Photosynthetic Adaptation to Temperature in C₃ and C₄ Grasses

A POSSIBLE ECOLOGICAL ROLE IN THE SHORTGRASS PRAIRIE

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ABSTRACT

Increasing pretreatment day temperatures of 20, 30, and 40°C resulted in decreased net photosynthesis in Agropyron smithii (C₃) while in Bouteloua gracilis (C₄) net photosynthesis was increased. The effect on photosynthesis of increasing analysis temperatures was the same as observed by increasing pretreatment temperatures. Resistance of the stomata and boundary layer were less affected by pretreatment temperatures than were the remaining resistances of a physical and chemical nature. Resistances for A. smithii were increased and those for B. gracilis were decreased by increasing pretreatment temperatures. Phenology of the species in the shortgrass prairie is such that A. smithii has its greatest growth activity during the cool portion of the growing season, whereas B. gracilis is most active in the warm portion. Thus, photosynthetic adaptation to temperature is strongly suggested as a strategy for ecosystem utilization by reduction of interspecific competition.

MATERIALS AND METHODS

Field-collected sods of Agropyron smithii Rybd. and Bouteloua gracilis (H.B.K.) Lag were divided and grown under three controlled growth chamber temperature pretreatment regimes. The pretreatment regimes were 40/15°C, 30/15°C, and 20/15°C day/night temperatures (approximately 12 hr at each temperature) with a 15.5-hr photoperiod (mixed fluorescent and incandescent, 10² ergs cm⁻² s⁻¹ at plant height). After 50 days under these conditions, net photosynthesis and transpiration measurements were made using an open system plant chamber incorporating an infrared gas analyzer and thermoelectric dew-point hygrometers. Leaf material enclosed in a ventilated, controlled environment Plexiglas plant chamber (7) was exposed to an air stream of outside air mixed in a large chamber (200 liters) and then brought to a controlled dew-point temperature. The plant leaves within the cuvette were irradiated with 3.4 × 10⁶ ergs cm⁻² s⁻¹ of artificial light (measured total irradiance from General Electric 400 W, lucealox and multivapor lamps) during the experiments. Photosynthesis temperature-response curves for each species were obtained by measuring three individuals from each temperature pretreatment over a range of leaf temperatures from 20 to 40°C at 5°C intervals. A. smithii plants used for analysis were in a vegetative stage of phenology without flowering culms present, although plants from the 30/15°C and 40/15°C treatments had no expanding leaves. B. gracilis plants used were in flower, although no flowering culms were enclosed in the plant chamber for analysis. Leaf temperatures were controlled within ±0.5°C of the desired temperature. The irradiances for growth and analysis were sufficient to saturate photosynthesis of A. smithii but not B. gracilis.

Resistances to CO₂ and water vapor diffusion were calculated from transpiration and net photosynthesis rates and from leaf and air temperatures (4). Resistance to water vapor diffusion was calculated as the sum of stomatal and leaf-boundary layer diffusion; the leaf-boundary layer diffusion was considered to be a small portion of the resistance because of high ventilation rates in the leaf cuvette and the narrow leaf width of both species. From calculations of CO₂ diffusion resistance (r-leaf) and the difference between transpiration rates and photosynthetic rates, an internal leaf resistance (r-int) was calculated as the sum of residual resistances to CO₂ diffusion and carboxylation.

RESULTS

Photosynthesis temperature, transpiration temperature and resistance temperature-response curves show the two species to

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Comparisons of the two species from 30/15 and 40/15 C pretreatments show that B. gracilis has greater rates of photosynthesis than A. smithii at all analysis temperatures. A. smithii plants from the 40/15 C pretreatment show lower rates of photosynthesis at all analysis temperatures compared to those grown at 30/15 C. Within B. gracilis the 30/15 and 40/15 C treatments show higher rates at all analysis temperatures than the 20/15 C treatment. The difference in B. gracilis photosynthesis between 30/15 and 40/15 pretreatments was the cooler pretreatment resulted in higher rates at 20 C and the warmer pretreatment resulted in higher rates at 40 C. Comparing photosynthetic rates between treatments showed them to be essentially equal at 25, 30, and 35 C analysis temperatures.

The increased rates of photosynthesis of B. gracilis plants from warmer pretreatments were generally accompanied by reduced resistances; however, interactions between r-leaf and r-int in plants pretreated at 40/15 C seemingly allow for the observed high rates of photosynthesis at 25, 30, and 35 C. The resistances, r-leaf and r-int, observed for A. smithii are greatest at higher analysis temperatures with the exception of r-leaf at 20 C analysis temperature for plants pretreated at 40/15 C. The data indicate that the r-int plays a significant role in controlling photosynthesis rates and has a greater response to pretreatment temperature than does the resistance of the stomata and r-leaf. Although the r-int consists of the physical and biochemical resistances (apart from r-leaf) in the carbon dioxide pathway, no attempt was made to determine which of these resistances comprising r-int might be more influential in the temperature responses of the two species.

**DISCUSSION**

The results support the hypothesis that the physiological response of the photosynthetic apparatus to temperature could play a significant role in the observed phenology of Agropyron smithii (C$_3$) and Bouteloua gracilis (C$_4$) in Colorado sites. The temperature effects of pretreatment and analysis treatment on net photosynthesis indicate that environmental temperature plays an important role in the differential suppression of metabolic activities in the two species. The pretreatment and analysis temperatures effective in suppressing net photosynthesis in each species correspond to temperatures in the community at the time of reduced growth and development activity by the particular species (unpublished results). The results indicate that r-leaf plays a role in regulating photosynthesis, presumably through stomatal regulation as boundary-layer resistance was minimal; however, the resistances associated with r-int were most responsive to both pretreatment and analysis temperature.

Experiments are now needed to provide evidence at the biochemical level to support or refute the responsibility of poor photosynthetic performance at a given temperature on the presence or absence of a particular photosynthetic pathway. Other possible physiological controls of the observed phenology of the species, such as their apparent response to water stress, also remain to be documented (1, 3). Further, there is the challenge to establish the control mechanism of physiological responses at the biochemical level which have significant implications regarding (a) relationships between environmental factors and photosynthetic capacities of plants utilizing different carbon-fixation pathways; (b) ecological significance of biochemical processes; and (c) adaptive strategies of plant communities composed of species of different photosynthetic pathways.
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LITERATURE CITED