THE GROWTH OF WHITE SPRUCE SEEDLINGS IN RELATION TO TEMPERATURE SUMMATION INDICES

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ABSTRACT

The growth (dry weight basis) of white spruce seedlings during their first and second growing seasons was measured. The relationships between seedling growth and time expressed chronologically and in terms of degree days were determined. When degree days were used the relationships were exponential and a zero reference temperature of 36° F. seemed preferable, although temperatures of 34, 38 and 42° F. might be used. The possible advantages of using such a relationship rather than the more conventional one of growth per calendar day are discussed with reference to nursery practices.

In the intensive management of most plant crops every economically justifiable effort is made to maintain those factors which determine crop quality and quantity at optimum levels. The requirements of a particular crop, however, change during the growing season and the levels of certain factors often must be adjusted. Improvement of fertility, for example, normally is accomplished by adding nutrient elements. It is of considerable importance then that the requirements of a crop be assessed and met accurately during its growth and in order to do this an accurate measure of the crop's development is necessary.

Many agricultural crops during the course of the growing season show associated morphological changes such as flowering, fruiting, etc., and applications of water, fertilizers and the like may be made in relation to these ontological changes. For other crops, including most tree seedlings, the morphologic changes are fewer and often less marked and it has been customary to use the calendar as the basis for making treatments. Obviously, some allowance has to be made for differences in location. Thus if one-year-old white spruce seedlings at a southern Ontario nursery, should be fertilized in mid-May, similar stock at a northern Ontario nursery, might not receive an equivalent treatment until mid-June. A problem arises in that the weather changes from year to year in any one place and if the southern nursery has a cold wet spring and the northern a warm one, the difference in treatment dates in the above example may only be two weeks and not four. A similar problem obviously exists when only one nursery is considered. Such modifications in treatment dates are dependent on the experience of the person making the recommendation and are often variable and not too objective. There is, therefore, a need for a system whereby the time of application of treatments can be related to measurable stages in the development of the crop.

It can be argued that, apart from photoperiodic effects, if a crop receives an optimum supply of light, water, nutrients and air, the main variable to affect growth is temperature. Crop geographers and agronomists have been

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particularly concerned with attempts to establish some temperature efficiency index whereby the length of the physiological growing season could be related to climatological data (Klages, 1942). One of these methods is the Temperature Summation or Remainder Index. This index comprises the summation of daily positive temperatures above some established reference zero. Thus, if the established zero is 42°F and the daily mean is 53°F then the positive temperature is 53 - 42 or 11°. Other temperature indices have been established but in Canada there has been considerable interest in the Temperature Summation Index, and during 1962 the Meteorological Branch of the Canada Department of Transport began publishing this index—termed Heat Units with a zero base of 42°F—in its Monthly Meteorological Summaries. The possible use of such an index in relation to the development of seedlings in forest nurseries would appear to be a method by which time of treatment application might be related to seedling growth. It is thus necessary to determine what relationships may exist between the growth of the seedlings and a measure of heat units, particularly as compared with growth related to calendar time. The purpose of this paper is to present some data for white spruce (*Picea glauca* (Moench.) Voss) relevant to this matter.

The growth of white spruce seedlings during their first two years of development (1960 and 1961) was determined at approximately fortnightly intervals, at Swastika Nursery in northern Ontario. These determinations were made as part of a study on nutrition. Since daily weather records were available, for 1960 from Swastika, approximately 20 miles east of the nursery, and in 1961 from the nursery itself, it was thought that these data might be valuable in establishing the relationships between growth and heat units. Seedling growth was measured as total seedling dry weight after drying at 70-80°C in a forced draft oven to constant weight. In 1960, fourteen samples were taken, each of four hundred seedlings. The sampling began in early June when seedlings were cotyledonous and ended in late October. In 1961, thirteen samples each of one hundred seedlings were taken; the first sampling was done in late May and the last in early November.

The seedling dry weights and associated calendar and degree days are given in Table 1. The data for 1960 will be considered first.

If the growth of the seedlings with time is considered in the conventional manner as shown in Figure 1 it will be seen that a curvilinear relationship exists; the relative rate of growth increases rather rapidly at first, declines later and from approximately 70 days on remains fairly constant. It is interesting to note that the seedlings make about fifty percent of their growth after the first of September. In Figure 2 the same growth data are plotted against degree days instead of chronological time and it will be noted that the forms of the curves are different from that in Figure 1 and are of the exponential or "compound interest" type. An exponential relationship such as this is common in the early growth of many organisms and allows for simple mathematical expression as a straight line:

$$\text{Log } Y = b \text{ Log } X + \text{Log } a$$

where Y = growth expressed as dry weight (mg.)

X = time as degree days

a = Y-axis intercept.

