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Soil Texture Influences Seedling Water Stress in More Ways Than One

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White spruce (Picea glauca (Moench) Voss) seedlings were planted in pans filled with soils of three different textures: two mineral and one organic (peat). A few months were allowed for adequate root growth into the surrounding medium. After a drying period, transpiration, stomatal conductance, and xylem water potential were measured on all seedlings. For any given level of soil water tension, coarse soil (peat) caused the seedlings to have a lower (more negative) level of water potential than fine soils (fine sand and sandy loam.) Peat was worse than fine sand, and fine sand was worse than sandy loam. The results show that site assessment for planting suitability must take into account the dynamic interaction between soil texture, water supply, and evaporative demand. Tree Planters' Notes 43(2):39-42; 1992.

When a seedling is planted in the field, it immediately starts transporting water from the soil to the atmosphere. While doing so, the water inside the seedling comes under tension as energy is required to extract additional water from the soil. One question of great interest to seedling specialists is the level of internal water tension the seedling must endure in the field. The importance of this question stems from the direct association between internal water tension, cell turgor, and seedling survival and growth.

Soil texture influences the internal level of plant water tension in two ways. The first one is a static influence, the second is a dynamic one. The static influence of soil texture on plant water tension is due to the direct control of texture on the level of water tension in the soil, or soil water potential. For a given water content, fine soils such as clays will have lower (more negative) soil water potentials than coarser soils such as loams and fine sands. In order for water to move from the soil into the plant, the energy level of the water inside the plant must be lower than that of the soil, as in any pumping system. Therefore, fine soils will produce a lower base level of water potential in seedlings than coarse soils.

The second influence of soil texture on plant water tension involves feedback from the plant to the soil. As a root extracts water from the surrounding soil, the water content in the soil at or near the soil-root interface drops, causing a corresponding drop in soil water potential of that near-root zone. The level of soil water potential in the near-root zone will depend on the level of water demand by the root. It will also depend on the ability of the soil further from the root to replenish the lost soil water around that root. Thus, in a dynamic world, properties like water content and hydraulic conductivity at a given soil water tension are also of great importance in determining the level of water tension in the plant. This fact has long been known to soil physicists and agriculturists (for example, Gardner 1960 and Cowan 1965). However, in seedling ecophysiological work, only a few researchers (Dosskey and Ballard 1980) ever consider the role of soil texture in the dynamic soil plant relation as a major influence on the plant's internal water potential. The intent of this report is to document, using white spruce seedlings, the effect of soil texture on internal plant water status during active transpiration. Also shown are computations of soil water potential at the soil root interface.

Methods

Winter-sown containerized white spruce (*Picea glauca* (Moench) Voss) seedlings were obtained from a nursery near Quebec City in late fall. The seedlings had an average height of 15 cm. Initial cavity volume of the containers was 50 cm^3. The seedlings were planted in plastic pans (60 cm by 15 cm by 10 cm), 10 seedlings to a pan. The pans were filled with one of the following soil types (listed in order of increasing particle size): a sandy loam (25% silt, 5% clay), a fine sand (7% silt, no clay), and a commercial fibric peat (the coarsest soil) similar to what is commonly used in containerized production of conifer seedlings. Six pans were used for each of the two mineral soils. Twelve were used for the peat. Moisture release curves were derived for each of the three soils using the pressure plate apparatus. These curves relate the soil water content to the level of water tension. The pressure plate apparatus is a pressure vessel and ceramic plate system that permits water extraction from soils at known tensions. The methods for this procedure are detailed by Klute (1986). The curves for all three soils are shown in figure 1.

The pans with the seedlings were placed in a greenhouse in cool, short-day conditions (15 °C, 9-h day) to prevent bud break but still allow root growth. Precalibrated gypsum blocks were placed in each pan and read three times a week. Water was added as needed to maintain the soil water tension above - 0.1 MPa in all the pans. Soil surfaces were covered with plastic mulch to minimize soil evaporation. Gravimetric soil samples were used to verify gypsum block readings. Readings obtained with the gypsum blocks are referred to as bulk soil water tension (ψ_s bulk), meaning that they represent the average soil water tension in each of the pans.

The seedlings were kept well watered for 2 months to allow for adequate root growth from the original root plug into the surrounding medium. After that period, a 5-day drying treatment was applied during which individual pans were hand-watered with amounts of water calculated to bring each pan as near as possible to a specific soil water tension target. In this way, a range of soil water tensions was obtained for each of the two mineral soil types, and, to a lesser extent, for the peat (figure 2).

