

## SOIL TEMPERATURE AND ROOT GROWTH IN CONIFER SEEDLINGS

In forest trees, seasonal root growth often occurs in two or more surges; prior to shoot growth in the spring, and later in the summer after the cessation of shoot growth. This root growth involves two components: elongation of existing roots and initiation of new lateral roots. The above processes responsible for increases in total root biomass are temperature-dependent. Low soil temperatures are thought to decrease root growth by reducing metabolic activity and the turgor of root cells due to reduced water uptake. Root plagiotropism (i.e. the growth at right angles from the vertical) occurs in many species, and is also temperature sensitive, which has an influence on rooting depth. It is suggested that roots sense temperature gradients in the soil and grow towards the more favorable temperature.

In agricultural crops, the dormant season is classified as having soil temperatures below 5°C, but conifer species are adapted to cold soil temperatures and can grow slowly at root zone temperatures as low as 2°C, although critical minimums are usually between 2 and 5°C. For hydroponically grown Scotch pine and Norway spruce seedlings, the temperature threshold for root initiation was between 8 and 12°C, below which there was no new root tips initiated in the spruce and only a few in the pine. In contrast, root elongation was suppressed more than new root formation at soil temperatures of 8°C for red pine. As far as lethal temperatures are concerned, needles are much more cold hardy than roots, being able to withstand temperatures below -40°C, while root cold hardiness of roots is much less (e.g. -11.5 and -7.5°C for alpine fir and lodgepole pine, respectively)

There are species differences in growth response to soil temperature. For example, greenhouse grown white spruce seedlings are more sensitive to soil temperatures than black spruce seedling. Greenhouse studies of Alaskan tree seedlings found increasing but variable rates of root elongation with increasing medium temperature, slowest in black spruce, and fastest in aspen and poplar. However, extrapolating results from greenhouse studies to the field should be done with caution, as in field studies the black spruce from cold, wet sites had the highest elongation rate, suggesting that site factors other than soil temperature (e.g. moisture) predominated over genetic differences among species in this experiment. Maximum root dry weight is obtained at approximately 19°C for potted white spruce and 27°C for potted jack pine, while needle, shoot and root growth of two-year-old potted Monterey pine seedlings is greatest at 15°C. Allocation of root biomass varies among species, as compared to aspen, paper birch, balsam poplar, larch and white spruce; black spruce allocates a greater proportion of its root biomass to fine absorbing roots versus larger conducting roots. This is suggested to be in response to the cold, nutrient deficient soils inhabited by the black spruce. It has also been suggested that woody species of northern origin have a lower root temperature optima than those of more southern origin.

Root temperature influences the growth rate of most plant organs, not just the roots. Low soil temperatures result in reduced tissue nutrient concentrations from the direct effects of temperature on nutrient uptake (especially phosphorus) and translocation; decreases in water uptake, transpiration and stomatal conductance. The various processes are interrelated, and it is difficult to separate the direct effects of low soil temperature on nutrient uptake from the indirect effects on

root growth, which also reduces nutrient uptake. As well, reduced shoot growth because of cold soil reduces nutrient uptake, and since root growth and metabolism depend on a supply of carbohydrates from the shoots, factors which reduce photosynthesis and shoot growth such as nutrient deficiencies are likely to reduce root growth and nutrient uptake even more. Soil temperature has also been implicated in timing of shoot growth, although it was found to have no effect on the bud break of Scotch pine seedlings.

Decreased water uptake at low soil temperatures due in part to the increased viscosity and decreased absorption of the water at cold temperatures may impose a physiological drought on the seedlings. This effect may be more pronounced on seedlings planted on sites with short growing seasons that are subject to summer droughts. As the cold soils in the spring reduce root growth and thus the volume of soil from which the roots can extract water, the seedlings may become drought stressed later in the season. Jack pine and white spruce seedlings potted at low soil temperatures experienced greater initial water stress after potting compared to seedlings potted at higher soil temperatures, which was thought to be due to greater water-flow resistance through the soil-plant-atmosphere continuum at low soil temperatures.

Water stress as mentioned above decreases photosynthesis. Stomatal conductance is affected by leaf water potential, thus when needle water potential becomes low enough to close stomata, photosynthesis and the resulting photoassimilates are reduced. Suppressed root growth at low temperatures was thought to be the primary cause of poor field survival of interior Douglas-fir seedlings, as the reduced root growth resulted in increased susceptibility to summer drought. After mid-June, decreased photosynthetic rates in Engelmann spruce trees were correlated with low soil temperature, which may continue for the entire summer at higher elevations. Even when there is ample soil moisture and low to moderate evaporative demand, white spruce trees near the tree line in Alaska close their stomata under conditions of low soil temperature. This was hypothesized to be a mechanism that enables this species to escape winter desiccation by preventing transpiration when the ground is frozen, but in the summer it reduces CO<sub>2</sub> uptake and hence tree growth.

Soil temperature is determined by site location, atmospheric weather conditions, ground cover and soil physical properties. Reasons for variation in soil temperature can be further broken down into heat input into the soil, the specific heat of the soil material, and the ability of the soil to transmit heat downward. Heat input into the soil varies with slope and aspect, and reflectivity of soil surface. Specific heat of the soil varies with the water holding capacity of the soil, for example, moist clay soils resist changes in temperature more so than do coarse soils. This results from the fact that water contains approximately 3,500 times as much thermal energy as the same amount of air at the same temperature. The transmission of heat through the soil profile varies with substrate, transmission through rock and mineral soil is high compared to organic soils.

Surface organic layers (i.e. the forest floor) insulate underlying mineral soil from temperature conditions at the soil surface, therefore soil temperatures beneath thick forest floors fluctuate less rapidly throughout the season. This is often undesirable in cold climates where seedling growth may be inhibited by low soil temperatures, as soils warm up more slowly in the spring. Seedling root zone temperatures (hourly temperature averages at 10 cm depth) monitored at three north-central B.C. spruce plantations in the sub-boreal spruce biogeoclimatic subzone, did not achieve daily temperature averages above 10°C in untreated soils until late June. It may therefore be advantageous to raise soil temperatures by various means such as mechanically creating mounds,

or by fire. In the case of fire, a blackened surface generally heats up more than an unburned forest floor or an exposed mineral soil surface

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