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Influences Of Microclimates On Mortality And Growth Of Planted White Spruce, (Picea Glauca (Moensh) Voss) Jack Pine And White Pine (Pinus strobus) (Pinus banksiana Lamb.)

by

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INFLUENCES OF MICROCLIMATES ON MORTALITY AND GROWTH OF PLANTED WHITE SPRUCE, JACK PINE AND WHITE PINE[1]

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ABSTRACT

Relationships between some microclimatic factors and mortality and growth of planted conifers were studied on the north and south aspects of a ridge in Eastern Ontario. It is shown that interactions between meteorological and physiographic factors complicate the classification of local climate for plantation purposes. Correlations between mortality of jack pine and white spruce and maximum temperature, and between height growth of white pine and mean temperature of the previous summer are suggestive rather than conclusive.

SOMMAIRE

Les relations qui existent entre les facteurs microclimatiques, la mortalité et la croissance des conifères de plantation ont été étudiées sur les versants nord et sud d'une crête dans l'est de l'Ontario. L'action réciproque des facteurs météoriques et physiographiques compliquent le classement du climat local à des fins de plantation. Les corrélations observées entre la mortalité du pin gris et de l'épinette blanche et la température maximum, et entre la croissance en hauteur du pin blanc et la température moyenne de l'été précédent sont hypothétiques plutôt que probantes.

THE PROBLEM

In forestry practice it is common to look upon local climate as a function of topographic position, with emphasis on aspect. Forest sites are often classified into broad categories on this basis, with many variations depending on local conditions and needs. For general descriptive purposes this approach is useful, but there are purposes in silviculture which require a more refined evaluation of local climate.

Questions arise as to the relative significance of the primary meteoric factors that make up local climate—precipitation, insolation, temperature and ventilation—and as to the interactions of these elements with physiography and vegetation. The answers may help to solve important problems in artificial reforestation. For example, climatic causes of seedling mortality may be determined with accuracy, and relationships between local climate and seedling growth rate may be found. It may be possible to classify the complexities of local climate for the efficient location of plantations, and to recommend in detail the matching of certain species to certain local climates. This report touches upon all these questions to a limited extent, but serves mainly to point out the scope of the whole problem rather than provide specific answers.

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THE EXPERIMENT

To obtain concrete information on these issues, a study was initiated in 1954 at the Petawawa Forest Experiment Station in Eastern Ontario (Lat. 45° 56', Long. 77° 33', Elev. 600 Ft.). It was conducted on a cutover strip on Green Ridge, a north-south-facing ridge 140 feet high, which provided a wide range in local climate. A physiographic profile is shown in Figure 1.

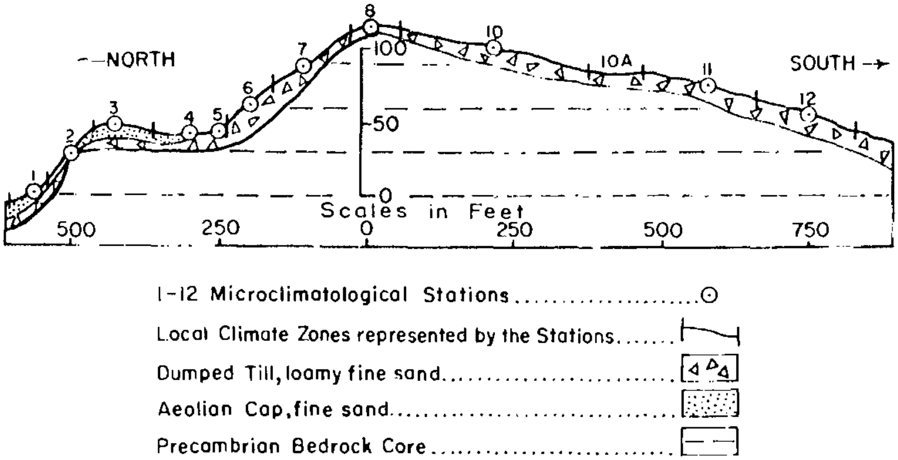

FIGURE 1. Profile of Green Ridge showing soil material and location of microclimate stations.

