Application of the Photosynthetic Light-Use Efficiency Model in a Northern Great Plains Grassland

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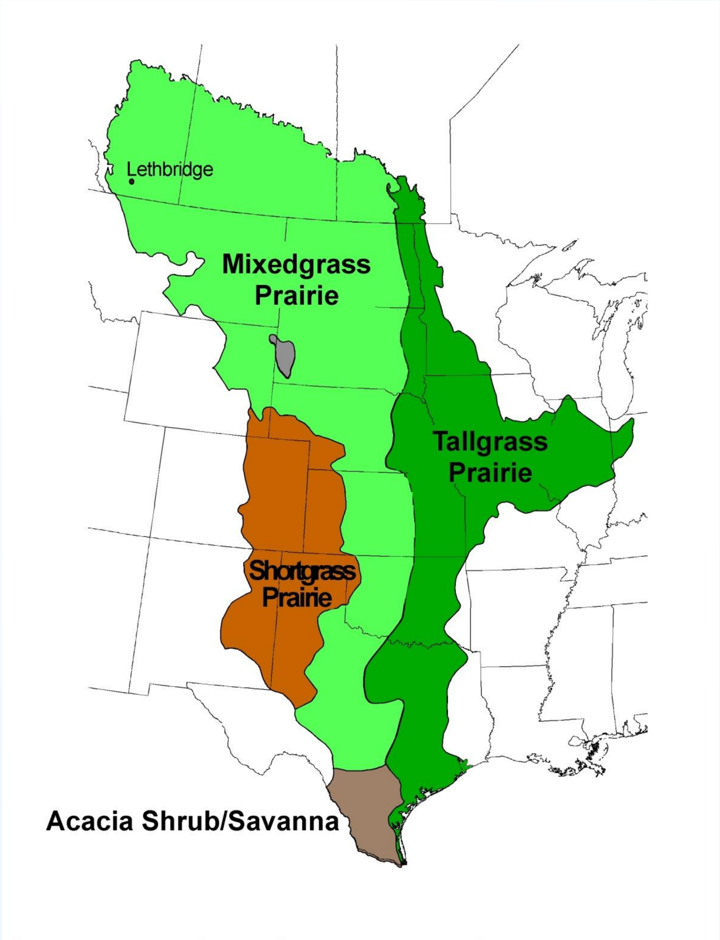
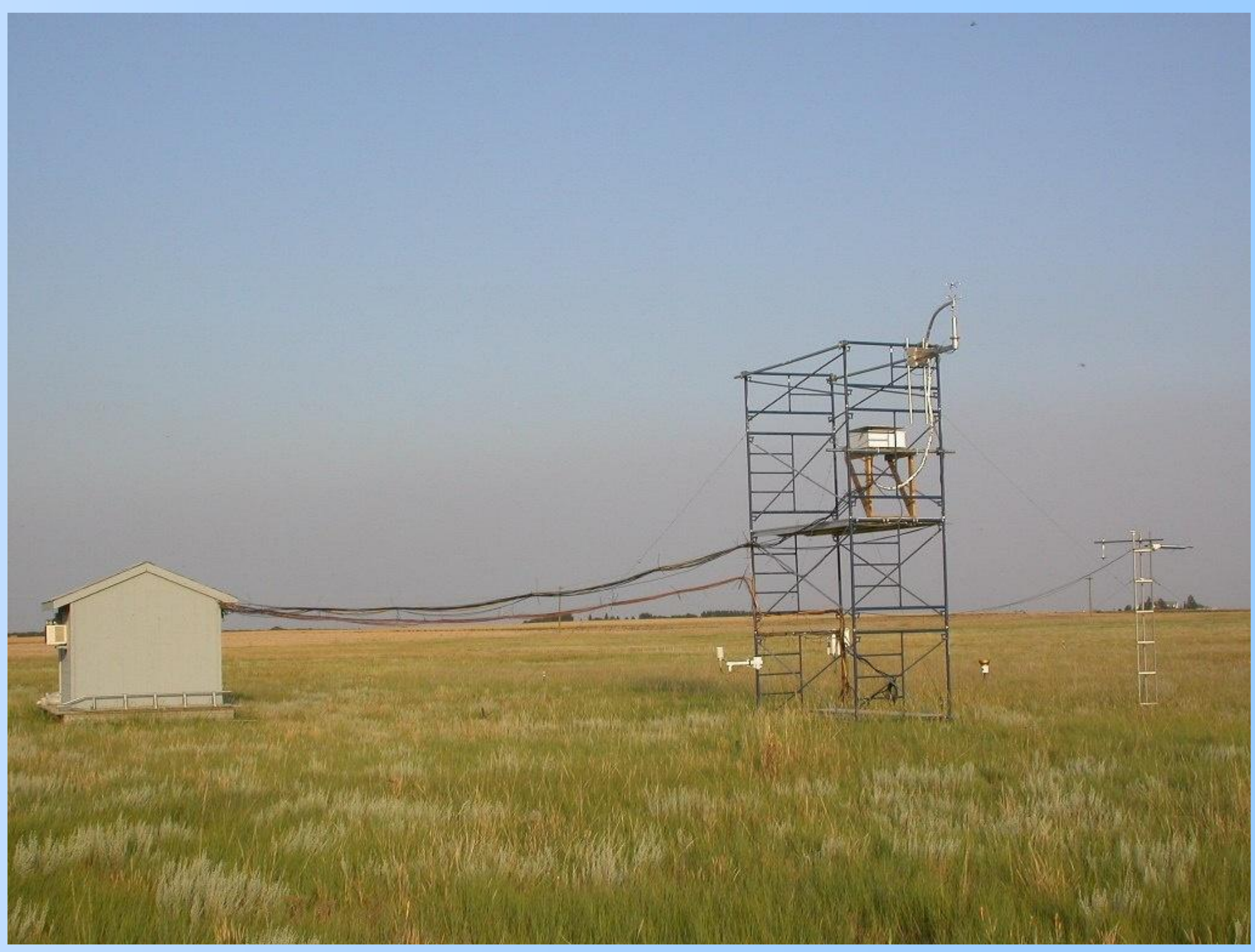


