GERMINANT SIZE OF JACK PINE IN RELATION TO
SEED SIZE AND GEOGRAPHIC ORIGIN

by C. W. Yeatman[1]

The initial size of conifer seedlings is closely related to seed size (Hadders 1963), and seed size is a maternal characteristic that is highly subject to environmental modification (Mergen *et al.* 1964; Righter 1945). The effect of seed weight must be accounted for in critical studies of seedlings which attempt to attribute differences in growth to specific genetic or environmental causes (Duffield 1960; Mitchell 1934, 1939).

This paper reports measurements of seed and germinants (seedlings at the full cotyledon stage) of 87 jack pine *(Pinus banksiana* Lamb.) provenances that included the full range of the species, from the northeastern coast of North America to the Mackenzie river valley in northwestern Canada. Seed weight, seed volume, hypocotyl length, cotyledon length, and cotyledon number were recorded to determine the relative effects of seed weight and seed origin on germinant size.

The seed collections were organized by M. J. Holst, Department of Forestry of Canada, and seed and seedlings have been widely distributed for experimental use in Canada, the United States, and abroad. The results presented here are part of a larger study of the growth of jack pine seedlings in relation to provenance and environment of culture (Yeatman 1964).

Review of Literature

There are numerous reports in the literature of correlations between seedling size and seed size. The significance of seed size varies with the species, conditions of cultivation and age of seedlings, and range in seed size and in genetic background of the seed samples. By growing seedling of Scots pine *(Pinus sylvestris* L.) under carefully controlled conditions, Schrock (1964) concluded that seed weight did not greatly influence the length of either hypocotyl or radicle, in

(1953) . Mitchell (1934) found a linear relationship between seed weight and the weight of germinants of Scots pine grown in sand without nutrients. He found a similar relationship for white pine (P. *strobus* L.) and applied a coefficient to seedling weight to correct for seed weight. The correction included an adjustment for seed coal weight, which was found to bear a closely linear relation to seed weight (Mitchell 1934, 1939). Hadders (1963) found that hypocotyl length of Scots pine was positively and highly significantly correlated with seed weight (r = 0.75), but that the subsequent growth of the epicotyl was not significantly related to seed weight. Reports of significant correlations between seed and seedling size in other coniferous species include: white pine (Spurr 1944), slash pine *(P. elliottii* (Shoulders 1961), ponderosa pine *(P. ponderosa* Dougl. ex Laws.) (Larson 1963), white spruce *(Picea glauca* (Moench.) Voss) (Burger 1964), *Abies spp.* (Mergen *et al.* 1964), Norway spruce *(Picea abies* (L.) Karst.) (Holzer 1960), and Silks spruce *(P. sitchensis* (Bong.) Carr.) (Burley 1964) .

The relationship between seed size and geographic origin has been studied in a number of

species. Ruden (1963) found a weak correlation between seed size and 11-year plant height of a number of provenances of Norway spruce, but noted that the seed weight differences were largely geographic and that the correlation for single tree progenies from one geographic area was inconclusive. Thulin and Miller (1964) reported that in 26 provenances of European larch *(Larix decidua* Mill.), seed size increased with altitude of seed origin. Wells (1964) found large differences in seed weight between provenances of ponderosa pine. Rudolf (1958) noted that jack pine from the warmer parts of the natural range tend to produce larger seeds than those from colder areas.

Haskell (1961) discussed the possible value of selection by cotyledon number within polycotyledonous tree species. Conifers show a wide range in cotyledon frequency (Butts and Buchholz 1940), which may be of diagnostic value in some instances for the early distinction of species, but of doubtful value within species or for hybrids.

Most attempts to link time of germination, germination percent, and seedling survival with seed size have not been successful (Burger 1964; Shoulders 1961), although Wright and Bull (1962) found that the germination time of European black pine *(Pinus nigra* Arnold) was strongly correlated with seed weight.

Jack pine seeds germinate rapidly when moisture and temperature are adequate (Rudolf 1958). Schantz-Hansen (1941) reported the germination of a number of jack pine provenances within 7 days, with no detectable differences between sources. Some differences in germinative capacity were noted, but these differences bore no relationship to site, age of stand, or geographical location. Critchfield (1957) found significant variation in time of germination between seed sources of the closely related species, lodgepole pine *(Pinus contorta* Dougl. ex Loudon). Seed of northern and high-elevation origin germinated at 20° C more rapidly and more uniformly than that of coastal origin.

