# Colloquium Papers and Authors

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# Soil Environment and Root Growth: Introduction to the Colloquium

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The supply of water, nutrients, air, and energy from the soil to the seed and plant depends to a large extend on the environmental conditions prevailing in the soil. A number of physical and chemical factors, such as pH, nutrients, water, air, and temperature define soil environment.

Extremes in soil pH restrict root growth. Acid soils usually contain toxic levels of Al, Mn, and Fe and are deficient in N, P, K, Ca, Mg, and Zn. Alkaline soils are harmful due to the presence of Na, Mo, B, Se, and bicarbonates in toxic concentrations (Gupta and Arbol, 1990). Low levels of one or more nutrients can limit root growths. Deficiency of K limits root mass, and length, and number of lateral roots. Calcium deficiency severely reduces root growth, and the roots formed are short and dense (Bennett, 1993; Marschner, 1995).

Soil temperature effects on plant are both direct and indirect (Wierenga et al., 1982). Temperature affects seed germination and seedling development, root growth, and nutrient uptake, as well as soil water movement, aeration, soil structure, nutrient availability, and decomposition of plant residues. These in turn affect plant growth. Like other biological processes, root growth increases with temperature until an optimum is reached and then declines if temperature rises further. Optimum soil temperature ranges for root growth differs with the species. For example, temperature for maximum production of root mass in oats (*Avena sativa* L.) is only 5 °C compared with 26 °C for corn (*Zea mays* L.). Similarly, the elongation rates of sunflower (*Helianthus annuus* L.), tomato (*Lycopersicon esculentum* Mill.), and cotton (*Gossypium hirsutum* L.) roots are maximum at 20, 30, and 33 °C, respectively (Glinski and Lipiec, 1990).

The availability of soil water affects both the rate of root elongation, and the absorption of nutrients by roots (Baver et al., 1972). Phosphorus compounds are very low in solubility and usually only a few hundred $g \cdot ha^{-1}$ of dissolved P occur in the plow layer (Troeh and Thompson, 1993). The amount of dissolved P and the rate of solution is roughly proportional to the amount of water present. Potassium absorption is most rapid near field capacity. The rate of microbial activity, which is responsible for releasing soil N, S, and micronutrients for root absorption, is also dependent on the availability of water.

Soil management practices, particularly tillage, can change the soil environment considerably. Tillage is used for preparing bed favorable for germination of seed, facilitating root growth, controlling weeds, and incorporating soil amendments. However, excessive tillage deteriorates soil structure, with subsequent erosion of topsoil by air and water. Heavy machinery used for tillage causes compaction of top- and subsoil. As a result, air and water movement through the soil is restricted and shoot emergence and root penetration is impeded. Vehicular traffic and a high density of cattle also result in soil compaction.

The papers presented in this workshop provide comprehensive discussions of the effects of soil environment on root growth. Baligar, Fageria, and Elrashidi give an overview of research on the suppression of root growth by low pH, aluminum, salinity, and heavy metals. They also detail the constraints on root growth caused by the deficiencies of macro- and micronutrients. McMichael and Burke discuss the effect of soil temperature on root morphology, root function, and root–shoot interactions. They present data showing genetic variability between, as well as within, species in response of roots to temperature. They also highlight recent efforts in adjusting soil temperature to favor root growth, and in genetic engineering to improve plant performance over abroad range of soil temperature. Wraith and Wright examine the association between root distribution, growth plasticity, and architecture and the utilization of soil water, as well as differences among species in these characteristics. They explain the hormonal responses to soil water deficit and resumption of water uptake following drought. They conclude by summarizing recent developments in modeling root growth response to

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soil water. Singh and Sainju describe the influence of soil physical and morphological properties on soil temperature, water and air content, and available nutrient supply, and the resulting consequences on root growth. They also analyze the effect of soil and crop management practices that alter these properties in relation to root growth. Since optimal root growth is crucial for maximizing crop yield, we believe that papers presented at this workshop should be of benefit to a wide array of horticulturists.

