Response of bahiagrass carbon assimilation and photosystem to below-optimum temperatures

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Rationale and Objectives

- Photosynthesis and growth of tropical grasses such as bahiagrass (*Paspalum notatum* Flueggé) is sensitive to cool season temperatures but information on the responsive mechanisms is limited in bahiagrass.
- The C_4 photosynthetic pathway generally performs best under high light and optimum warm temperature.
- Damage to carbon assimilation and photosystem under below-optimum temperatures has not been studied well in C_4 forages.
- Current CROPGRO-forage simulation models are less accurate in predicting winter growth due to lack of reliable leaf level photosynthesis algorithms.
- We hypothesize that below-optimum temperatures may have different short and long term effects when grown under full sunlight. Near the end of the study, all treatments were subjected to 3 days of stressful chilling temperatures to see if prior growth temperature pre-disposes any acclimation effect, and the degree of damage and rate of recovery from chilling temperatures were studied.

Methodologies

Growth Conditions:
The experiment was conducted during Fall 2006 at Mississippi State University (38º 28' N, 88º 47' W), Mississippi, USA, using controlled environment chambers known as Soil-Plant-Atmosphere-Research (SPAR) units.

Plant Culture:
Sod of bahiagrass (*Paspalum notatum*) cv. 'Pensacola' measuring 2 x 0.5 m was obtained from a 15-year old, well maintained pasture and was established in the SPAR soil bins, filled with sand. After initial growth for 20 d in the sand of soil bins, was clipped to 5-cm height and allowed to grow until the treatments were initiated. Plants were fertilized by irrigating three times a day, using drip system, with Hoagland's nutrient solution delivered at 0800, 1200 and 1600 h to ensure favorable nutrient and water conditions for plant growth.

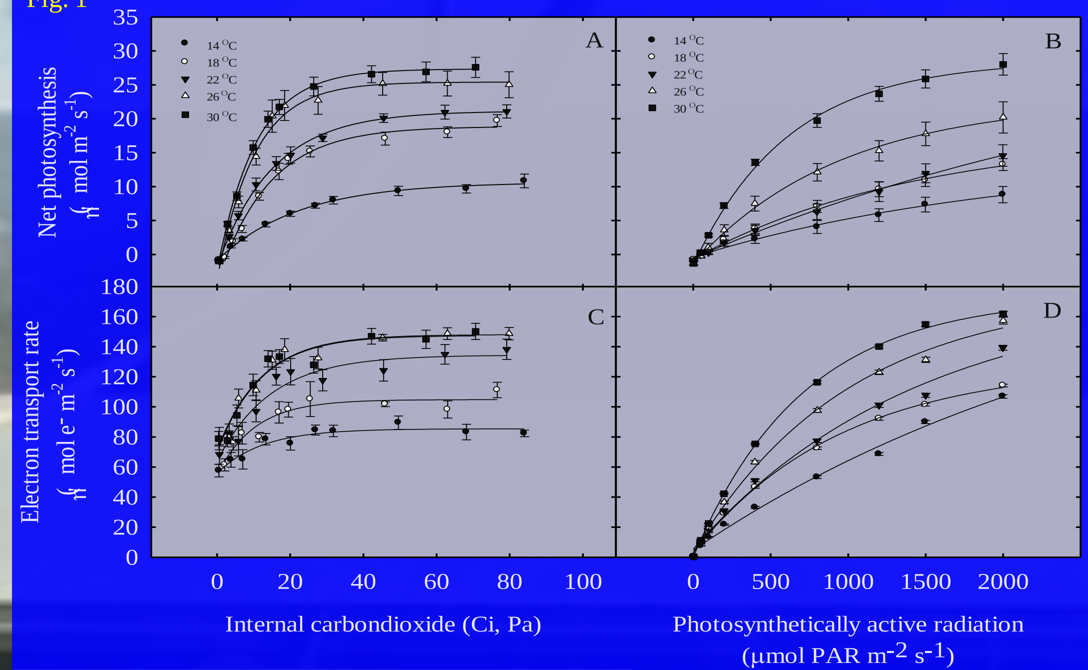
Temperature Treatments:
Bahiagrass was grown in all chambers at 30/22°C until the treatments were initiated. Five treatments consisting of day/night temperature of 14/6, 18/10, 22/14, 26/18 and 30/22ºC were imposed from 45 d through 78 d after transplanting and each temperature was randomly assigned to two chambers, i.e. replicated twice.

Measurements:
Gas exchange measurements were made on attached leaves using an open gas exchange LI-6400 system (LICOR Inc., Lincoln, Nebraska, USA) fitted with a 6400-40 leaf chamber fluorometer (LCF). Three sets of two topmost fully-expanded leaves of similar age in each of chamber were selected for measurements. A/Ci and A/PPFD response curves along with fluorescence were made between 1000 and 1400 h during the 11th to 20th day after start of temperature treatment on topmost fully-expanded leaves . Seasonal A and F was measured at regular intervals.