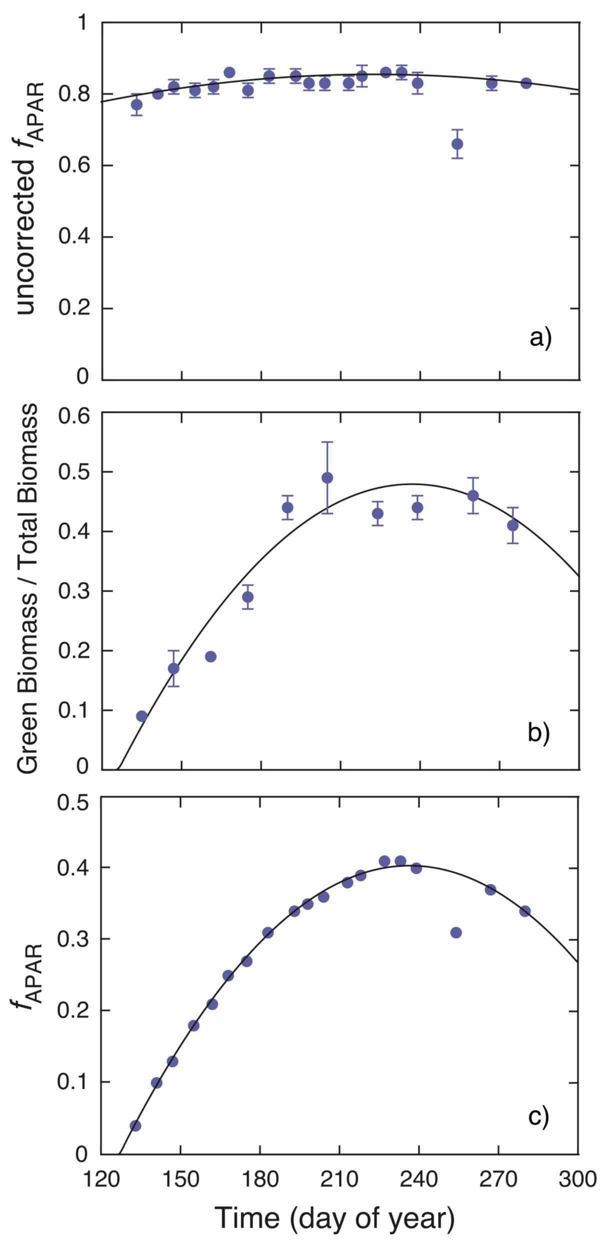
Grasslands of the Great Plains (Ostlie *et al.* 1997)

Summary

- We measured the fraction of absorbed photosynthetically active radiation using two methods (f_{APAR} and f_{CHL})
- A strong linear relationship occurred between f_{APAR} and f_{CHL}
- Strong linear relationships existed between NDVI and both f_{APAR} and f_{CHL} up to peak LAI
- After peak LAI there was hysteresis in both the NDVI-f_{APAR} relationship and the NDVI-f_{CHL} relationship
- Calculations of photosynthesis (GEP) using the LUE model were strongly correlated with measurements up to peak LAI
- After peak LAI, a stress function was necessary to reduce LUE and model calculations of photosynthesis in order to match the measurements of photosynthesis