The ridge is forested with a mixed stand, largely of oak (*Quercus rubra* L.) and white and red pine (*Pinus strobus* L., *P. resinosa* Ait.), which originated after a fire some 80 years previously. In 1954 a three-chain-wide swath was clear-cut along a north-south line 1500 feet long crossing the ridge approximately at right angles. Along the centre of this swath in a strip one chain wide all shrubbery was removed, leaving only the herbaceous vegetation.

Along the centre line of the cleared strip eleven microclimatological stations were established at points selected arbitrarily to represent the main topographic positions, hence local climates. A twelfth station (no. 9) was located on a knoll on the east edge of the swath. In 1955 daily observations were made at these stations from May 1 to September 30. Air temperature at the one-foot level was read from shielded maximum-minimum thermometers; the thermometers were randomly redistributed each week to minimize the effect of instrumental error on calculated mean temperatures. Temperatures at the four- and eight-inch depths in mineral soil (covered by ½ inch of natural duff) were measured with bent stem mercury-in-glass thermometers. These soil temperatures were read at 7:30 a.m. and are close to daily minimum values. Evaporation measurements of a sort were made with unshielded Piché atmometers, placed one foot above ground level, with surrounding vegetation clipped.

It is difficult to obtain accurate and representative measurements of soil surface temperature. In this study mercury-in-glass thermometers were placed on the soil which was exposed after removal of the duff layer; then the thermometer bulbs were covered with a double layer of burlap, a procedure adapted from Hayes (1941). Half-hourly readings of these thermometers were made on two sunny days, June 16th and August 9th, to determine the pattern of diurnal variation.

To study vegetation reactions to local climates on the profile of Green Ridge, seedlings were planted about May 1, 1955, along the centre one-chain-wide strip of the cut swath. The four conifers chosen were those most commonly used in reforestation in the region — white pine, red pine, jack pine (*Pinus banksiana* Lamb.) and white spruce (*Picea glauca* (Moench) Voss). They were planted in rows approximately parallel to the contours and crossing the centre line of the strip at right angles, eight specimens of one species to a row, with trees and rows spaced five feet apart. The species were assigned to rows randomly in series of four. The planting stock was graded to eliminate weak and abnormal specimens. A total of 2,080 trees was planted, all healthy nursery transplant stock (2-2) obtained from the Ontario Department of Lands and Forests. Each tree was tagged and its development was recorded annually, 1955-59 inclusive. Vegetation which might compete with the planted stock was removed periodically.

To relate seedling performance to the microclimatic records, the planted strip was divided into zones running across the strip; the boundaries are shown on the profile in Figure 1. Each zone has relatively uniform topography and hence, presumably, local climate. In the analysis, each zone was designated by the number of the microclimatological station located near its centre; it is assumed that each station is representative of the whole zone in which it is located, since a check on performance of trees immediately around each station with that of each whole zone showed a close correspondence. However, stations 4 and 5 were included in one zone and their data averaged, and an additional zone, 10A, was distinguished during the analysis, although there is no microclimatic station to represent it.

This manner of division resulted in unequal numbers of seedlings in the different zones, the numbers varying from a minimum of two rows (16 specimens) of each species in each of zones 1 and 2 to twelve rows in zone 10. For the assessment of height growth, some seedlings in each zone were omitted because of leader damage, mostly caused by deer browsing.

Physiographic Influences

Before proceeding with comparisons between seedling development and microclimate, other factors involved must be considered. As Figure 1 indicates the physiographic site conditions are not uniform. The slopes and contours of the bedrock and soil mantle vary considerably, and the soil depth and drainage vary accordingly. The predominant soil material is dumped till of stony loamy sand, but a variable aeolian cap of pure fine sand covers the lower north side (zones 1-4).

For one physiographic reason or another, whether steep slope, excessively drained topographic position, shallow soil, or coarse soil texture, all zones except number 2 can be classified as relatively dry sites. The prevailing natural vegetation, particularly the pine, oak and Vaccinium species, supports this assessment.

