WEATHER AND FOREST SEEDLINGS

by

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1. Introduction

This report is part of an ongoing study to determine if and how climatic elements influence the growth of forest seedlings. The total study is directed to reducing losses of seedlings before they are transplanted into the forest. This study was commissioned by the Canadian Forestry Service because there has been considerable loss of seedlings through death prior to planting in the field. I was asked and commissioned to

(1) list environmental parameters that are significant to the growth of seedlings but are not being measured;

(2) list instrumentation (with costs) required to conduct the monitoring necessary to describe the overwintering environment;

(3) recommend changes in overwintering procedures, where possible, to reduce seedling mortality;

(4) summarize data and prepare a report giving methods and conclusions.

In my study, I twice visited each of four stations where seedlings are being grown to be planted in forested areas:

St. Regis, Hinton, Alberta;

Pine Ridge, Smoky Lake, Alberta;

Prince Albert Forestry Station, Prince Albert, Saskatchewan; and

Pineland, Hadashville, Manitoba.

I also visited the Northern Forest Research Center in Edmonton. In all places I was welcomed, given a tour of the facilities, and provided with much information on the problems about which I was concerned. The people with whom I spoke recognized that my problem was also their problem.

2. Station Procedures

As might be expected, the mortality varied from station to station, and from one species of tree to another. I was presented with few actual data although I inquired. I wondered whether the different sets of plants were kept separate so that one could associate mortality with a specific treatment. Each station seemed to believe that the record of its station was good compared with those of other stations.

2.1 Hinton

At Hinton, seedlings are usually started in March. These are moved out of the greenhouses in May, and are planted in the forests before winter. The second planting occurs after the first seedlings leave the greenhouses. These are moved out of doors where they are allowed to harden. Pine seedlings are usually planted out in the forest areas by September. Spruce seedlings tend to be too small for planting into the forest areas before winter. These are kept out of doors and are overwintered. The third planting, in June or early July, are fed for growth for about five weeks. Then the fertilizer mixture is changed and the temperature allowed to fall within the greenhouses. In September they are moved out of doors and prepared for overwintering in the containers.

For overwintering, the pallets are placed on frames that keep them about 5 cm above the ground. Around a number of pallets a board is placed upright to protect the seedlings, the height of the top of the board being similar to the tops of the pallets. After a snowfall which covers the seedlings, these are further protected by cardboard placed over the top of the snow and stapled down to the edges of the pallets. Later snow lies on the cardboard and between the pallets, or between pallets and the boards around the area. Chinooks frequently remove the snow in open areas. The protection given the seedlings keeps at least some of the snow above and around the seedlings during one year in two.

When spring comes, and the seedlings begin to grow once again, they are kept moist and given fertilizer until May or June, when they are planted out. Seedlings tend to be smaller at Hinton at the time of planting in forests than at the other stations.

2.2 Pine Ridge

At Pine Ridge, there are large areas of land planted with spruce and pine trees to be transplanted into the forest areas as bare root stock when they are ready. They also have plants growing in containers in greenhouses. The first planting occurs in March, to be removed from the greenhouses to shade areas in May or June, so that the greenhouse space may be used once again for June planting. Although most of the March seedlings are kept until the following spring for planting in the forests, some are taken by purchasing firms. Although the station recognizes no responsibility for these, the officials realize that there are advantages. Plants are flushing and ready for planting at about the same time as the surrounding forest areas are ready. Also, wet lands do not hinder greatly the personnel who do the planting, but trucks would have difficulty carrying the seedlings into the area.

June seedlings are usually kept over until the following spring. The overwintering is done in shade areas, with snow fencing at a height of about 2.5 m above the surface. For some plants the pallets are placed on 2" x 4" lumber on the asphalt. Other seedlings are removed from the pallets and placed on the ground. Around the shade area there is a strip of burlap, about 30 cm high next to the ground, to protect the seedlings. The snow fencing over the seedlings permits the snow to filter down to cover them when there is enough snow. Also, this protects the seedlings from the direct sun and so tends to keep the snow longer in spring than it otherwise would remain. Temperature observations are taken in this shade area at a number of locations, both in the air and in containers, the observations being recorded throughout the twenty-four hours.