Calculations of f_{APAR} from Radiation Measurements

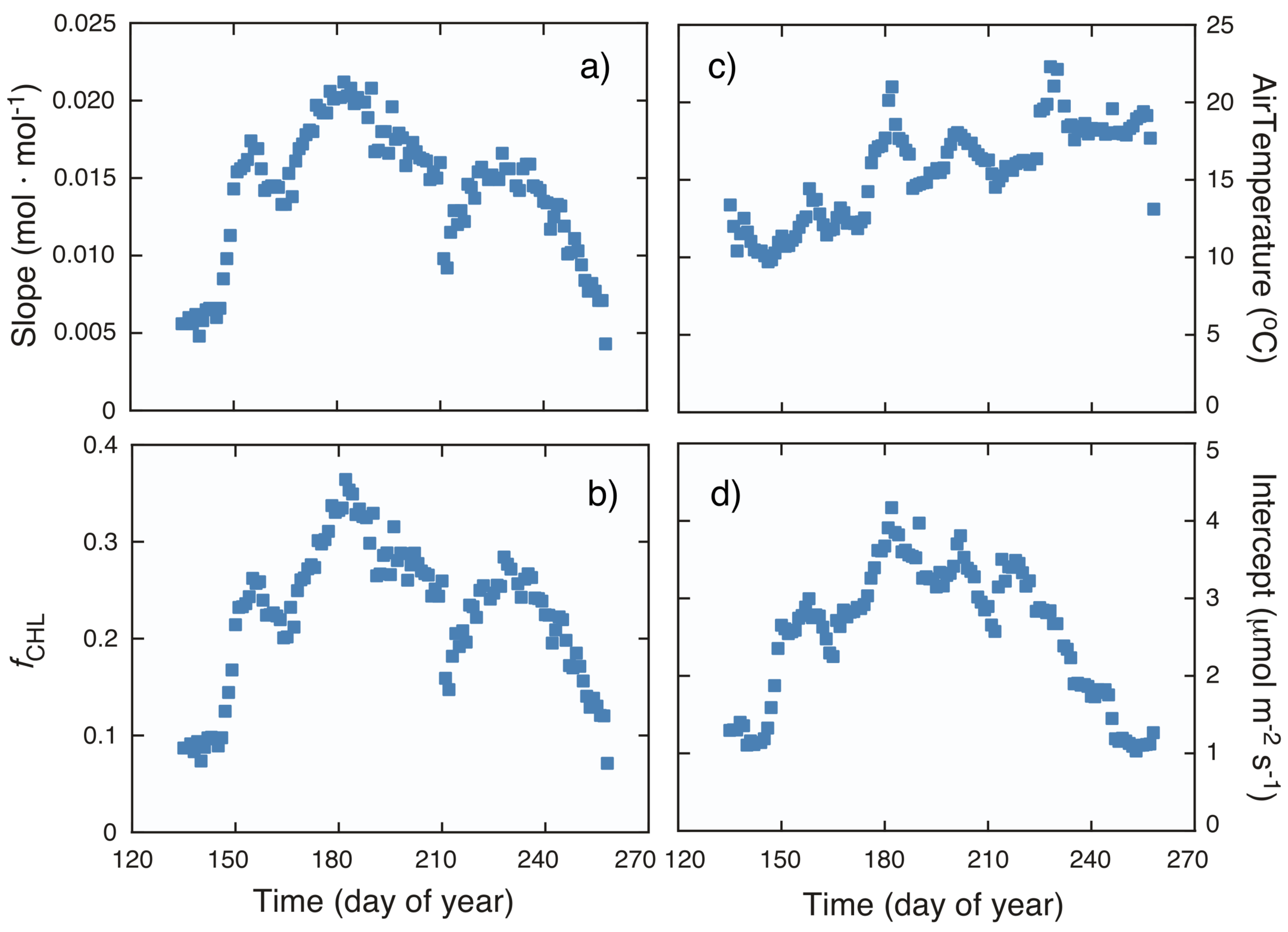


To calculate uncorrected f_{APAR} we made measurements of incident and reflected PPFD at midday, above and below the plant canopy using a light-bar quantum sensor. The f_{APAR} values were corrected by using the ratio of green biomass to total biomass harvested in sample plots.

We also used an indirect (inversion) method to estimate f_{APAR} based on the light response of NEP. We term this alternative calculation f_{CHL} (see below).

We hypothesized that f_{APAR} and f_{CHL} should be linearly related during periods of constant light-use efficiency and plant pigmentation, but that this relationship would breakdown if these conditions were not met (e.g. late in growing season).