There are however noteworthy local points of difference. About 5 feet in elevation below station 1 a bare sandy roadway crosses the cleared strip.

Station 2 is unique in that the brow of the Precambrian bedrock is close to the surface and some seepage of ground water occurs. Station 10 on the south slope has somewhat finer soil texture, hence more moisture-holding capacity, than stations 6 and 7 on the north slope. Station 8 is not truly representative of the ridge top since it is situated in a saddle between two knolls (on one of which station 9 is established) and hence receives some drainage from above. The effects of these features will be brought out later.

RESULTS

Microclimate

A comparative report of the microclimatic data, written largely from the meteorologist's viewpoint, has been published by MacHattie and McCormack (1961). In it spatial and seasonal trends of air and soil temperature are analyzed; and a deduction about evapo-transpiration made; the cleared Green Ridge is compared with a similarly oriented, forested ridge on which similarly located microclimatological stations were established, and significant related phenological data are presented. Only the salient features of the observed microclimatic patterns on Green Ridge will be considered here. They are summarized in Figure 2.

(a) Piché Evaporation — The pattern corresponds closely with the profile, increasing with elevation, a tendency which is attributed to increasing ventilation.

(b) Air Temperature — The patterns of maximum and minimum air temperature are, in the main, mirror images: at the stations where the maximum temperature is lowest the minimum temperature is highest, and vice versa. The pattern of temperature extremes, like that of Piché evaporation, appears to be mainly a result of the increase in ventilation which is associated with an increase in elevation.

The most extreme temperatures occur at stations 4 and 5, in an air catchment pocket.

The low maximum air temperature (and 4" soil temperature) at station 2 is due to seepage water keeping the ground moist, with consequent evaporative cooling.

The anomaly of higher daily maximum temperature on the north slope than on the south is explained as being associated with lower evapotranspiration on the north-facing slope. This in turn may be a result of a difference in vegetation density or rooting depth, or may result from less soil moisture-holding capacity due to the steeper slopes and somewhat coarser soils.

(c) Soil Temperature — Temperature at the 4" depth follows a different pattern from air temperature, being generally higher on the south face than on the north face (at corresponding elevation) as a result of greater direct insolation reaching the ground surface. On the north face a larger proportion of insolation is intercepted by vegetation (and does not reach the actual ground surface). The 4" soil temperature is relatively high at stations 3 and 4 which are practically horizontal and is very low at seepage station 2.