Materials

Representative collections of seed were made from jack pine stands throughout the range of the species in Canada and the United States. The specific place names, latitude, longitude, elevation, and stand descriptions of 100 collections were listed by Hoist (1963). The place names and geographic distribution of the 87 provenances used in this study are shown in figure 1.

Methods

Seed dry-weight, hypocotyl length, length of the largest cotyledon, and cotyledon number were measured for 50 provenances. Dry-weight of seed coat and seed volume were measured on 19 of the 50 seedlots. Seed dry-weight and cotyledon number only were recorded for an additional 37 provenances. Statistical tests were made of the relationships between the provenance mean values of these variables, and with annual normal growing degree-days at the place of origin. The latter index of climate is a temperature-time summation and is principally associated with the growing season measured from the same base temperature, 42°F (5.6°C).

Variations in sampling intensity were unavoidable owing to the small amounts of seed available and to limitations of time, but it is felt that the values presented here are reasonable estimates of the true values for these seed collections.

Seed volume and seed weight were determined from three sub-samples of 50 seed per provenance. Empty seeds were removed before counting by floating in 95-percent ethanol. Cut-tests showed at least 95 percent full seed after separation. The volume of 50 seed was measured with a mercury volume-meter. The seed was dried at 208°F (98°C) for 20 hours before weighing to obtain the dry-weight of 50 seed.

Germinants were grown from fresh seed sown in pots in a greenhouse. The pots contained moist soil covered with a half-inch layer of sand on which the seed was sown. The seed was lightly covered with crushed quartz to conserve moisture. Germination was evident after 7 days and complete when shading was removed at 10 days from sowing.

Seed coats were collected from 19 provenances as they were shed from germinated seed. An attempt was made to avoid the possible bias of collecting only those seed coats shed earlier or later. Three sub-samples provided the basis for calculating the mean dry-weight of 50 seed coats.

The lengths of hypocotyl and longest cotyledon were measured on 16 germinants per provenance (a pair of seedlings was taken at random from each of eight pots). Cotyledon numbers were recorded for 30 seedlings per provenance in another sowing (10 seedlings in each of three pots).

The number of growing degree-days associated with each provenance location was interpolated from the isogram of annual normal growing degree-days above 42°F (5.6°C) published by Boughner and Kendall (1959, Fig. 6) and reproduced here in figure 1. The isolines shown in Michigan and Wisconsin are extensions of the published curves and conform closely to the pattern of "growth degrees" above 50°F (10°C) for the lake States published by the Subcommittee on Forest Tree Seed Collection Zones (1957). The isogram for length of growing season (Can. Dep. Mines and Tech. Surv. 1957), based on a 42°F (5.6°C) temperature limit, is illustrated in figure 1 for comparison. Owing to the wide scatter of meteorological stations, particularly in the northern part of the jack pine range, these generalized curves

LOCATION OF JACK PINE SEED SOURCES
with
ISOGRAMS OF LENGTH OF GROWING SEASON
and
NORMAL GROWING DEGREE-DAYS ABOVE 42° F. (5.6° C)

Scale in miles
100 0 100 200 300 400

LEGEND
Length of growing season
(Atlas of Canada, 1957) ————
Growing degree-days
(Boughner and Kendall, 1959) — — — —