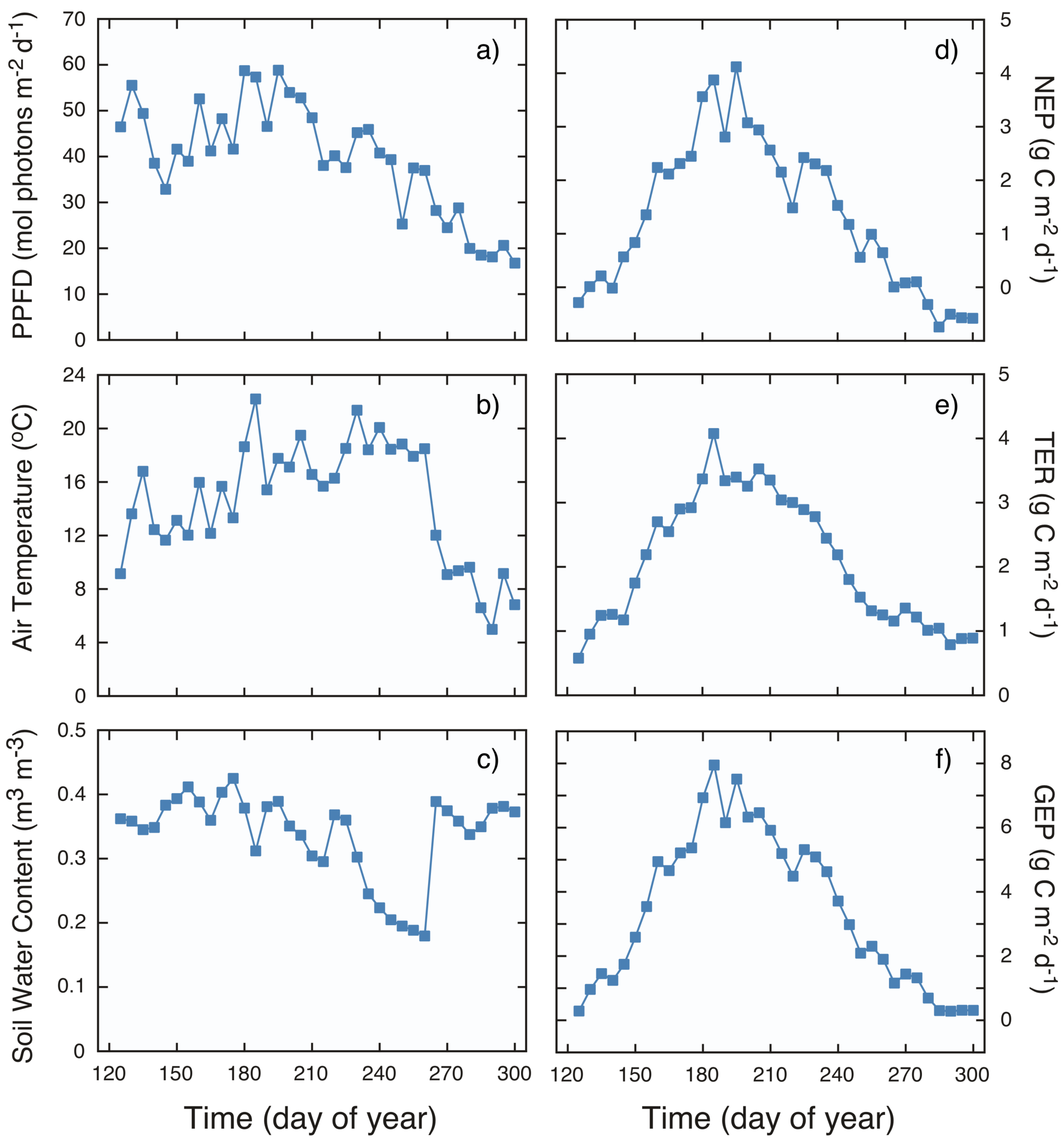
Calculations of f_{CHL} from the Light-response of NEP



$$NEP = PPFD\alpha_{max} f_{CHL} \frac{(p_i - \Gamma_*)}{(p_i + 2\Gamma_*)} - TER$$

The f_{CHL} was calculated from the slope of a linear regression between NEP and PPFD during low light (PPFD < 300 μmol m^{-2} s^{-1}). The y-intercept of the regression was an estimate of TER. The slope calculations assumed that p_i was constant at 280 μbars and that Γ_* varied with changes in temperature (Brooks & Farquhar 1985), maximum quantum yield (α_{max}) was held constant at 0.08 mol mol^{-1}.