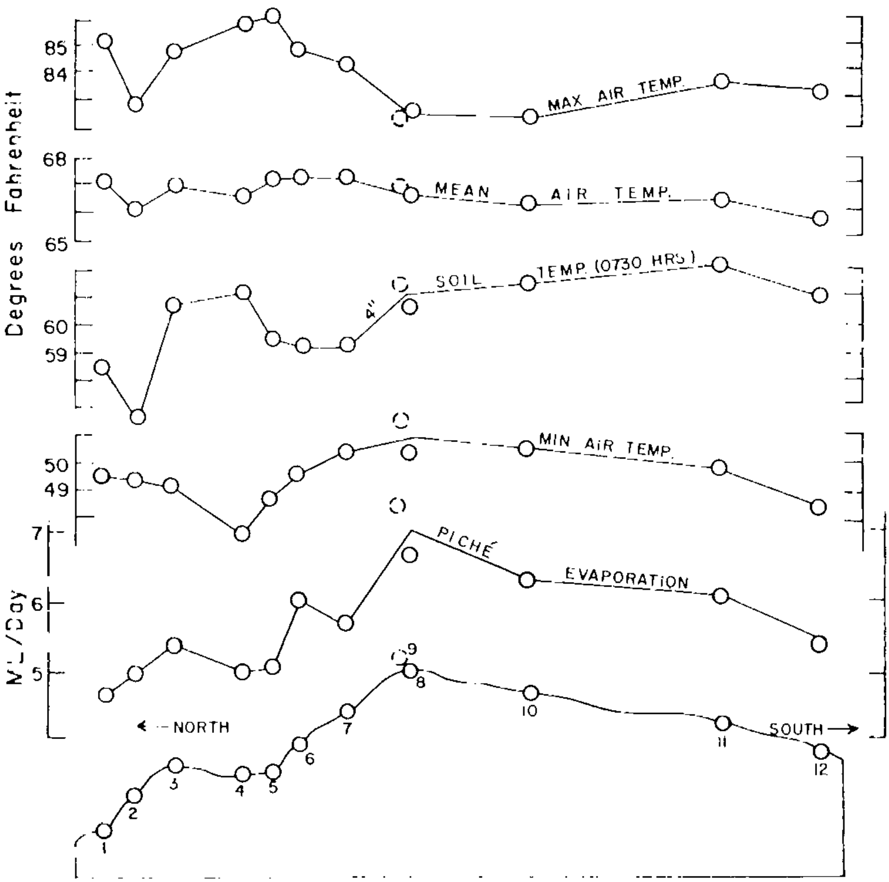

FIGURE 2. Season means of daily readings May 1-Sept. 30, 1955, of temperature and Piche evaporation at the numbered stations.

8" soil temperature (not shown) at stations 1, 4, 8 and 11, averaged for the four months May to August, was found to parallel the 4" temperature at the same stations.

The maximum ground surface temperature observed at each station on June 16th (when half hourly readings were taken throughout the day) is shown in Figure 3, where it is plotted against the extreme maximum one-foot air temperature for the summer (which occurred on July 9th at most of the stations). The inordinately high temperatures at station 1 will be discussed later. The low temperatures at station 2 agree with the preceding discussion. For the other eight stations there is a perceptible trend towards lower maximums at higher elevations, which again is attributed to the increase of ventilation with elevation.

Season

The growing season of 1955 was an extremely dry one. Total precipitation

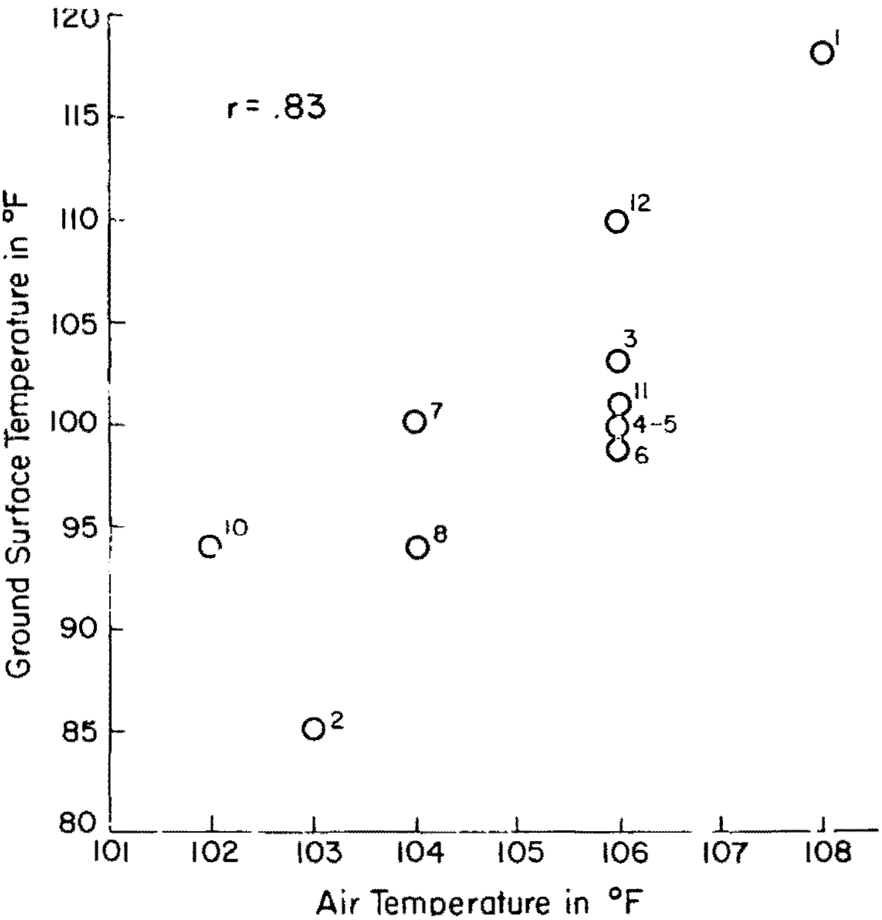

FIGURE 3. June 16th maximum ground surface temperature plotted against the season's maximum one-foot air temperature.

at the Experiment Station for the five months of May to September was 8.81" compared with 15.36" average for the previous 20 years; there were only 41 rain days (precipitation 0.01" or more) compared with 51 for the average. The months of May, June and September were particularly dry.