TABLE 1
MEAN SEEDLING DRY WEIGHTS (MG.) AND RELATED TIME UNITS—
DAYS AND DEGREE DAYS

	Sample No.	Mean Seedling D. Wt. (mg)	Time Days	Cumulative Degree Days (Heat Units) above			
				34°	36°	38°	42°
1	1	1.7	1	716	647	581	447
	2	2.2	9	920	833	749	579
	3	4.1	21	1214	1103	995	777
	4	4.9	31	1450	1319	1191	933
	5	7.9	42	1760	1607	1457	1155
9	6	9.3	52	2041	1868	1698	1356
	7	14.0	63	2328	2133	1941	1555
	8	17.0	73	2592	2379	2167	1741
6	9	27.3	86	2960	2721	2483	2003
	10	33.3	93	3128	2875	2627	2115
0	11	39.6	111	3401	3112	2828	2251
	12	46.6	120	3475	3171	2875	2279
	13	53.9	133	3619	3289	2967	2329
	14	58.2	146	3623	3291	2967	2329
1	1	73.7	1	109	92	80	60
	2	64.5	18	320	272	230	156
	3	62.2	25	397	339	287	193
	4	75.3	39	667	585	509	367
	5	111.2	54	998	888	784	586
9	6	149.3	67	1376	1241	1111	861
	7	227.5	81	1809	1646	1488	1182
6	8	236.5	88	1980	1803	1631	1297
	9	249.6	102	2293	2088	1888	1498
1	10	289.4	117	2733	2498	2268	1818
	11	405.7	147	3096	2817	2545	2025
	12	439.2	158	3186	2895	2612	2072
	13	502.9	177	3283	2960	2665	2109

FIGURE 1. Relationship between mean seedling dry weight and time (calendar days) - 1960.

TABLE 2

REGRESSION AND EXPONENTIAL EQUATIONS FOR GROWTH OF WHITE SPRUCE
—1960. W = SEEDLING DRY WEIGHT (MG.); X = TIME AS DEGREE DAYS OR
CALENDAR DAYS

Degree Day	Regression Equation	Correlation coefficient R	't' for regression coefficient
42° F.	$\log W = 1.0017 \log X - \log 1.111$	0.995	37.65
38° F.	$\log W = 1.0014 \log X - \log 1.073$	0.977	15.87
36° F.	$\log W = 1.0013 \log X - \log 1.138$	0.977	45.98
34° F.	$\log W = 1.0011 \log X - \log 1.142$	0.997	45.92
Calendar Days	$\log W = 1.0254 \log X + \log 2.344$	0.984	18.40

FIGURE 2. Relationship between mean seedling dry weight and degree days using four different zero temperatures - 34, 36, 38 and 42°F - 1960.

The growth data for the 1960 white spruce seedlings were rectified and linear regressions of the form represented by the equation above determined. The results are presented in Table 2. The correlation coefficients are all highly significant (for $P = 0.01$, $R = 0.661$, 12 degrees of freedom). The 't' values for the regression coefficients which are a measure of the "goodness of fit" of the curves to the data are all significant at the one percent level (for $P = 0.01$, $t = 3.06$) but best fit is obtained when zero temperatures of 36° F. or 34° F. are used. From Table 1 it will be noted that when 42° F. and 38° F. are used as zero temperatures, increase in seedling size is not associated with an increase in degree days for the last two samples. This has been noted previously for two-year-old white spruce (Armson, 1960) and would indicate that lower zero temperatures should be used.

The relationships between growth and time expressed as degree days and calendar days for the seedlings during their second year of growth are given in Table 3. All correlation coefficients and 't' values are significant at the one

TABLE 3

REGRESSION AND EXPONENTIAL EQUATIONS FOR GROWTH OF WHITE SPRUCE
—1961. W = SEEDLING DRY WEIGHT (MG.); X = TIME AS DEGREE DAYS OR
CALENDAR DAYS

Degree Day	Regression Equation	Correlation coefficient R	't' for regression coefficient
42° F.	$\text{Log } W = 1.0010 \text{ Log } X + \text{Log } 60.26$	0.974	20.90
38° F.	$\text{Log } W = 1.0008 \text{ Log } X + \text{Log } 57.55$	0.987	20.89
36° F.	$\text{Log } W = 1.0007 \text{ Log } X + \text{Log } 57.55$	0.987	20.89
34° F.	$\text{Log } W = 1.0006 \text{ Log } X + \text{Log } 56.83$	0.985	18.69
Calendar Days	$\text{Log } W = 1.0137 \text{ Log } X + \text{Log } 58.07$	0.974	13.79

percent level but there is less difference in goodness of fit for different zero temperatures and this reflects the fact that on this occasion using zero temperatures of 42° F and 38° F the number of degree days increased to the end of sampling. This might indicate that sampling should have been continued later than it was. Again, however, there is a better fit if a temperature summation index is used instead of calendar days.

It may be concluded, for those engaged in the intensive culture of conifers, especially white spruce, that, for a given provenance, if the size of seedlings (expressed as dry weight) to be produced is specified, then the expression of the growth of the seedling with time may be expressed mathematically in terms of readily obtained climatological data, namely degree days or heat units. Tentatively, the use of 36° F as a zero reference temperature would seem preferable, although 42° F would be suitable. Crop treatments, such as fertilizer amendments and possibly root pruning and lifting, could then be made in relation to degree days measured as the growing season progresses, having previously established the most appropriate time for treatment.

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