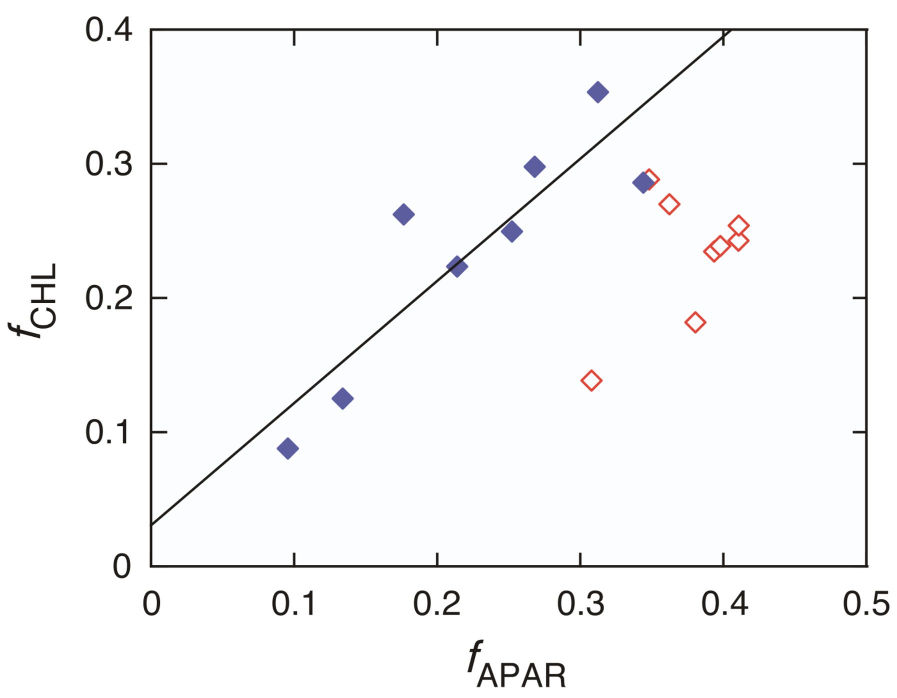
Seasonal Variation in Environmental Conditions and Measurements of Ecosystem CO_2 Exchange



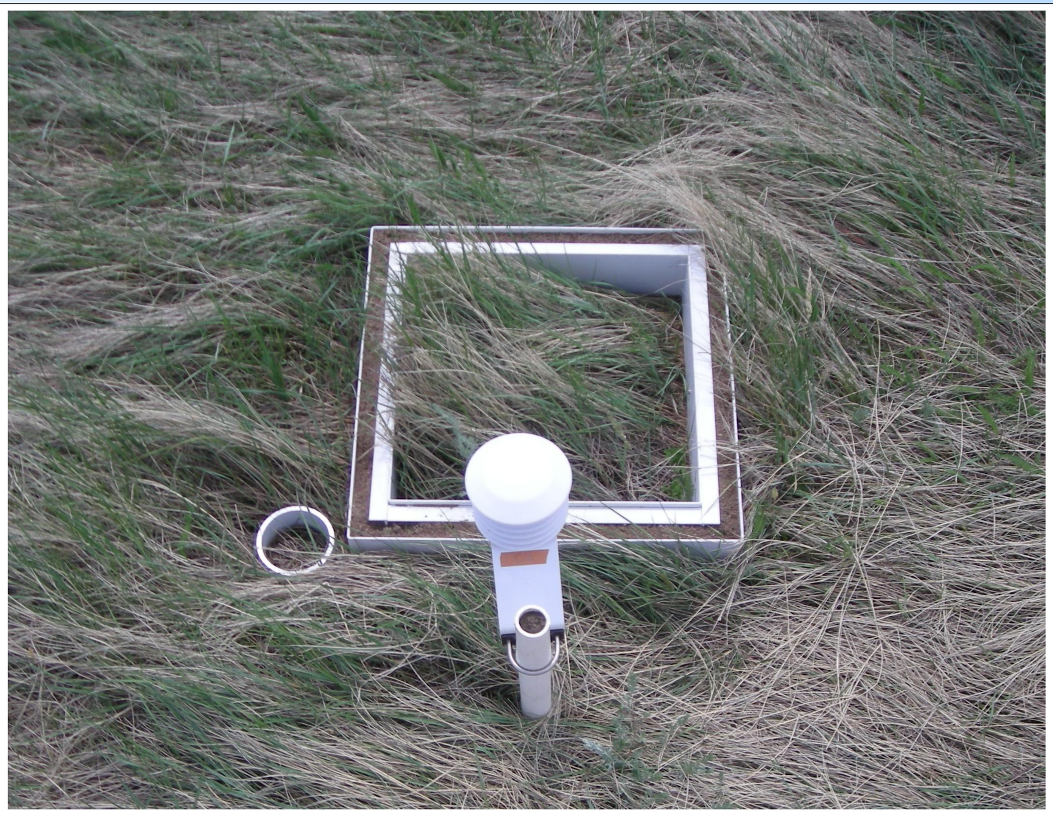
NEP = Net Ecosystem Productivity (+ values = sink)
TER = Total Ecosystem Respiration (+ values = source)
GEP = Gross Ecosystem Productivity (+ values = sink)
- values from eddy covariance measurements