Mortality

During the summer, mortality of the seedlings planted about May 1 was exceptionally high - - about 50 per cent for each species. Actually this was fortunate for the experiment since it accentuated the differences between sites. The variation of mortality with topography is shown in Figure 4.

One might have expected that the general pattern of mortality would show some correspondence with that of Piché evaporation, increasing with the

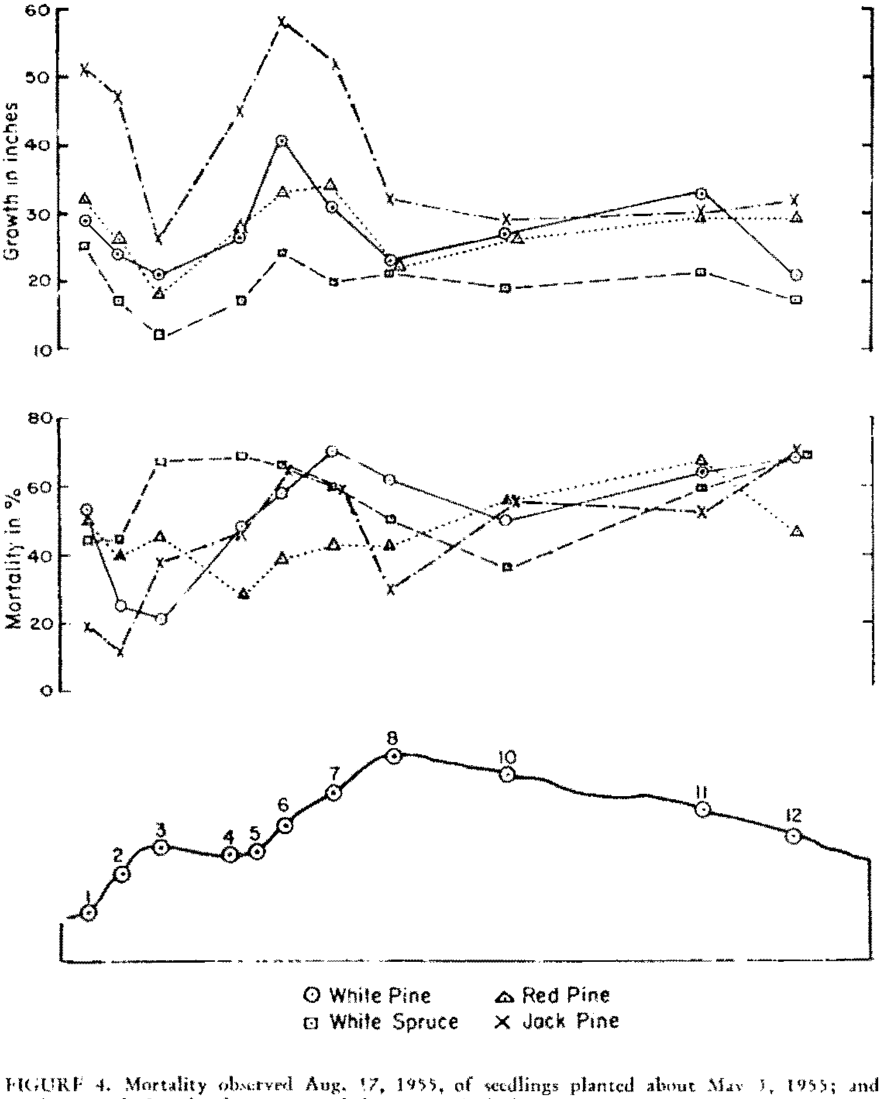

FIGURE 4. Mortality observed Aug. 17, 1955, of seedlings planted about May 1, 1955; and height growth for the four-year period 1956-59 inclusive.

