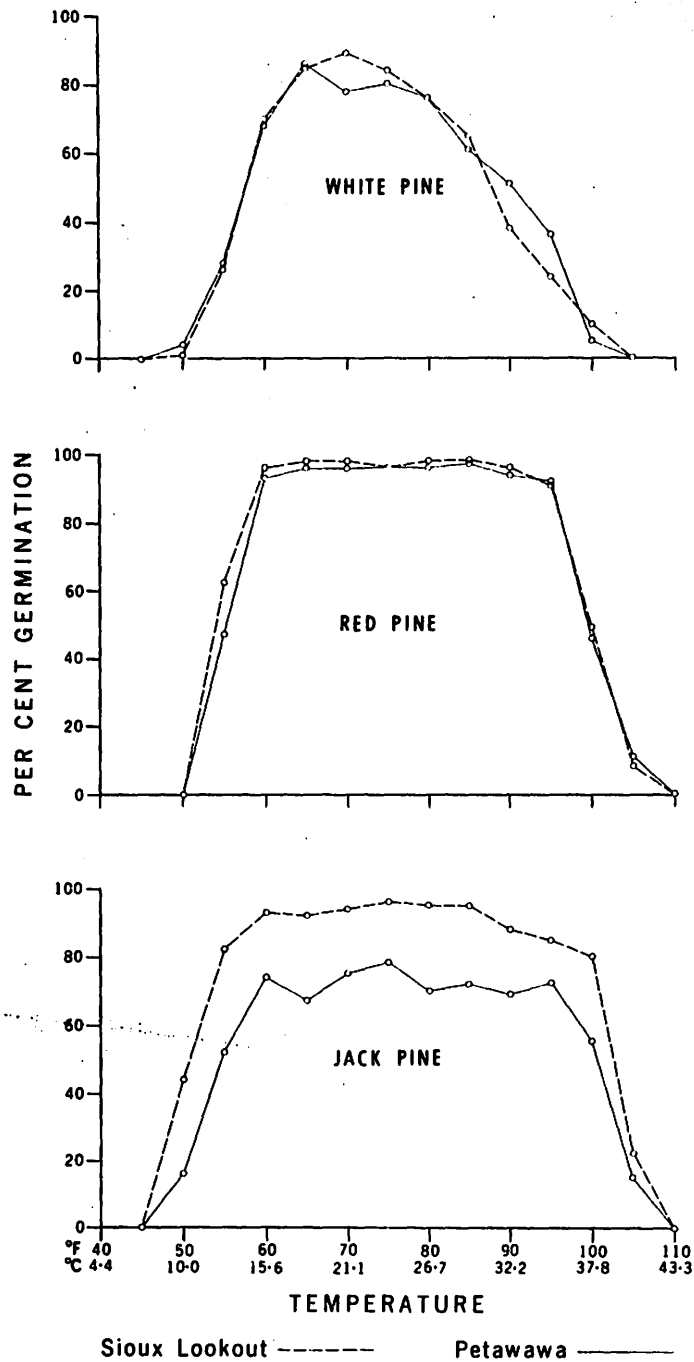


Figure 10. Per cent germination of white, red, and jack pine seed from Petawawa and from Sioux Lookout, after 28 days at constant temperatures.

Alternated temperatures

Seeds germinating in nature are subject to different day and night temperatures and even to fluctuating temperatures during the day and night. However, it must be proven that more seeds begin to germinate earlier, and that maximum germination is achieved more rapidly in alternating temperatures than in constant temperature before the additional cost of providing and controlling alternating temperature facilities is warranted.

Obviously the maximum germination response demonstrated in these experiments at the constant OCTs for each species could not be bettered by alternating temperatures. Limited to one exploratory test, the logical choice was to determine if the germination response to constant temperatures of 100F and 105F (above the demonstrated OCTs could be bettered by alternating periods at these temperatures with periods at low temperatures (50F and 60F) as detailed under methods.

It is apparent from the germination data in Table 2 that although germination responses to some alternated temperatures were better than they were to the limiting temperatures 50F and 105F, none of them were as good as the responses to 60F. All responses to alternated temperatures were inferior to the maximum germination at the demonstrated OCTs.

CONCLUSIONS

Differences in constant temperature had a significant effect on germination of white, red, and jack pine seeds from Petawawa and from Sioux Lookout, 7, 14, and 28 days after seeding.

Table 2. Percent germination, by species, at constant* and at alternated temperatures, 28 days after seeding.

TREATMENTS		TEMPERATURE (F)			
		50	60	100	105
White pine		% Germination			
Constant Temperature (F)		2	70	15	0
Alternated Temperature (F)	100/50	20		20	
	100/60		19	19	
	105/50	3			3
	105/60		1		1
Red pine		% Germination			
Constant temperature (F)		0	96	49	8
Alternated Temperature (F)	100/50	22		22	
	100/60		82	82	
	105/50	5			5
	105/60		31		31
Jack pine		% Germination			
Constant temperature (F)		45	93	76	22
Alternated Temperature (F)	100/50	80		80	
	100/60		80	80	
	105/50	35			35
	105/60		63		63

*Percent germination data for constant temperatures are averages of experiments 1 and 2.

Provenance of the seed lots used in these experiments had no demonstrable practical influence on germination responses to temperature of either white, red, or jack pine seed.

Cardinal temperature for germination 28 days after seeding are as follows:

	LCT	OCT	UCT
White pine	50F(10.0C)	65F to 75F(18.3C to 23.9C)	100F(37.8C)
Red pine	55F(12.8C)	60F to 95F(15.6C to 35.0C)	105F(40.6C)
Jack pine	50F(10.0C)	60F to 95F(15.6C to 35.0C)	105F(40.6C)

Maximum germination of red, and jack pine seed from both provenances occurred more quickly at certain temperatures within the OCTs i.e. in 7 days at 70F to 85F for red pine, and at 70F to 90F for jack pine. White pine required 28 days to achieve maximum germination.

Some responses to higher temperatures (100F and 105F) alternated with periods of lower temperature (50F and 60F) were slightly better than to the same constant temperatures, and some were very much worse. None of the better responses approached the maximum germination at the demonstrated OCTs.

ACKNOWLEDGEMENTS

The assistance of forest research technician C.R.C. Farr in the conduct of these experiments is acknowledged.

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