SEED SOURCES

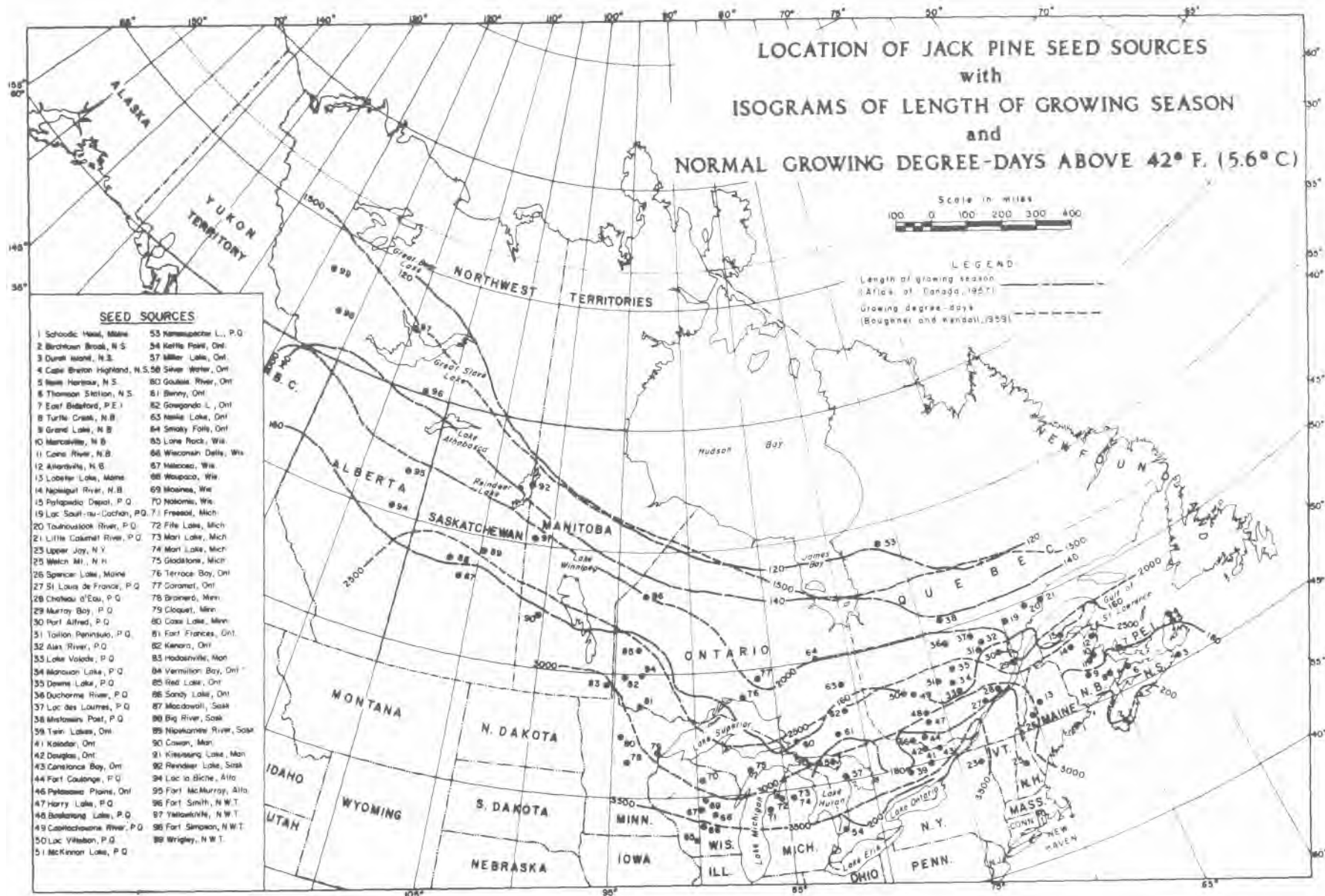|	
1 Schoodic Head, Maine	53 Kenauspacter L., P.Q.
2 Birchtown Brook, N.S.	54 Kettle Point, Ont.
3 Durell Island, N.S.	57 Miller Lake, Ont.
4 Cape Breton Highland, N.S.	58 Silver Water, Ont.
5 Nom Herteau, N.S.	80 Goulais River, Ont
8 Thomson Station, N.S.	81 Benny, Ont
7 East Bideford, P.E.I	82 Gowganda L., Ont
8 Turtle Creek, N.B.	63 Nellie Lake, Ont
9 Grand Lake, N.B.	84 Smoky Falls, Ont
10 Marcelville, N.B	85 Lone Rock, Wis.
11 Cains River, N.B.	66 Wisconsin Dells, Wis.
12 Allardville, N.B.	67 Metacoxa, Wis.
13 Lobster Lake, Maine	68 Waupaca, Wis.
14 Nepisiguit River, N.B.	69 Mosinee, Wis
15 Patapedia Depot, P.Q.	70 Notomis, Wis.
19 Lac Sault-au-Cochon, P.Q.	71 Freesoil, Mich.
20 Touhoustook River, P.Q.	72 Fife Lake, Mich.
21 Little Cascapel River, P.Q	73 Mart Lake, Mich.
23 Upper Joy, N.Y.	74 Mart Lake, Mich.
25 Welch Mt., N.H.	75 Gladstone, Mich
26 Spencer Lake, Maine	76 Terrace Bay, Ont