elevation of the profile on both aspects, particularly in this droughty season when the newly planted seedlings would be subjected to wilting (MacHattie and McCormack 1961). But in so far as there was a relationship between mortality and Piché evaporation, it was an inverse one. For instance, on the south aspect, where the slope is fairly uniform and hence the effect of elevation should be more apparent, the average mortality decreased rather than increased with elevation. This anomaly is probably related to the Piché atmometer being a better indicator of ventilation than it is of drought.

When mortality was compared with maximum temperature, some relationships were found which appear to be significant. But the significance of correlation is conditional on the omission of station 1 data from the calculation of correlation coefficients. The relationships will be described first; then reasons for omitting station 1 will be considered.

Mortality of seedlings in 1955 was plotted, species by species, against June 16th surface maximum temperature. No relationship was found for white or red pine. But for white spruce and jack pine a trend towards higher mortality with higher temperature appeared; this is shown in Figure 5. Omitting station 1 data, the correlation coefficients are .78 for white spruce, and .76 for jack pine. These coefficients lie between the 2% (.75) and 1% (.80) levels of significance.

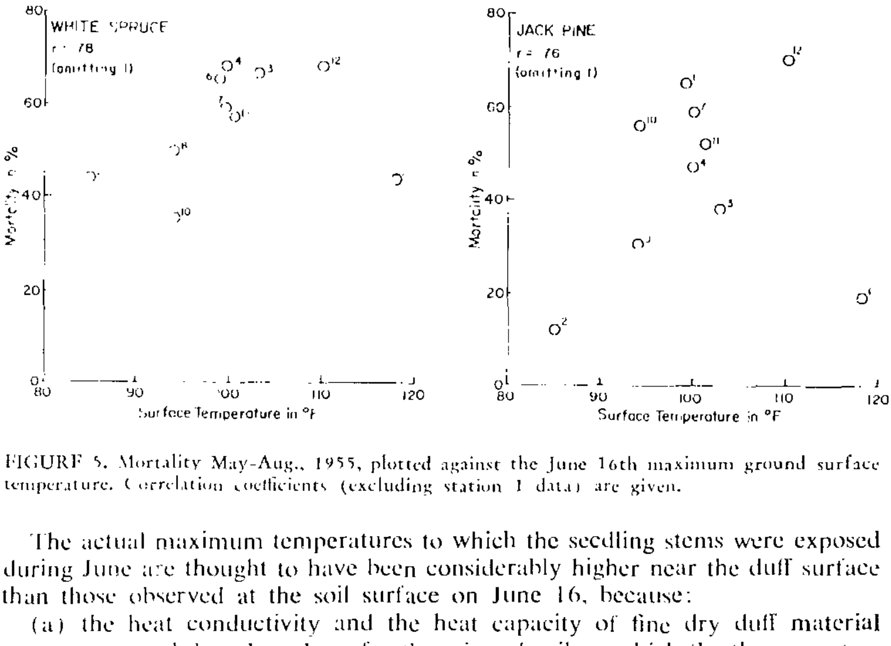

FIGURE 5. Mortality May-Aug., 1955, plotted against the June 16th maximum ground surface temperature. Correlation coefficients (excluding station 1 data) are given.

The actual maximum temperatures to which the seedling stems were exposed during June are thought to have been considerably higher near the duff surface than those observed at the soil surface on June 16, because:

(a) the heat conductivity and the heat capacity of fine dry duff material are much less than those for the mineral soil on which the thermometers were resting; so for the same income of radiational energy the temperature would rise higher, (Geiger 1950, p. 29);

(b) June 16th was not the hottest day in June.

Observed ground surface temperatures are used in Figure 5 only as an indication of the probable ranking of the stations with regard to duff surface temperature.