At Pine Ridge, there are seedlings located in three other regions. One of these is in an open area among trees, protected from wildlife by a snow fence. In another area a trench was dug and four pallets placed in the depression, with the tops of the pallets about level with the top of the ground. The space around the pallets was back filled. Thus the situation approximated that found for bare root stock. In another area a small number of pallets are kept off the ground but the space below the pallets is protected because gravel is piled around the pallets to cut off the flow of air into the space below.

2.3 Prince Albert

At Prince Albert, the seedling program is similar to that at Pine Ridge. There is a large area where seedlings are grown in the field for later transplanting into forest areas. Planting in containers is done in April. They are moved to shade areas in June, and usually into forests in the fall. June planting usually stays in the greenhouses until September but with a change in the fertilizer supplied and a lowering of the temperature during the last half of the period for hardening. The seedlings are moved to shade areas for overwintering.

Snow drifts through the snow fences to give the plants protection. A 5-cm snow cover will give some protection from the cold, even in early winter.

The seedlings are sent to forest areas for planting during the spring. They do not differentiate between the mortality of bare root stock and that of containerized seedlings.

2.4 Pineland

At Pineland, the planting of seeds starts in February, but the seeds are not warmed for germination until March. They are moved to shade areas in May, for planting in forests before winter. June seedlings are moved to shade areas in September for hardening. Spruce and red pine seedlings are carried through the winter season. Jack Pine seedlings are ready for planting in the fall because of the more rapid growth.

The "shade area" differs from those of the other stations in two ways. There are heating pipes in the ground below. These can be turned on for warming the seedlings, a procedure that has been found useful in early spring. When warm air covers the district, the snow above the seedlings melts, and the seedlings melt too. The peat moss in which the roots lie does not thaw so rapidly. The needles of the seedlings lose water, which is not replaced from below. This process can damage the seedlings. The heating pipes melt the peat moss and so permit water to pass to the needles and protect them from drying. Secondly, the snow fences are places within 15 cm of the seedlings. The space between the pallet and snow fence fills with snow readily. This usually remains unless the weather becomes very warm.

There is one test being run at the station. A number of pallets are piled together in a small area. They are covered by snow and then by cardboard and plastic to protect the plants from the melt. The snow which falls subsequently, lies on top of the protection. The staff expects to keep the seedlings in this cache until May. They will then be brought out, fertilized for a short time, and sent into the forest areas for planting.

3. Critical Periods for Seedlings

Weather and climate affects the growth and viability of forest seedlings. During the growth period when the seedlings are in greenhouses the effects of weather are slight and can be ignored for the purpose of this study. There is an effect of the sun on a sunny day heating the greenhouse but such effects can be compensated for.

3.1 Hardening off

When the plants are carried outside the greenhouse the weather and its changes influence their survival. Rainfall or lack of it is usually compensated for by watering the plants. The cessation of growth and hardening of the buds, etc., for preparation for winter are changes which are temperature-dependent. Data should be kept of the temperature regime and the length of time the seedlings are given for hardening before they are subjected to sub-freezing temperatures. Maximum and minimum temperatures for each day should supply all the data needed.

All discussions seem to suggest that the critical period extends from the time of the first frost until the plants are ready to withstand winter temperatures. There appears to be a hardening process that continues during this period so that the seedling can stand colder temperatures as the period extends itself. A continuation of the observations of maximum and minimum temperatures with assessment of frost damage, if any, will, I believe, help to identify the effects of temperature during this period.

Conversations with forestry scientists at the various establishments I have visited consistently indicated that the temperatures of the seedling roots may have significant effects on the future vitality of the plant. At Pine Ridge some temperature probes are placed to record temperatures in the vicinity of the roots but these have not yet been analyzed. Data are then lacking on this feature of the microclimate of the seedling.

Obviously the roots of seedlings in the forest and also in containers being overwintered drop to and below freezing. Is there a value below which damage occurs to the roots? In what manner does this value change during the hardening period? At what temperature in the spring (or during a thaw in winter) does the root begin to become active and begin to supply moisture to the plants? These are questions that may be investigated if a program of root temperatures is initiated. Such a program may lead to knowledge of a cause for seedling mortality.

