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Growth and Physiological Response of Fraser Fir [*Abies fraseri* (Pursh) Poir.] Seedlings to Water Stress: Seasonal and Diurnal Variations in Photosynthetic Pigments and Carbohydrate Concentration

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***Abstract*. Four-year-old seedlings of *Abies fraseri* [(Pursh) Poir] (fraser fir) were grown in semicontrolled conditions in hoop houses with five watering regimes (0.00, 0.62, 1.25, 2.50, and 3.70 cm/week) with the goal of determining the seasonal variation in the physiological response to drought stress. Drought stress was monitored by measuring predawn (Ψpd) and midday (Ψmd) potentials in a subset of plants from each treatment. Physiological variables monitored were chlorophyll fluorescence (F_v/F_m), Chl a, Chl b, total carotenes, and total carbohydrate concentrations. Morphological characteristics including height growth, root collar diameter, and terminal shoot growth were also measured. Predawn stem water potential values were generally higher (–0.8 to –1.9 Mpa) than midday values (–1.3 to –2.9 Mpa). Irrigation consistently increased Ψpd and Ψmd compared with non-irrigated treatments. Photosynthetic pigments (Chl a, Chl b, and carotenes) decreased midseason (14 July) and increased toward the end of the season (25 Aug.) in predawn and midday measurements. There was a significant effect ($P < 0.05$) of drought stress on photosynthetic pigment concentrations in predawn and midday samples in the late-season measurements (25 Aug.). These results were accompanied with a similar significant difference in F_v/F_m between non-irrigated and irrigated trees. We concluded that significant effects observed on photosynthetic pigment concentrations in some of the treatments did not affect carbohydrate concentrations. Exposure of *A. fraseri* to water stress did not cause a reduction in supply of metabolic carbohydrates; consequently, the decline and mortality in water-stressed plants can only be the result of hydraulic failure caused by xylem cavitation leading to cessation of water flow in tissues, desiccation, and cellular death. Further studies are needed to confirm these preliminary conclusions.**

Fraser fir [*Abies fraseri* (Pursh) Poir.] is widely planted for Christmas tree production in the midwest and eastern United States. The species has a unique natural distribution, restricted to the southern Appalachian Mountains of southwestern Virginia, western North Carolina, and eastern Tennessee, characterized by high elevations, prevalent fog cover, lower summer temperature extremes, and regular summer rainfall. The species has been intensively planted elsewhere in the United States as a result of its desirable attributes (Beck, 1990; Nzokou and Leefers, 2007); however, the physiological consequences of planting this species under summer drought stress-susceptible conditions are not well understood.

Drought stress is characterized by reduction of water content, increased closure of stomata, and decrease in cell enlargement and growth. Severe water stress may result in the arrest of photosynthesis, progressive suppression of photosynthetic carbon assimilation, disturbance of metabolism, and finally the death of the plant (Deltoro et al., 1998; Jaleel et al., 2008). After stomatal closure, there is a decrease in CO_2 intake and intercellular CO_2 partial pressure, thereby a reduction in CO_2 assimilation and net photosynthesis (Deltoro et al., 1998; Dubey 1997; Farquhar et al., 2001). Stomatal closure is the result of either hydropassive or hydroactive mechanisms (Dubey, 1997). In the hydropassive mechanism, guard cells loose water so rapidly that the loss cannot be balanced by water movement from adjacent cells (Shope et al., 2008). In the hydroactive mechanism, stomatal closure is the result of the reduction in stored abscisic acid from the mesophyll chloroplast to the apoplasts (Hartung, 1983). In addition, the rate of CO_2 assimilation is depressed at very moderate water deficits or even before the plant's water status changes in response to the drop in water pressure deficit (Bunce, 1981) or soil potential (Gollan et al., 1986). Therefore, it can be expected that diurnal changes in plant water potential caused by daily variation associated with environmental conditions will interact with water stress to affect the photosynthetic system. Direct consequences of these processes are inhibition of cell expansion, which adversely affects crop growth and yield. On the other hand, water stress causes ultrastructural changes in the chloroplasts that adversely affect photosynthesis (Dubey, 1997). Under drought stress, contents of photosynthetic pigments (Chl a, Chl b, and carotenes) diminish (Pukacki and Kaminska-Rozek, 2005; Terzi et al., 2010; Yordanov et al., 2000). For example, in fully active leaves of *Xerophyta scabrida* submitted to drought stress, the CO_2 assimilation, thylakoid activity, and respiration rate declined, whereas chlorophyll and carotene contents were successively broken down (Deltoro et al., 1998). When drought coincided with high radiation, it led to a decrease in carotenoid content in evergreen woody species *Quercus ilex*, *Quercus coccifera*, *Pinus halepensis*, and *Juniperus phoenicea* (Baquedano and Castillo, 2007).

However, photosynthetic systems have the ability to recover from drought stress when water becomes available (Nar et al., 2009). This process involves a complex of signals comprising metabolites produced during rehydration. For example, re-accumulation of Chl (a + b) and carotenoid synthesis was observed in stressed plants once leaves reached ≈91% of the maximum leaf water content (Schwab et al., 1989; Tuba et al., 1996). This underscores the need to understand not only diurnal patterns, but also seasonal changes in photosynthetic pigments caused by variations in stress conditions that

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