27 St Louis de France, P.Q	77 Caramat, Ont
28 Chateau d'Eau, P.Q	78 Brainerd, Minn.
29 Murray Bay, P.Q	79 Cloquet, Minn
30 Port Alfred, P.Q	80 Cass Lake, Minn
31 Torilon Peninsula, P.Q.	81 Fort Frances, Ont.
32 Alex River, P.Q.	82 Kenora, Ont.
33 Lake Valada, P.Q	83 Hadashville, Man
34 Manouan Lake, P.Q.	84 Vermilion Bay, Ont.
35 Downs Lake, P.Q.	85 Red Lake, Ont
36 Duchorme River, P.Q	86 Sandy Lake, Ont
37 Lac des Loutres, P.Q	87 Macdowall, Sask
38 Mistassini Post, P.Q	88 Big River, Sask
39 Twin Lakes, Ont.	89 Nipekamew River, Sask
41 Kaladar, Ont.	90 Cowan, Man.
42 Douglas, Ont.	91 Kississing Lake, Man.
43 Constance Bay, Ont	92 Reindeer Lake, Sask
44 Fort Coulonge, P.Q	94 Lac la Biche, Alta.
46 Petawawa Plains, Ont	95 Fort McMurray, Alta.
47 Harry Lake, P.Q.	96 Fort Smith, N.W.T.
48 Baskatong Lake, P.Q.	97 Yellowknife, N.W.T.
49 Capitachouane River, P.Q	98 Fort Simpson, N.W.T.
50 Lac Villebon, P.Q.	99 Wrigley, N.W.T.
51 McKinnon Lake, P.Q	