If root temperatures are a factor in the vitality of seedlings, data should be collected to discover whether the root temperatures of seedlings placed on frames which permit cold air to penetrate below the pallets reach critical temperatures not reached by seedlings placed on the ground. If this proves to be the case, the practice of placing pallets off the ground should be changed to cut off the cold from penetrating the containers from below. The practices at the different stations show different methods by which this can be accomplished.

3.2 Periods of drying

Another phenomenon associated with weather that affects seedlings as it affects all living vegetation is evaporation. Evaporation is a natural process associated with the supplying of food by the roots to the stems and leaves of the plants. To supply water for evaporation during the summer, foresters water the seedlings regularly so that the peat moss or soil does not dry completely.

A time when evaporation is critical for the life of the seedling is during a thaw in the winter such as is associated with a chinook, or in the spring when the snow has melted from around the seedling. Under these circumstances the warmed needles will tend to evaporate water into the dry air. But until the soil is thawed, little water will flow into the roots from the soil and through the stem to the needles. These then will tend to dry, resulting in the loss of vitality.

Some recognition of this stress can be learned from information available on soil and air temperatures at Ellerslie, Alberta, during the period 1-7 April 1976. This was a sunny, warm week. The snow had just left the ground and soil temperatures to 100 cm in the early morning of 1 April were close to $-1^{\circ}C$, i.e., at the freeze-thaw temperature of the soil. During the week, the successive maximum temperatures were: 3.3, 5.6, 9.1, 13.3, 15.8, 19.4, and $17.4^{\circ}C$. In the soil at 1 cm, thawing did not occur until 3 April when the temperature there rose briefly just above freezing, although the air temperature went to $9.1^{\circ}C$. On 5 April, with the air temperature rising to $15.8^{\circ}C$, the soil at 5 cm first thawed and its temperature rose to $1.5^{\circ}C$. On the following day, the soil at 10 cm thawed and did not freeze thereafter. At 20 cm the temperature rose first above freezing at 20 h, 7 April. Considerable heat must be supplied from above to melt the soil and so to permit a free passage of water to the plant's needles. The occurrence of red belt in the Rockies is evidence of the effects of evaporation on mature vegetation.

Although evaporation is a critical process for the plant, there is no scientific method which gives satisfactory answers to the rate of evaporation. Thus we can subjectively recognize that the seedling is drying but are unable to calculate the rate. Geiger (1965, p. 255) presents a formula for evaporation from vegetation. If V is the evaporation in millimetres of water per hour,

$$V = C(e - E')$$

where C is a constant depending on the wind speed and the units used, E' the vapor pressure in the air, and e the saturation vapor pressure at the temperature of the surface. In a chinook condition one may take the temperature of the snow surface as $0^{\circ}C$. If the dew point of the air is $-7^{\circ}C$ (which is a reasonable value for chinooks in Calgary) and the wind speed is 10 m s^{-1}, the evaporation calculated by the formula is 0.0005 mm/h^{-1} or 0.012 mm/d^{-1}. Such values cannot explain the rapid evaporation of snow during a chinook when at times 10 cm snow (10 mm water) disappears in a day. With seedlings, the temperature of the needles will be above $0^{o}C$, and so evaporation will be even more rapid than from a snow surface if the water is available to the seedlings.

One suggestion for measuring evaporation that came during my discussions with forecasters was an adaptation of the method used in lysimeters. A pallet of seedlings can be weighed when the snow over it is low and a chinook is imminent. Then it can be protected from precipitation (if any) and weighed at intervals. The drop in weight will not be much. Whether it is worth the cost of scales suitable for the work is something I hesitate to judge. Certainly, people familiar with seedlings will be capable of making a subjective judgement of the amount of evaporation during a mild day.

4. Recommended Records to be Kept

Based upon the above analysis, I can make my recommendations on the climatological data desirable for the study of seedling mortality. These are statistics which should be available to a scientist who, knowing the mortality of the seedlings at the end of the season, can identify those events which may have been responsible for a high mortality.

4.1 Daily maximum and minimum temperatures

First, the data should include daily maximum and minimum temperatures from the time the seedlings are taken from the greenhouse for hardening until they are removed from the station for planting. If a climatological station is within 30 km, the data from this station could supply the desired information. In general the maximum temperatures do not vary much in that distance. The minimum temperature varies over short distances because of topography, shelter of trees, and closeness to bodies of water. The value from the climatological station unadjusted could err for the station, but, as stated in the next paragraph, data from the station can provide the adjustment necessary.