On the day preceding the measurements, air temperature was raised to about 20 °C. Three pans, one per soil type, were selected randomly as controls and were watered to near zero soil water potential. The following day, needle conductance and xylem pressure potential were measured on all seedlings between 11 am and 1 pm. Needle conductance, a measure of stomatal opening, was determined using a Li-Cor LI-1600 steady state porometer (Li-Cor, Inc., Lincoln, Nebraska). Xylem water potential, a measure of plant water tension, was obtained with a PMS pressure chamber (PMS Instruments Co. , Corvallis, Oregon). At the time of measurement, temperature, relative humidity, and photon flux density in the photosynthetically active wavelengths (PAR) in the greenhouse were 21 °C, 30%, and 1,100 $\mu mol/m^2s$. One pan filled with fine sand was discarded; excessive dryness had caused heavy damage and mortality among seedlings. Projected needle surface areas needed to correct the porometer readings were measured with an image analyzer.

In addition to these measurements, soil water potential at the soil-root interface was computed using a method proposed by Jones (1983). Soil water potential at the soil-root interface of the droughted plants was computed from measurements of stomatal conductance and xylem pressure potential of the droughted plants, and of the control plants that had just been well irrigated and were subjected to the same atmospheric conditions:

$$\psi_{s(d)} = \psi_{x(d)} - \psi_{x(i)} \times \frac{g_{n(d)}A_{(d)}}{g_{n(i)}A_{(i)}} \qquad (1)$$

where ψ_s is soil water potential at the soil-root interface (MPa), Ψ_x is xylem water potential (MPa), g_n is needle conductance (cm/s), A is leaf area (cm^2), and the *d* and *i* subscripts refer to the droughted and irrigated plants. Details on the derivation of the model are given in Jones (1983). A Scheffé's test (Freese 1974) was used because of unequal sample sizes to determine significant differences between soils for new root growth.

Results and Discussion

The moisture release curves for each of the three soils (figure 1) reflect the textural differences between the three soil types. These textural differences also affected roots growing out of the original peat plug into the soil during the period of adequate watering. Average dry weight of new root growth was 0.051 g in the fine sand, 0.041 g in the sandy loam, and 0.105 g in the peat. The coefficient of variation was 45%. Scheffé's test revealed that new root growth in the peat was significantly higher ($P< 0.05$) than that in either of the two mineral soils. Low soil densities, as found in fibric peat, are known to promote root growth in conifers under adequate watering (Örlander *et al*. 1990, Prévost and Bolghari 1990).

At the end of the drying period, all measured midday xylem water potentials (ψ_x) were lower (more negative) than the measured bulk soil water tensions (figure 2). However, ψ_x, of seedlings in coarse soils were lower than ψ_x of seedlings in fine soils for the same level of bulk soil water tension. Figure 3 shows soil water tensions at the soil-root interface, computed using equation 1, plotted against the measured bulk soil water tension. The results of this computation show a pattern of response very similar to that shown in figure 2, a normal occurrence since

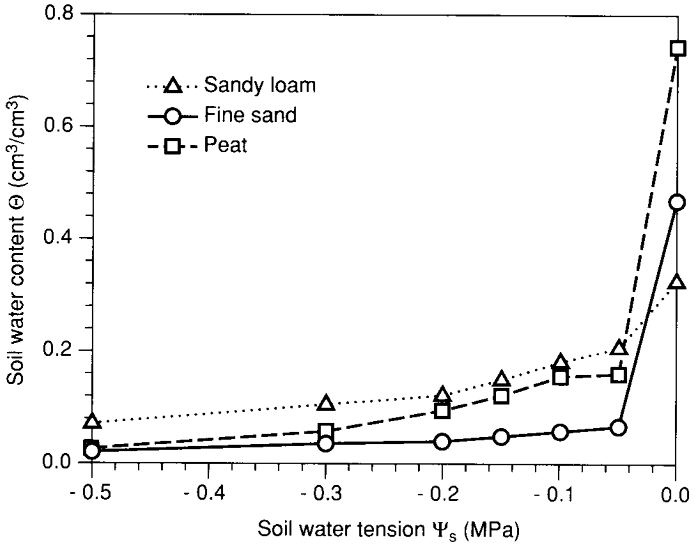

Figure 1—*Soil moisture release curves for the three soils used in the experiment.*

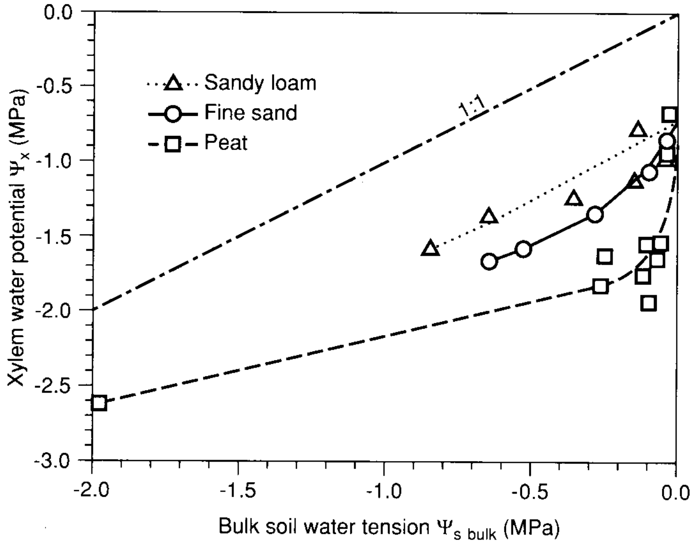

Figure 2—*Xylem water potential in white spruce seedlings* (ψ_x) *versus soil water potential measured with gypsum blocks* ($\psi_{s\ bulk}$) *in fine sand, sandy loam, and peat during active transpiration. Each point represents an average of 10 seedlings; the curves are hand fitted.*