FIGURE 1   Distribution of jack pine provenances and isograms of climatic indices.

provide a better measure of variation over this wide geographic expanse than do values derived from specific weather stations nearest the places of seed collection.

Results

The mean values of seed weight and germinant characteristics are listed by provenance number in table 1, together with the values of the climatic index, growing degree-days at the place of seed origin. A value for mean germinant size (germinant index) was derived by adding to hypocotyl length the product of cotyledon number and cotyledon length. The appearance and 'relative size of the germinants is illustrated in figure 2, representing 30 provenances in six longitudinal groups from East (bottom) to West (top).

It is of interest to record that seed weight (all references herein are to mean dry-weight of 50-seed samples) was highly correlated with seed volume ($r = 0.98***$, $n = 19$). The correlation between seed weight and seed-coat weight was also very highly significant ($r = 0.82***$, $n = 19$). The fact that the two measurements were made on different sub-samples of seed could be expected to add to the error variation in the latter. There was sufficient range in the proportion of seed-coat/whole seed weight, from 31 percent to percent, to suggest that seed-coat thickness does not necessarily change in direct proportion to seed size, but this could only be determined by a more detailed study. The heaviest seed (S. No. 66) in particular had relatively light seed coats.

No differences between provenances were apparent in time or rate of germination. Differences in proportion of filled seed bore no relationship to seed origin or to seed size. In a preliminary trial of seed quality, practically all seed that sank in the liquid separation germinated on moist sand, indicating that filled seed were also viable seed.

The characteristics of the germinants of 50 provenances in relation to seed weight and to growing degree-days are shown in figure 3. The regression between seed weight and growing degree-days (fig. 3A) is significant at the 5-percent level. One provenance (S. No. 41) from an isolated stand in southern Ontario had exceptionally small seed. Calculations of regression including 49 and 86 provenances, and excluding S. No. 41, show that seed weight in general increases with longer and warmer growing seasons. Up to 68 percent of the variation in seed weight is accounted for by the associated crowing degree-days as shown below:

Number of provenances	F_b ratio[1]	$100r^2$ (percent)
50	6*	11
[2] 49	13***	22
87	44***	58
[2] 86	74***	68

[1] Levels of significance: *, 5%; ***, 0.1%.
[2] Omitting S.41.