Statistical Analysis:
Nonlinear regression model of exponential rise to maximum was employed to determine relationships between *A* and *PPFD* or *Ci* using curve fitting software (SigmaPlot for Windows 9.0). Regression analysis was used to determine the response of derived parameters to temperature. A time-series analysis (SAS Institute Inc. 1999) was carried to determine the effects of days after temperature treatment (D) and temperature (T) on measured seasonal photosynthesis parameters. Fisher LSD test was used to determine treatment differences at *P* = 0.05 level of significance (SAS Institute Inc. 1999). The vertical error bars are ±SE.

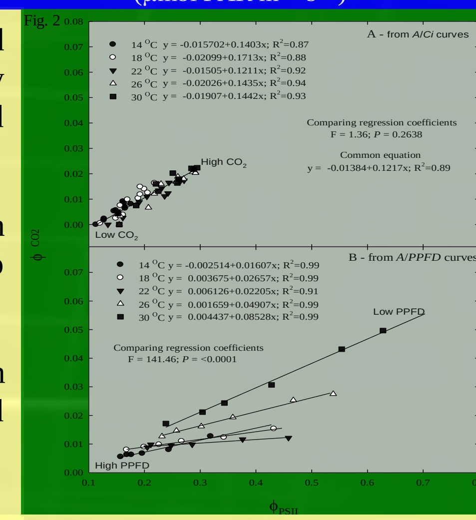
A-ETR/Ci or *PPFD* responses curves

Fig. 1



- Below-optimum temperature reduced bahiagrass photosynthesis as evidenced by carbon assimilation (Fig. 1A and B) and electron transport rate (Fig. 1C and D).
- At a given Ca, the Ci was not reduced with decrease in temperature suggesting no stomatal limitation.
- With decrease in growth temperature from 30 to 14°C, both Φ_{PSII} and Φ_{CO2} decreased (Fig. 2A and B).

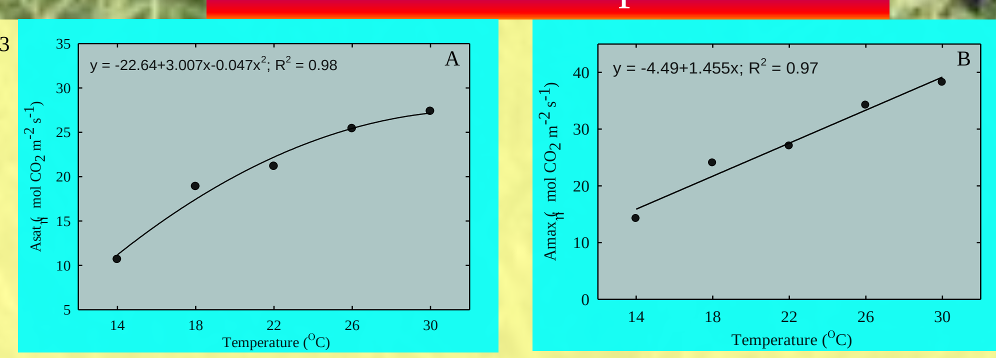
Fig. 2



- The relationship between Φ_{PSII} and Φ_{CO2} at different temperatures derived from *A/Ci* curves showed no significant difference (*P* = 0.2638) and a single linear regression (R^2=0.89) described the relationship across all the growth temperatures.
- In contrast, relationship derived from *A*/*PPFD* curves at different temperatures were linear and significantly different (*P* < 0.0001).