PPFD = Photosynthetically Active Photon Flux Density

Relationship between f_{APAR} and f_{CHL}



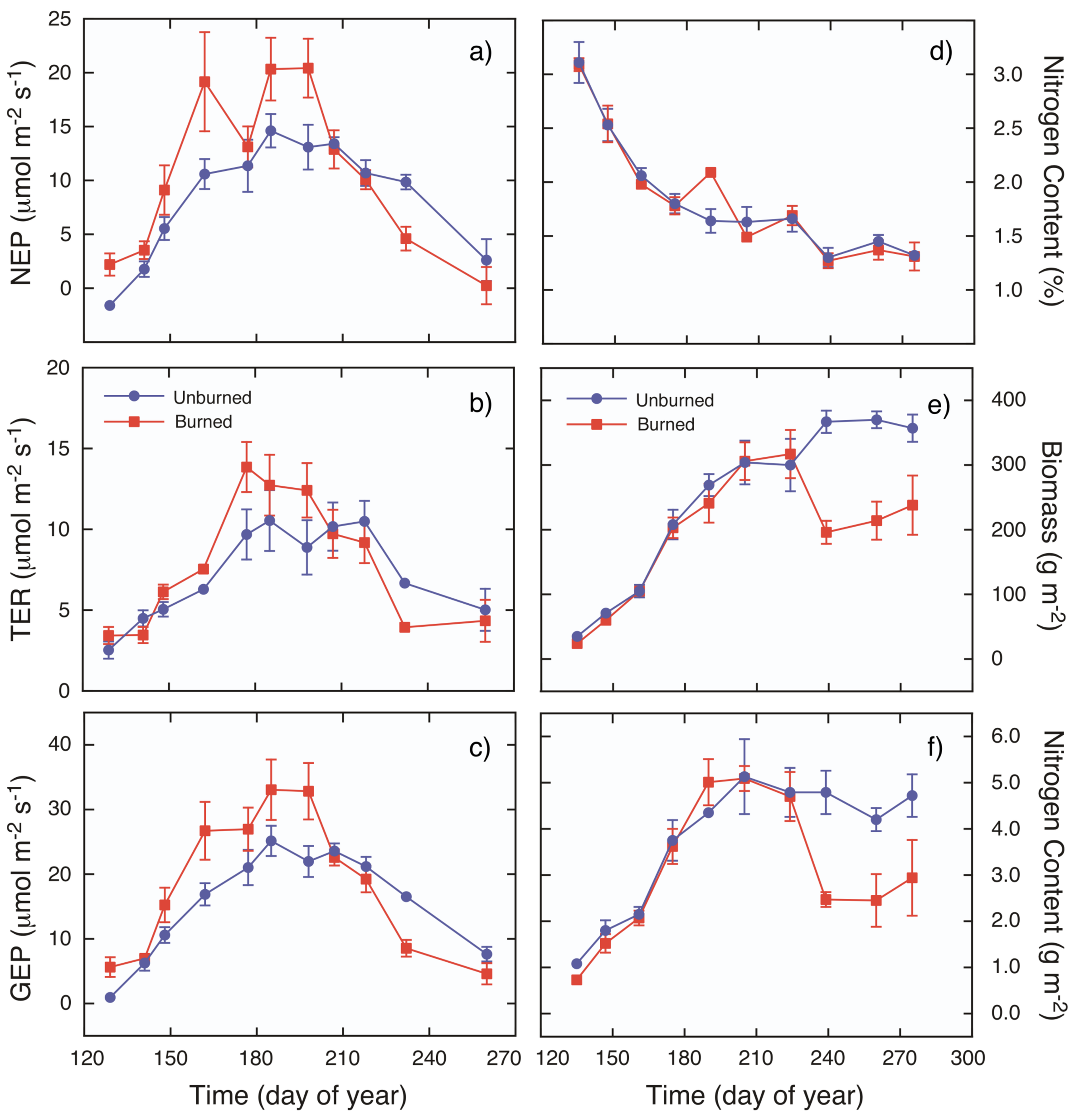
There was a strong linear relationship between f_{APAR} and f_{CHL} during the initial development of the plant canopy until peak GEP (blue symbols, days 133-193), with a slope near 1 and a y-intercept near 0. After mid-July (day 193, red symbols), f_{CHL} generally declined while f_{APAR} remained relatively high, and this caused hysteresis in the f_{APAR}-f_{CHL} relationship.