4.2 Grass minimum temperatures

Information is needed for the air in the vicinity of the plant. One of the probes described below should be located above but close to the tops of seedlings in a typical location. This might be attached to the stick designed to measure the snow depth. When the snow covers the seedlings, the location of the probe can be placed higher on the stick but not far above the snow surface. A reading early in the morning in this position will give very close to the minimum temperature. This value will give the minimum temperature of the seedling itself until snow covers the plant.

4.3 Snow depth

Another measure that should be recorded regularly is the depth of snow over the seedlings. If a ruler is placed near the seedlings such that it will remain upright during the winter, then a reading of the depth of snow cover can be taken without disturbing the seedlings or the snow. Such information should be available from the various areas where the seedlings are being overwintered. A deep snow cover is an excellent protection from loss of heat by the underlying soil.

4.4 Soil and peat moss temperatures

To check the effects of the root temperatures on vitality, temperature records for the root area should be kept. These can be taken by temperature probes inserted in the container at the level of the roots. Such temperatures should be taken in different locations if variations in such values can be expected. If the pallet is placed so that air can circulate below the containers, a probe should be located in this space to determine the degree to which heat is lost by the root area to this space below. For comparison purposes, another probe should be located below containers which have been placed on the ground or asphalt.

4.5 Summary

In summary, the following is a list of weather records that should be kept.

For the area:

1. Maximum screen temperature, daily
2. Minimum screen temperature daily
3. Surface or near surface temperature 0830 h and 1630 h, until snow cover; 0830 h while there is a snow cover of 10 cm or more.

For each of the different areas where seedlings are kept:

1. In the root area, 0830 h and 1630 h when there is no snow cover or until 15 November; 0830 h only with a snow cover (2.5 + cm) or after 15 November.
2. In the air space below the seedlings, as with 1.
3. Below the seedlings placed on ground or asphalt, as with 1.

4. Snow depth, once daily, 0830 h.

For comparison purposes, one set of observations could be taken in the bare root seedling area.

A discussion in the Appendix analyzes data to explain the frequency of observations. As stated there, the daily observations should be continued over weekends during or immediately after a thaw.

5. Current Weather Records for the Four Stations

At the present time, weather records are being kept at Smoky Lake, but at the other three stations, the information is scanty.

5.1 Hinton

No weather records are being kept at the Hinton Forestry Station. However, the Hinton Airport is not far distant and the data they collect will give an adequate over-all picture of the situation at the forestry station. A thermograph would be a useful means of checking the airport observations. They need probes to measure temperatures at the soil-air or snow-air interface and also within and below the seedlings. At least five probes seem necessary, one for the surface temperature and two sets of two to measure sub-surface temperatures in two different locations. A third pair might be useful if the station were to have three different conditions under which the seedlings were kept over winter. Rulers to measure snow depth at the different locations of the probes are also necessary. On one of these, the probe for air temperatures might be attached.

5.2 Pine Ridge, Smoky Lake

Currently the station takes weather observations, maximum and minimum temperatures and precipitation for Alberta Forestry. They also have probes which can be attached to recorders. They are currently recording temperatures around the seedlings in the shade area. They are carrying out experiments in other plots as well, and for these, probes and rulers are also needed. They apparently have sufficient probes for their needs if they eliminate some of their current observations which seem to me to be superfluous.

5.3 Prince Albert

Here, as with Hinton, no weather records are kept during the winter. The Prince Albert Airport records probably give as good records as would be kept at the station for the general weather picture in winter, although the thermograph they have would be a check on the difference between the two stations if kept in operation.

They, as with Hinton, need temperature probes and rulers to measure snow depth to determine the environment of their seedlings. They need at least 7 probes, one for air temperature and three sets for temperatures in the root area and below it. One of these sets should be put into their bare root area for comparison purposes.

5.4 Pineland

At the Pineland station, there is a Stevenson screen which is not used. The stations of Pinawa and Beausejour are not far distant. However, I recommend that a thermograph be installed in the screen to check on the differences between Pineland and these two stations. The station should have a set of probes over the main area of overwintering, and one probe in the snow cache would give information on the conditions there. Two other sets of probes to be used at other locations within the station, as, for example, among bare root stock, could be used to advantage.