When the mortality data were plotted against extreme maximum one-foot air temperature for the season, white spruce was the only species to show a significant result (Figure 6). If we again omit station 1 data, the correlation coefficient is .94. Practically the same coefficient was obtained when the

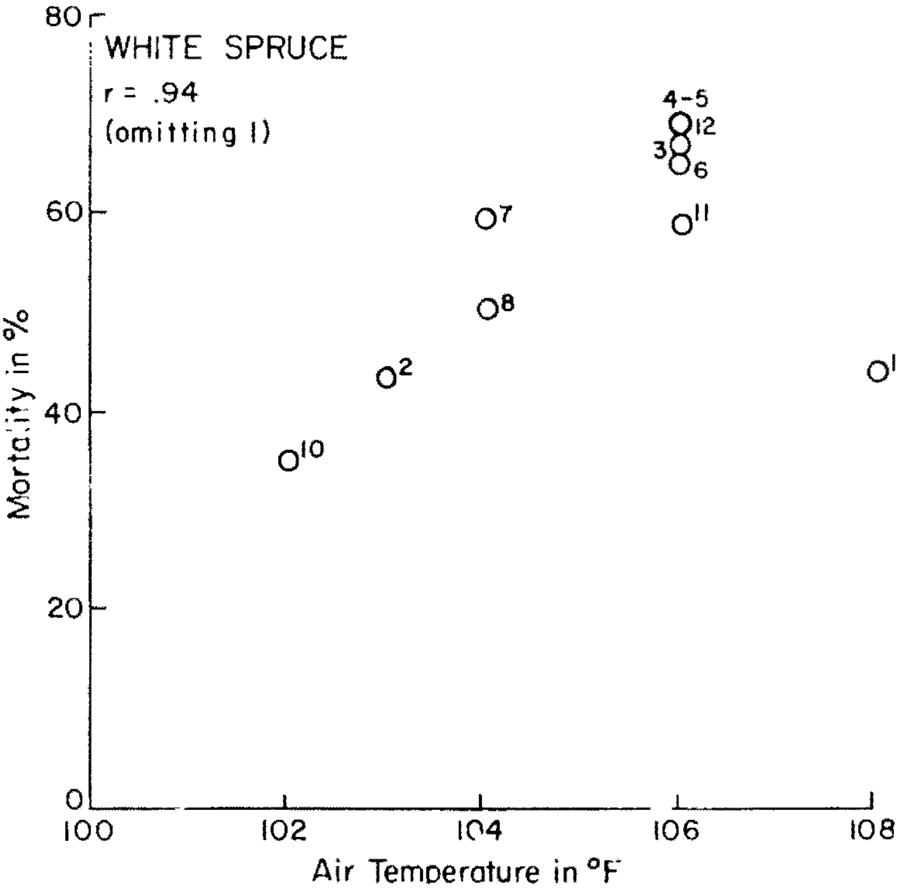

FIGURE 6. White spruce mortality May-Aug., 1955, plotted against the season's maximum one foot air temperature.

average of the five highest of daily maximum air temperatures at each station was used in place of the single extreme maximum.

Consider now the station 1 data on mortality versus maximum temperature. Something is obviously odd when the soil surface temperature is 118° F on a 30° north-facing slope, while the highest temperature on the adjacent 5° south-facing slope is 110° F. The original report on the microclimate of Green Ridge (MacHattie and McCormack 1961) attributed the high soil surface temperatures at station 1 to the organic matter which was subsequently found mixed with the mineral soil at the point where station 1 surface thermometer was exposed.

Looking at Figure 3, it is apparent that if the station 1 maximum soil surface temperature is odd, so is the maximum one-foot air temperature. Possibly this is because the station 1 site was more protected from wind than the other sites and the thermometer shield overheated; also the reflection of solar radiation from the bare sandy roadway may have been a factor. However, there is no way of readily checking on these conjectures and the rejection of station 1 data remains an arbitrary decision.

There are two possible explanations for correlations of mortality with maximum temperature: heat injury of stems, and soil drought. These effects are not separate, for seedlings are more susceptible to heat injury when they are subjected simultaneously to drought.