the computation of near-root ψ_s relies heavily on the seedlings' internal Ψ_x

The results show that, unless they are very moist, the coarser soils in this experiment cause a greater water stress in seedlings than finer soils when the seedlings are actively transpiring. Computations of soil water potential at the soil-root interface show that most of the effect is external to the seedlings and takes place in the soil in the near-root zone. This vote against coarse soils goes somewhat against the static measurement of soil water tension since, for any given volumetric water content, coarse soils hold their water more loosely than fine soils. But, as they dry, the coarse soils lost their ability to move water to the near-root zone faster than fine soils. With all the larger pores drying out first, water transfer in drying coarse soils must be done through increasingly tortuous routes. In the extreme case of highly porous peat, water films may even become disconnected altogether and cease to move anywhere in the liquid phase, whatever tension the seedlings might be under. This is why the peat causes a greater drop in seedling water tension than either mineral soil (figure 2) even though its moisture release curve (figure 1) suggests a more intermediate response.

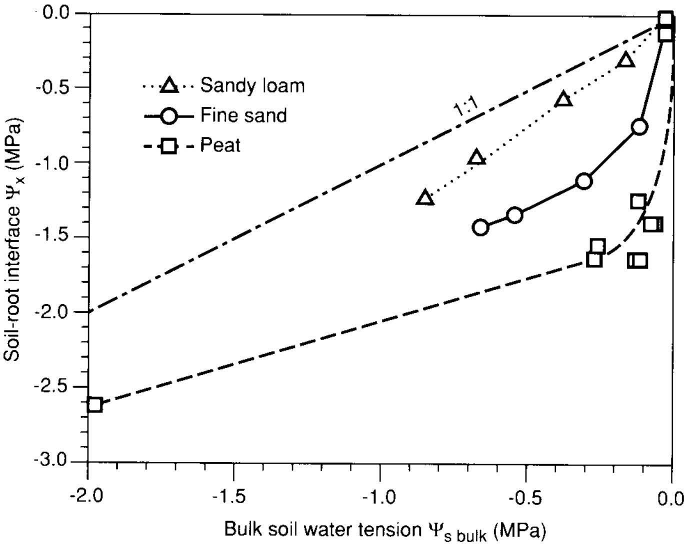

Figure 3—*Computed soil water tension at the soil–root interface* (ψ_s) *versus soil water potential measured with gypsum blocks* ($\psi_{s\ bulk}$) *for white spruce seedlings planted in three different soils. Each point represents an average of 10 seedlings; the curves are hand fitted.*

On the other hand, drying finer soils retain a greater number of smaller pores filled with water and capable of delivering water to the near-root zone. Thus, transpiring seedlings in drying finer soils remain at higher (less negative) levels of internal water tension than they would in coarser soils for the same level of soil water extraction. However, too many fine pores may be too much of a good thing as very fine soils, such as clays, pose a new set of problems for seedlings, including low hydraulic conductivities at any water content, low root penetrability, and low aeration.

Summary

So, based upon these data, which is better for the seedlings, coarse soils or fine soils? It all depends on how much water there is and how much the plant is transpiring. In nurseries, where water contents are kept high, coarser soils offer the advantages of aeration, low bulk density, and ease of water extraction by the seedlings (the first influence of soil texture). However, as nursery managers know well, sand and peat, in particular, must be kept quite wet in order to keep the seedlings growing. In the field, however, soil water content is often far from optimal. Seedlings must transpire if they are to keep their stomata open for CO_2 absorption. The water status around their roots therefore becomes critical, and soils with a greater degree of fine particles, such as loams, present a definite advantage for the seedlings (the second influence of soil texture). Therefore, when assessing a site for planting, one has to consider both soil texture, drainage, and possible water demand by the seedling. The coarser soils used in this experiment are better in areas of good moisture supply. On sites where a higher seedling water demand is expected or water supply is not optimal, finer soils might benefit the seedling. Measurements of soil water tension, although useful, offer only a partial view of soil texture influence on seedling water tension. The results of this experiment should apply to other soils because of the high repeatability of such experiments dealing with physical systems. However, the level of reactions shown here by white spruce might not be the same for all species because of differences in root growth and other physiological properties.

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