5.5 Equipment required

In summary, I suggest:

Hinton:	1 thermograph (AES)	$325
	1 thermometer stand (AES)	175
	1 digital thermometer (Sci. Assoc. #140-2)	149
	5 probes (Sci. Assoc #140 A3)	75
	Recharger (Sci. Assoc. 140 D)	6
	3 rulers	3
		$733
Pine Ridge:	6 rulers	$6
Prince Albert:	1 thermograph (AES)	$325
	1 digital thermometer (Sci. Assoc. #140-2)	149
	7 probes (Sci. Assoc. #140 A3)	105
	Recharger (Sci. Assoc. #140 D)	6
	3 rulers	3
		$588

Pineland:	1 thermograph (AES)	$325
	1 digital thermometer (Sci. Assoc. #140-2)	149
	8 probes (Sci. Assoc. #140 A3)	120
	Recharger (Sci. Assoc. #140 D)	6
	4 rulers	4
		$604

In these listings, AES refers to Atmospheric Environment Service which has meteorological instruments. Sci. Assoc. refers to Science Associates, Box 230, 230 Nassau Street, Princeton, New Jersey 08540. I am not familiar with the digital thermometer, but the reputation of the firm is good and others who know about such instruments feel it would fill the need. The prices quoted are those given to me in October, in U.S. funds. There will need to be an adjustment because of possible increases in prices, as well as the exchange into Canadian funds. Because neither is known, I have copied the figures given me.

6. Recommendations

It is difficult for me to make firm recommendations about practices to be followed. In my discussions, I obtained very little evidence about comparative successes of different processes, except that several foresters mentioned that the drying out of seedlings under chinook conditions or in the early spring caused loss of vitality of the seedlings. This relationship is easily understood. A solution is not so easy to propose.

At Hinton, where chinook conditions are most common, they attempt to keep snow over the seedlings to protect them. On those occasions when the snow cover goes, there appears little that can be done. At Pineland, heating pipes have been installed under the seedling plot. When in the spring a thaw removes the snow, the heating pipes are turned on. This thaws the ground so the roots are able to replace the water lost from the needles.

The method at Pineland to combat drying would not be suitable for the situation in Hinton. It might be worthwhile to adopt it at Pine Ridge and Prince Albert, but this possibility needs to be examined in terms of the cost-benefit ratio.

One situation which may be critical is the root temperatures. Little has been done at the stations on this possibility, but if the program proposed is developed, information will be forthcoming. I suspect, as I have indicated above, that the roots can be subjected to too low temperatures when they are in pallets with air spaces below. It seems worthwhile not only to examine the environment of such seedlings, but also to try to protect some of the roots. Some attempts are made to use snow around the pallets for this purpose. Wood and burlap are also used. To me, the protection should be such that the movement of air into the space from the outside is at a minimum. The burlap at Pine Ridge fails to do this. Burying the bottoms in trenches is excellent, but the work for large numbers of seedlings would be great. Straw or sawdust piled around the pallets would cut to almost zero the exchange. If temperatures in the space are compared with various systems of stopping the air flow, the results will lead to a knowledge of the best system of banking the pallets.

7. Summary

The current literature recognizes that the growing of forest seedlings in containers results at times in a high mortality of these seedlings. Some causes are already known but often the foresters are only vaguely aware of the reason for the deaths.

The program described in Sections 5 and 6 suggests that data be collected of the temperatures of the seedlings. These compared with the subsequent mortality rates should, after two or three years, identify situations which appear to cause losses in vitality and sometimes death. Changes in programs will then be initiated to eliminate those programs which cause high mortality. With these procedures, there should be small experimental plots managed somewhat differently but with weather records and resultant mortality noted. The mortality from these sets should lead to eliminate programs that are unsuitable for seedling growth. Gradually programs suitable for seedling growth on the prairies will be developed.

APPENDIX

RAPID CHANGES IN SOIL TEMPERATURE UNDER SNOW

One problem related to the recording of weather data relates to the rapidity of change. If changes are rapid, and if it seems desirable to know about these, then the frequency of observations must be adjusted to the rate of change. With air temperatures, the measurement of maximum and minimum temperatures daily gives a record of the most important changes and these are the values usually recorded. With soil temperatures related to seedlings, no set of observations is currently available, and information must be collected by personnel at each forestry station.