System for Chamber Measurements of Ecosystem CO_2 Exchange

NDVI Measurements

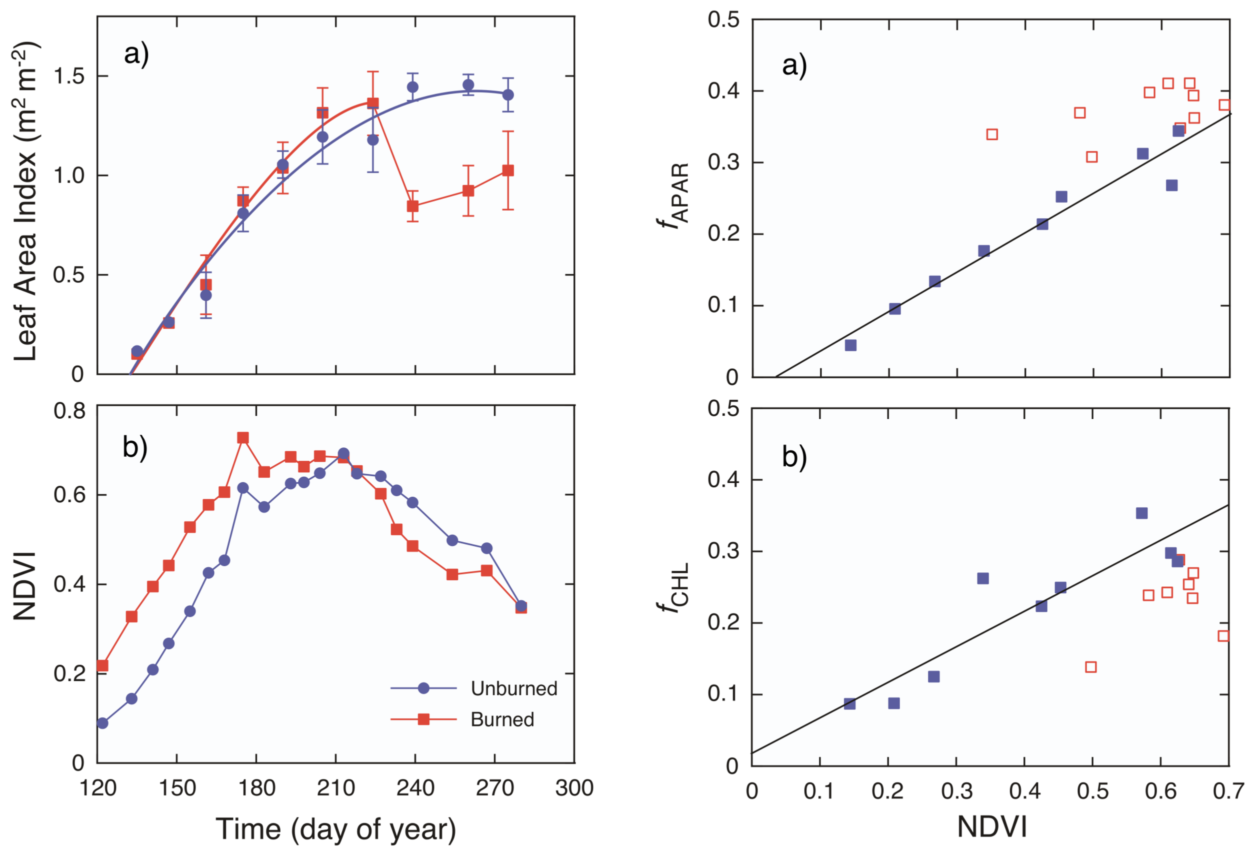
Seasonal Variation in Chamber Measurements of Ecosystem CO_2 Exchange, Plant Biomass and N Content



Mid-day measurements of net ecosystem production (NEP), total ecosystem respiration (TER), and gross ecosystem photosynthesis (GEP) were made with the closed chamber system illustrated above. Measurements were made in unburned areas and areas burned in the fall (September 2012) before this study was conducted (2013).