Cotyledon length was highly correlated with cotyledon number ($r = 0.71***$), and the scatter evident in figure 3B was probably exaggerated by the fact that the two measurements were made on different samples of germinants.

Figures 3 C, D, E, and F illustrate the relationships between two dependent variables, cotyledon number and germinant size, and two independent variables, climatic index and seed dry-weight. Dry-weight alone accounts for higher proportions of the variation in the dependent variables than does the climatic index. However, if the exceptional provenance, S. No. 41, is omitted from the calculations, the effect of climatic index alone gains in relative magnitude until it is nearly equal to or better than that of seed weight:

		Independent variables	
Dependent variables		Growing degree-days (percent)	Seed weight (percent)
Cotyledon number,	*a*	33	64
Do.	*b*	49	53
Germinant size,	*a*	47	54
Do.	*b*	58	53

a = for 50 provenances.
b = for 49 provenances, excluding S. No. 41.

The multiple regressions of cotyledon number and germinant size against seed dry-weight and the climatic index taken together are illustrated in figures 4A and 4B. In each case about 75 percent of the variation ($100 R^2$) is accounted for, and both the independent variables make significant contributions to the functions. The relative magnitudes of the standard regression coefficients (b'_i) indicate that seed dry-weight alone contributed twice as much to variation in cotyledon number but that seedling size was affected about equally by each of the independent variables, seed dry-weight and growing degree-days. In both instances, the addition of growing degree-days to the functions contributed significantly more to the variance due to regression than did dry-weight alone ($F = 20.4***$ and $F = 43.8***$ respectively).

Conclusion

It has been shown that the size of jack pine germinants grown in soil and under normal conditions of light in a greenhouse was dependent upon both seed size and the climate of seed origin, as characterized by growing degree-days. Although seed size was significantly correlated with growing degree-days, the relationship was relatively weak for the 50 provenances that were subjected to detailed analysis. Provenances from areas with

Table 1.--Mean values for seed weight, germinant size, and climatic index for 50 jack pine provenances

Seed lot number	Dry weight 50 seed [1]	Hypocotyl length	Cotyledons	Length of longest cotyledon	Germinant Index [2]	Growing degree-days at origin	Dry weight 50 seed coats [1]	Volume 50 seeds
	Mg.	Cm.	No.	Cm.	Cm.	Hundreds	Mg.	Mm.^{3}
1	141	3.00	3.77	2.17	11.00	26	−	−
2	150	3.12	4.20	2.37	13.07	29	−	−
3	146	3.05	3.90	2.31	12.06	28	51	186
5	166	3.15	3.90	2.42	12.59	25	−	−
7	162	3.39	4.30	2.58	14.48	27	−	−
11	158	3.46	4.13	2.61	14.24	27	−	−
14	162	3.14	4.10	2.41	13.02	26	−	−
15	172	3.34	3.90	2.59	13.44	24	−	−
20	168	3.29	4.07	2.48	13.38	18	−	−
23	196	3.51	4.30	2.96	16.24	36	−	−
25	179	3.49	4.27	2.51	14.21	30	68	231
26	175	3.22	4.43	2.74	15.36	30	−	−
27	172	3.52	4.23	2.56	14.35	33	−	−
29	172	3.30	4.13	2.56	13.87	23	−	−
32	156	3.28	4.03	2.62	13.84	22	−	−
33	168	3.16	4.10	2.53	13.53	30	−	−
35	159	3.02	3.87	2.31	11.96	26	60	216
37	175	3.28	4.00	2.61	13.72	21	−	−
38	152	2.89	3.47	2.30	10.87	19	−	−
41	108	3.06	3.43	2.43	11.39	35	40	141
46	178	3.69	4.57	2.83	16.62	31	69	222
47	136	3.35	3.97	2.61	13.71	30	−	−
50	154	3.09	4.07	2.49	13.22	26	−	−
53	141	2.46	3.79	2.04	10.19	11	56	195
57	163	3.32	4.23	2.62	14.40	32	−	−
60	137	3.41	3.73	2.58	13.03	26	−	−
61	158	3.61	3.90	2.81	14.57	27	−	−
62	146	3.16	3.77	2.38	12.13	25	−	−
63	159	3.32	3.93	2.50	13.14	23	58	207
64	153	3.09	3.93	2.31	12.17	20	−	−
66	255	3.54	4.47	2.94	16.68	36	70	294
70	167	3.59	4.50	2.65	15.51	29	64	213
72	170	3.41	4.17	2.61	14.29	32	−	−
73	203	3.59	4.47	2.71	15.70	33	73	255
76	141	3.05	3.67	2.26	11.34	22	59	186
77	155	3.14	3.87	2.55	13.01	19	59	198
78	202	3.52	4.67	2.83	16.74	33	−	−
80	162	3.29	4.33	2.72	15.07	32	−	−
82	149	3.07	4.03	2.48	13.06	28	58	186
85	131	2.96	3.87	2.30	11.86	26	−	−
86	152	3.14	4.00	2.48	13.06	21	55	192
87	197	3.24	3.87	2.68	13.61	26	−	−
89	152	3.04	3.87	2.26	11.79	24	−	−
91	161	3.17	4.00	2.51	13.21	21	62	204
94	151	2.92	3.77	2.31	11.63	23	−	−
95	172	2.95	4.13	2.31	12.49	21	60	210
96	180	2.98	4.00	2.44	12.74	17	−	−
97	131	2.38	3.43	1.99	9.21	15	54	168
98	179	3.09	3.87	2.40	12.38	18	71	225
99	145	2.89	3.70	2.33	11.51	17	60	183