To learn about the probable changes in soil temperatures, an analysis was made of soil temperatures across the prairies for the winter of 1975-76. Records are given in the Monthly Record of Meteorological Observations. Records for depths of 5 cm and 10 cm for 24 stations from Beaverlodge and Fort Vermilion to Winnipeg and Gimli were examined. The records give the morning (about 8 a.m.) and evening (about 5 p.m.) temperatures daily at each level. The records give values in degrees Fahrenheit, and the same unit will be used in the following discussion.

In October, there was seldom snow on the ground, the temperatures were generally above freezing, and the sun high enough in the sky to cause a significant daily cycle of air and soil temperatures. This cycle was obvious in the records at 5 cm and to a lesser extent at 10 cm. At 5 cm, mean ranges of $3^{\circ}F$ were common, with individual daily ranges of 10°F. At 10 cm, ranges were much smaller, although some stations had a mean daily range of 2°F. With soil temperatures approaching freezing, it seems desirable to be made aware of changes in the soil temperatures of these values.

Two observing points at Swift Current, one at the airport, and the other at the Agricultural Research Station, are close together. A comparison shows marked differences. At the airport the mean daily October range was from 41.0 to 42.9, or 1.9°F; at the research station, from 39.4 to 45.5, or 6.1°F. The range for the month of October at the airport was 19°F, at the research station, 29°F. These data reveal the fact that many factors influence soil temperature changes. Moisture in the soil and the overlying vegetation play a significant part. For example, the mean range at Cree Lake, in north central Saskatchewan, is only 0.9°F. Here the ground must be quite moist in October to keep the daily range small.

Snow fell on most stations by the end of November but only at Fort Vermilion in the far north was the ground well protected by the snow. However, the temperatures at 5 cm were reaching the freeze-thaw temperature of -1°C or 31°F, and the freezing process dampens any temperature change. There were daily ranges of over 5°F in the dry south, but in general, the daily ranges are not significant, at least after 15 November.

The snow cover in the southern parts of the provinces tended to be light during the months, December to March, inclusive. With such conditions, soil temperatures tended to vary during the day reflecting the changes in the air temperatures, but in general they were less than in November. In December, only 2 of the 24 stations had a day when the range at 5 cm reached $5^{o}F$; the corresponding figures are for January, 3 stations, and for February, 5 stations. As discussed below, many of these large changes were associated with temperatures above freezing.

To learn more about rapid changes, the data were reexamined to identify those periods when, under 4 in. or more of snow, the temperature at 5 cm changed by $4^{o}F$ in 24 h, or $5^{o}F$ in 48 h. From the records of the 24 stations, 50 periods were identified, 30 with rising temperatures and 20 with falling temperatures. Of the 30 with rising temperatures, 27 were periods when the air temperature went above freezing, and 21 of these saw temperatures of $40^{o}F$ or above. These were examples of rapidly rising temperatures under snow with thawing conditions discussed by Longley (1967).

When the 20 occurrences of rapid cooling were examined, it was discovered that in 16 of the 20 occurrences, the air temperature had reached thawing during the two-day period preceding the cooling. The four other instances occurred in Saskatchewan during the first week of January 1976 when the air temperatures dropped to $-25^{o}F$ or below, and snow cover was light.

The drop in temperature in the soil after a thaw requires an explanation which is not forthcoming. Is it possible that the water from the thawing snow penetrating the cover and then freezing reduced its insulating quality and so permitted more rapid loss of heat from the soil to the overlying cold air? It seems probable, but further study is needed to clarify the mystery.

Even though we cannot explain these rapid changes, the information has significance in suggesting the frequency of observations of soil temperature after snow covers the ground. Apparently almost all rapid changes occur during a thaw when the temperature of the soil rises toward the freeze-thaw point, or just after a thaw when rapid cooling occurs. To keep adequate records of soil temperature with a snow cover, once daily is sufficient unless a thaw occurs. Even the absence of temperature records over a weekend would not result in much lack of information. During and for two days after thawing temperatures, it might be useful to have observations made even over weekends to check the changes that occur.

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