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# Soil Temperature and Root Growth

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Genetic diversity of root systems has been observed under optimal conditions, and may be further modified by the environment. Soil conditions, such as temperature, available water, aeration, nutrient content, and soil strength, are important factors that can impact root growth, development, and, ultimately, productivity. Temperature is the subject of this presentation. We will review pertinent information from the literature, and include some of our own observations with selected agricultural crops to highlight specific effects of temperature on root growth. Our intention is not to present in great detail all of the aspects of soil temperature/root growth interactions, but rather to provide a brief overview of the relationships to aid the reader in conducting further study.

## SEASONAL CHANGES IN SOIL TEMPERATURE

Soil temperature is generally lower than that of the air, but seasonal fluctuations can occur with depth depending on soil and aboveground factors. For example, the average soil temperature taken at the 10 cm depth in Lubbock, Texas, from day of year 150 (30 May) to day of year 275 (2 Oct.), 1994, ranged from a low of 17 °C to above 30 °C (Fig. 1). The general trend is for the soil temperature to increase from early in the spring to mid-July, then decrease in the Fall. Daily fluctuations are evident, however, due to changes in evaporative demand and soil water content. Aboveground plant development, as well as changes in soil water status, can also influence seasonal changes in soil temperature at various depths (Fig. 2). As the soil dries during the season in nonirrigated plots (Fig. 2B) the higher temperature isotherms move progressively deeper in the soil profile at a faster rate than in the irrigated plots (Fig. 2A). The soil becomes cooler as canopy closure occurs, as evidenced by the movement of the 24 °C isotherm toward the soil surface. The same isotherm also moved toward the surface in the nonirrigated plots as the canopy closed, but this occurred at a later time in the season. The dotted lines in both figures represent the predicted rooting depth as a function of changes in temperature. Note that the rate of downward root growth was faster in the nonirrigated plots.

## TEMPERATURE EFFECTS ON ROOT GROWTH

Root growth is significantly impacted by changes in soil temperature (Abbas Al-Ani et al., 1983; Bland, 1993; Cooper, 1973). Morphological changes, as well as root function and metabolism, can be influenced by such changes.

### Root morphology

Changes in root morphology as a function of changes in temperature are generally characterized by differences in root length, dry mass, and branching. In general, root growth tends to increase with increasing temperature until an optimum is reached above which root growth is reduced (Brar et al., 1970; Cooper, 1973; Glinski and Lipiec, 1990; Pearson et al., 1970). McMichael and Quisenberry (1993) observed that the optimum temperature for root growth in cotton (*Gossypium hirsutum* L.) was between 28 and 35 °C vs. between 23 and 25 °C in sunflower (*Helianthus annuus*

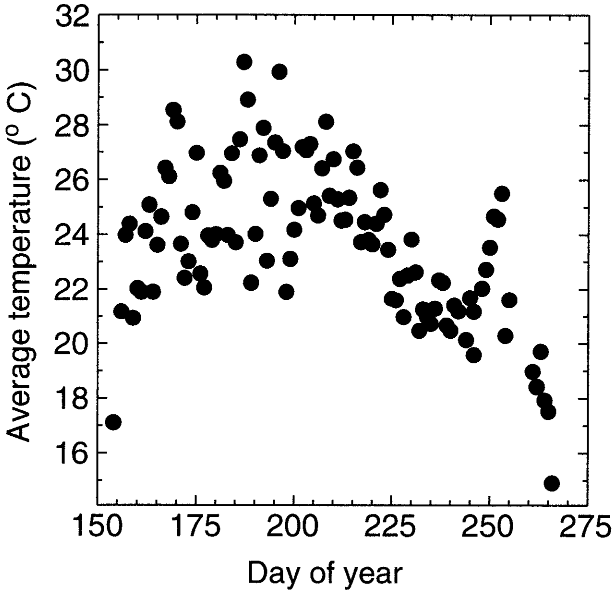

Fig. 1. Seasonal changes in soil temperature at Lubbock, Tex., 1994 (10 cm depth) (from D.R. Upchurch and J.J. Burke, unpublished data).

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