[1] Based on 3 subsamples of 50 seed per provenance.
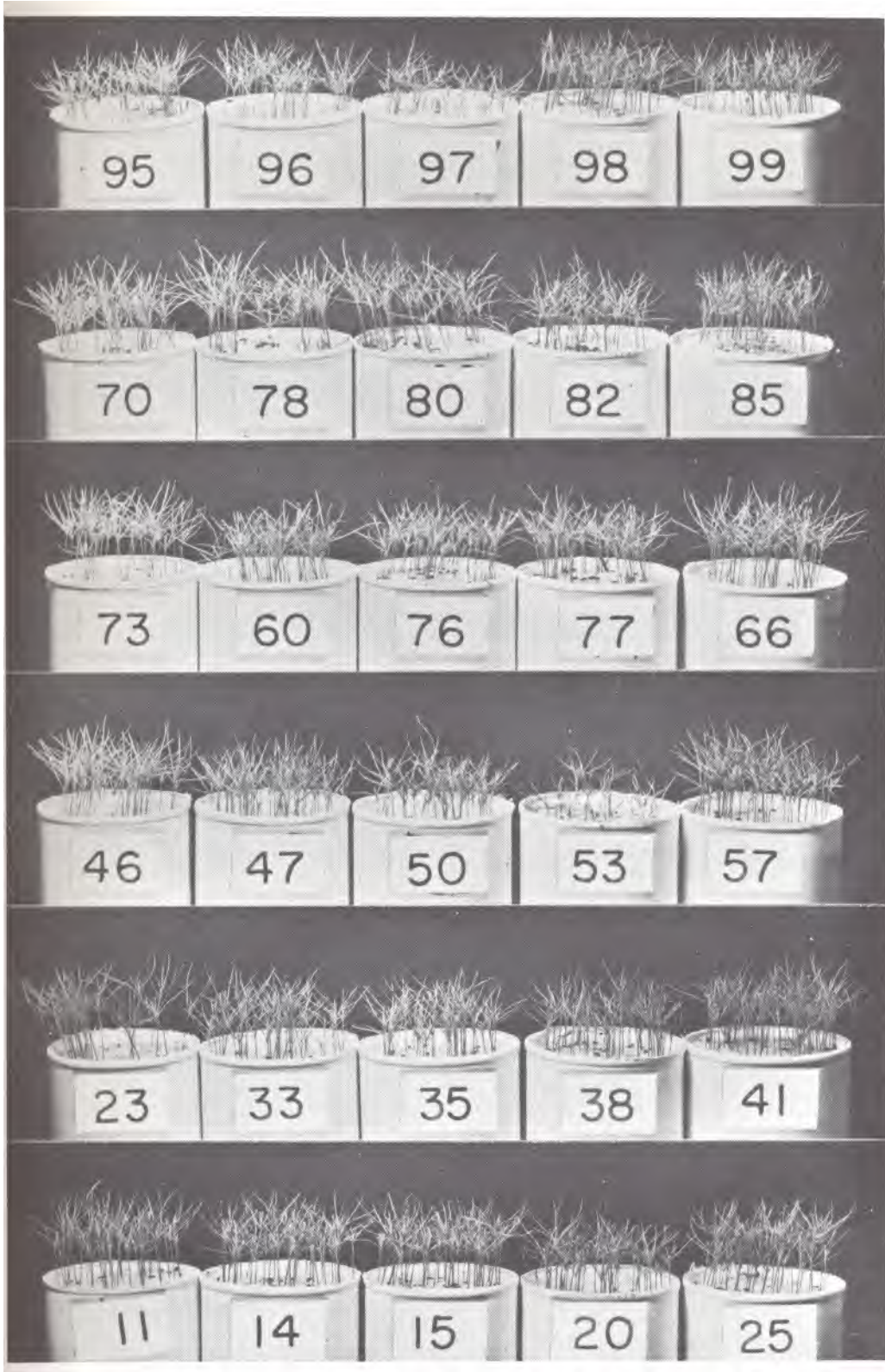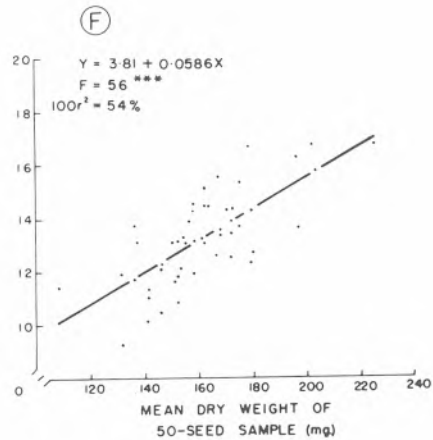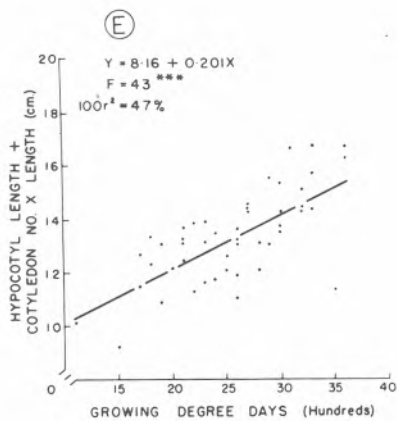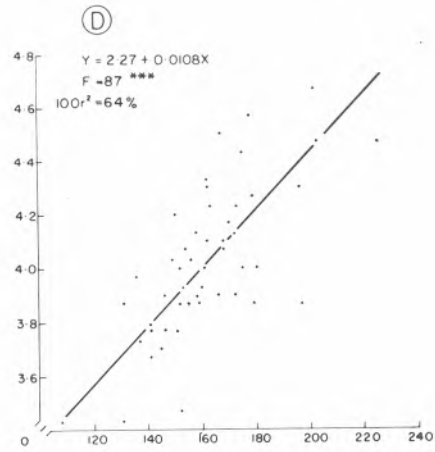[2] Germinant index is the hypocotyl length in cm. plus the product of cotyledon number and maximum cotyledon length.