The sensitivity of jack pine to high soil surface temperature implied by our results may appear surprising considering the xerophytic tendency of jack pine, but studies in the Lake States (Shirley, 1936, Anon. 1937) have indicated that high surface temperature frequently kills or injures jack pine seedlings (including 2½ year olds) and that heat causes greater mortality than drought.

The effects of heat injury are not always apparent immediately. Referring to Ursic's work with 1-0 loblolly pine seedlings, Hare (1961) states: "Measurement of subsequent growth is the most reliable method of assaying physiological heat injury and often the most practical, but sufficient time must be allowed to assure that delayed effects will not be missed. Ursic found that many pine seedlings appeared normal for two months before they died of heat treatment". Because the results of heat injury may thus be slow to appear, it is possible the extent of mortality due to heat has been underestimated generally, in the literature, in favour of drought.

Height Growth

Height comparisons were obtained by determining the average leader growth for each species and station over the 1956 growing season, and for the four-year period 1956 to 1959 inclusive. Variations in the height of the growing stock when planted in 1955 invalidated the use of total height in 1959 as the growth criterion. The 1955 height growth was excluded to allow for individual variation in adjustment to re-establishment following transplanting.

Specimens affected by deer browsing, disease or insect damage were excluded, except in the case of jack pine which was browsed so thoroughly that the undamaged trees formed an inadequate sample. Despite this damage the jack pine outgrew the other species in practically every zone. The average height growth of all jack pine is used.

The topographic variation of height growth for the four-year period 1956-59 is shown in Figure 4. One might have thought that growth would be poorest where mortality was highest, but the reverse seems to have happened. Height growth followed much the same pattern as mortality over most of the profile.

Duff and Nolan (1953) found that shoot growth in red pine is largely determined by the growing conditions of the previous year; Mikola (1951) states that height growth in Finland is closely related to the temperature during bud formation in the preceding year. Comparing our 1956 height growth data with the 1955 microclimate data, no significant correlations were found with Piché evaporation, with seasonal means of daily maximum air temperature or of minimum air temperature, or with mean diurnal range in air temperature. The only significant correlation found was between white pine height growth and mean air temperature, and this was conditional on omission of station 2 data. If the exceptional height growth of station 2 (which was double that to be expected on the basis of its temperature) is attributed to its perpetually moist soil, the remaining stations give a correlation coefficient of .83 ($p < .01$) for 1956 heigh growth vs 1955 mean air temperature.

Species differences in height growth, were clearly pronounced, with jack pine being superior in all zones, particularly on the north slope. White spruce was the slowest growing species in all zones. These inter-species differences reflect normal early growth differentials. The four species maintain the same relative height positions in most zones, corresponding to their accepted order in the shade-tolerance scale, i.e., the least tolerant jack pine is tallest, and the most tolerant white spruce shortest. The noteworthy point is that the differences in local climates between zones did not appreciably affect this order over the first few critical years after planting.

CONCLUSION

This study relates observations of summer season surface microclimate to performance of planted conifers. The results indicate correlation between mortality and maximum ground surface temperature for jack pine, between mortality and maximum air temperature for white spruce, and between height growth and mean air temperature of the previous summer for white pine. There is, however, the possibility that the temperature-mortality correlations are merely symptomatic of some particular weakness in the specific planting such as relatively poor root-shoot ratio. This could not be determined from available data.

No correlations were found between Piché evaporation and either mortality or height growth of the seedlings.

From a broad viewpoint the results emphasize the complexity of local climate in relation to seedling survival and growth. Regarding the influence of topography, Geiger (1950) has pointed out the major importance of aspect during the day, and of cold air collection in low areas at night. This study emphasizes the additional strong influence of soil moisture on local climate, and the daytime significance of relative elevation. Increasing elevation usually means increasing ventilation, and increasing evapotranspiration. Decreasing soil moisture can mean decreasing evapotranspiration, hence increasing maximum temperature. It is seen that classification of local climate in terms of aspect alone is of very limited utility.

Interactions between meteoric and physiographic factors increase the difficulty of distinguishing the effects of individual factors on seedling survival and growth. The direct effect of soil variation on seedling performance cannot readily be separated from the indirect effects operative through soil-local climate interactions.

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