Functional responses

Fig. 3

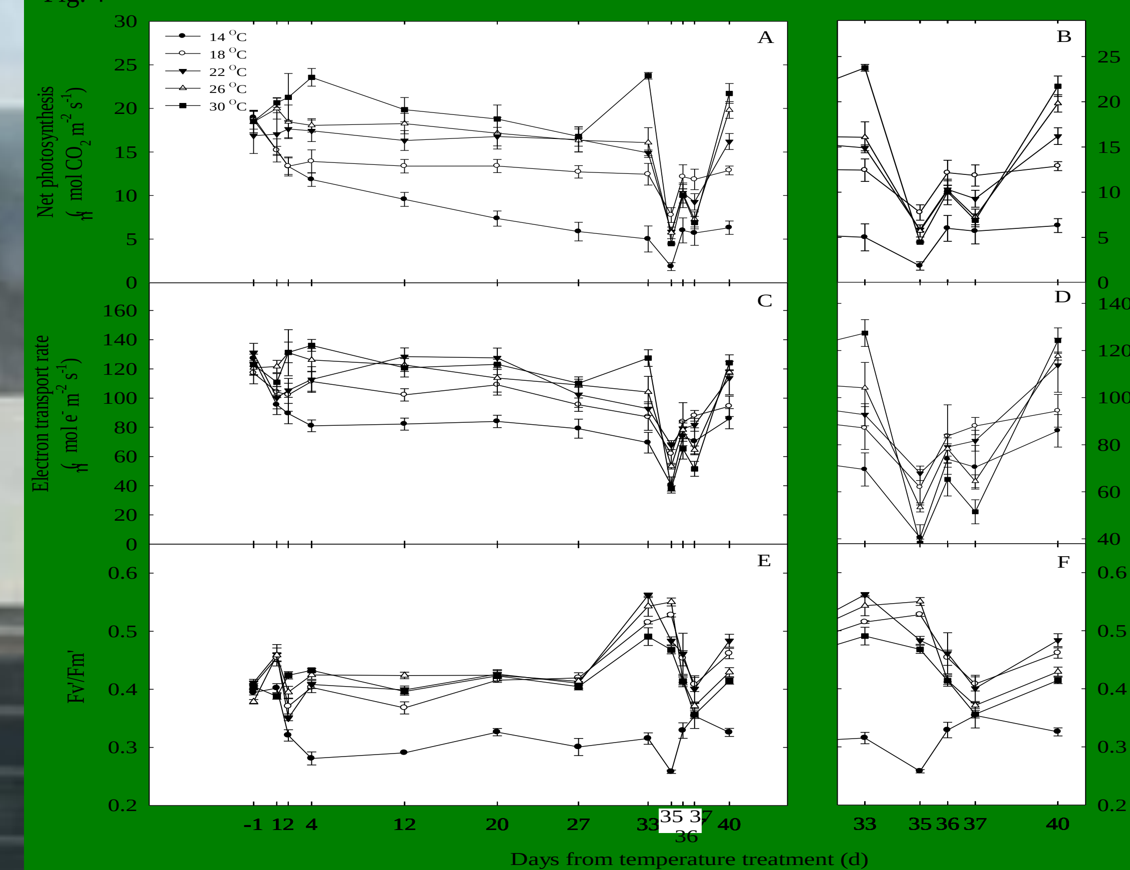


Linear or quadratic regression best described response of photosynthetic parameters to below-optimum temperatures and can be used to improve leaf level photosynthesis simulation in CROPGRO-Forage model.

PEPC activity (μmol CO_2 m^{-2} s^{-1})	= -1.282 + 0.1337x; R^2 = 0.92
Rd (μmol CO_2 m^{-2} s^{-1})	= -1.487 + 0.1097x; R^2 = 0.98
Q_E (μmol CO_2 photon^{-1})	= 0.049 – 0.0047x + 0.0015x^2; R^2 = 0.97
E_{QE} (e^- photon^{-1})	= 0.021 + 0.0063x; R^2 = 0.97

Seasonal photosynthesis

Fig. 4



- The average *A* values during the experimental period, excluding the subsequent cold shock period, were 10.4, 14.2, 16.3, 18.1 and 20.5 μmol CO_2 m^{-2} s^{-1} at 14, 18, 22, 26 and 30°C, respectively (Fig. 4A).
- The average *A* values during three days of cold shock were 4.2, 10.5, 8.5, 7.7 and 7.2 μmol CO_2 m^{-2} s^{-1} in the treatments that were at 14, 18, 22, 26 and 30°C, respectively (Fig. 4B).
- The mean *ETR* values during the treatment period were 77, 94, 101, 104 and 104 μmol e^- CO_2 m^{-2} s^{-1} at 14, 18, 22, 26 and 30°C, respectively (Fig. 4C).
- Beyond 4 d of temperature treatment, the leaves at 14°C showed a gradual decline during the entire measurement period. However, the leaves grown at 18°C maintained nearly the same leaf *A* levels as they did 4 d after temperature treatment.
- The Fv'/Fm' values clearly differentiated the sensitivity of the photosystem to cold temperatures and leaves at 14°C had significantly lower values than the rest of the treatments during the treatment period (Fig. 4E).

Conclusions

- We observed reduction in *A* and *PEPC* efficiency, Φ_{PSII}, Φ_{CO2}, *Fv'/Fm'*, and electron transport rate with decreased growth temperature.
- This study demonstrated that both enzymatic activities and photosystem of bahiagrass are inhibited by below-optimum growth and measurement temperatures.
- The instantaneous measures of fluorescence parameters that are sensitive to below-optimum temperatures can be used to screen forage grasses for cold-stress tolerance.
- The derived response functions and parameters can also be used to improve leaf-level photosynthesis algorithms in CROPGRO-forage models.