FIGURE 2. — Jack pine germinants of 30 provenances
ranging from East (bottom) to West (top).
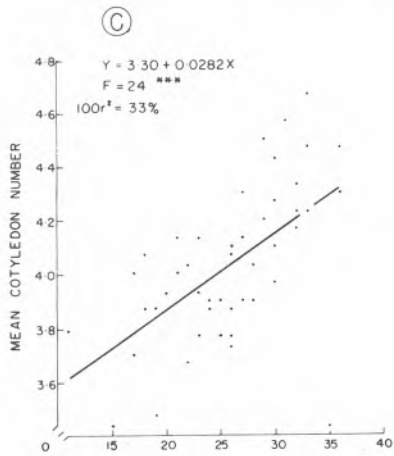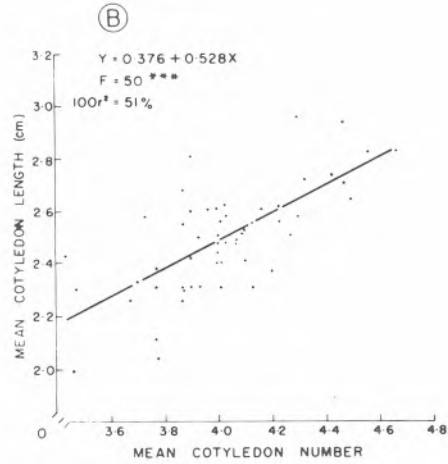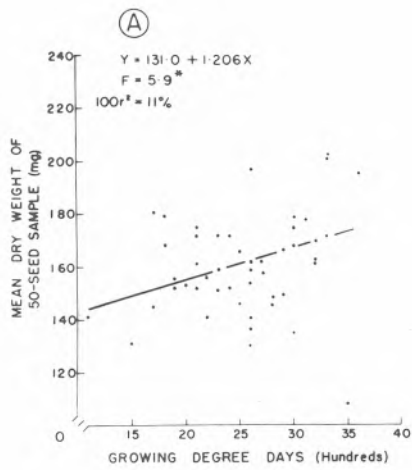
FIGURE 3. — Simple regressions between seed weight, growing degree-days, and characteristics of germinants of 50 jack pine provenances.
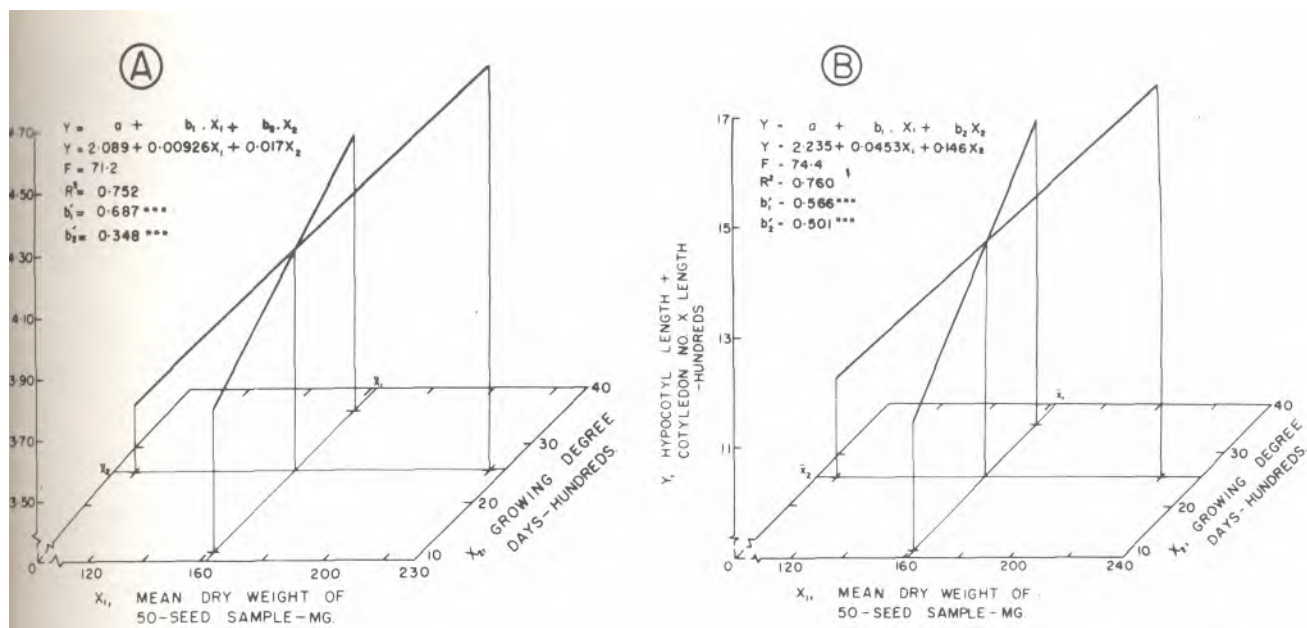
FIGURE 4. - Multiple (2-variable) regressions between seed weight, growing degree-day, and characteristics of germinants of 50 jack pine provenances.

longer and warmer growing seasons were inherently more vigorous in their development of the cotyledonary system, including the hypocotyl, independently of seed weight. Such analyses of germinants grown under very uniform conditions may prove to be useful for early genetic evaluations of vigor and growth potential, especially when compared with the results of experiments dealing with older seedlings.

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