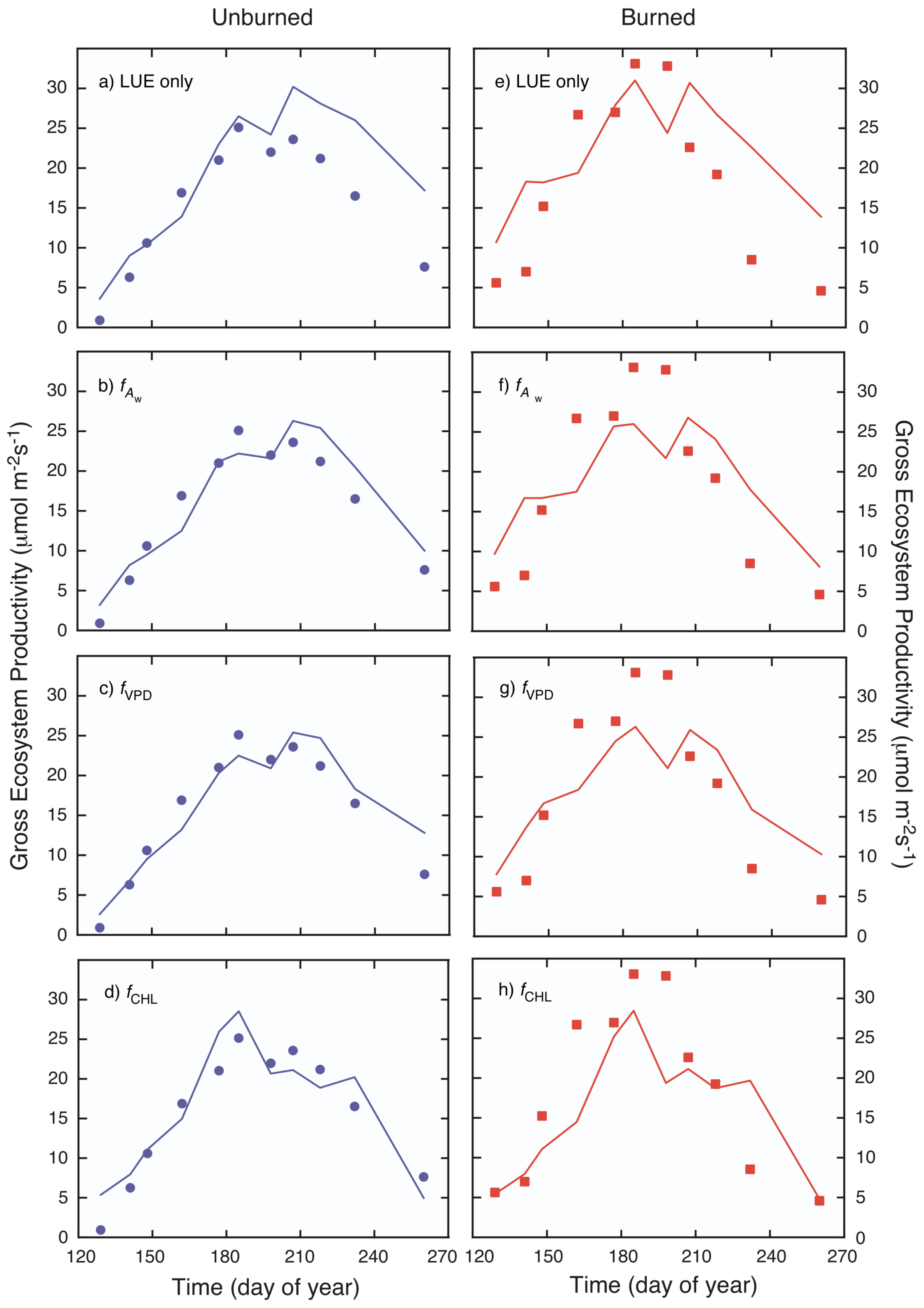
There was no significant difference between burned and unburned plots for NEP, TER or GEP. However, there was a significantly different seasonal pattern of change, with all CO_2 exchange parameters starting earlier and then declining sooner in the burned compared to unburned plots.

Relationship between NDVI and the two f_{APAR} estimates



There were strong linear relationships between NDVI and both f_{APAR} and f_{CHL} in the unburned area during the initial plant canopy development (blue symbols, days 133-193) until peak LAI. However, there was hysteresis in both relationships after mid-July (day 193, red open symbols). This complicates the use of NDVI to estimate f_{APAR} when GEP begins to decline after peak LAI.

Seasonal Variation in Measured GEP and LUE Model Calculations of GEP



LUE model calculations (lines) were compared to chamber GEP measurements (symbols). Stress functions were required to reduce LUE and model GEP calculations after peak LAI, during periods of low soil moisture and high VPD. Both stress functions were similarly effective at improving model fits to observed GEP.

LUE Model Calculations

$$GEP = PPFD\alpha_{max} f_{APAR} \frac{(p_i - \Gamma_*)}{(p_i + 2\Gamma_*)} f_{Aw}\ (or\ f_{VPD})$$

The LUE model was calculated as shown above, where f_{Aw} and f_{VPD} were water stress functions (scale 0-1). Initial calculations of GEP assumed that there was no apparent water stress and f_{Aw} was kept constant at a value of 1. Subsequent calculations assumed water stress was apparent and applied either f_{Aw} or f_{VPD} based on soil moisture measurements (A_w relative scale, 0-1) or VPD (kPa) measurements, respectively. A final set of calculations was done using f_{CHL} in place of f_{APAR} with no stress function applied (f_{Aw} = 1).

$$f_{Aw} = 1 - (1 + 1.3A_w)^{-3.5} \qquad f_{VPD} = \frac{1}{1 + e^{(1.3(VPD-3))}}$$

Linear regression statistics (slope, *y*-intercept, R^2 value) for comparisons between the LUE model GEP calculations and GEP measurements.

	Unburned	Burned
1) No Water Stress Function		
Slope	0.808	1.207
y-intercept	0.033	-8.337
R^2	0.800	0.555
2) f_{Aw} Stress Function		
Slope	0.959	1.319
y-intercept	-0.156	-6.876
R^2	0.883	0.605
3) f_{VPD} Stress Function		
Slope	1.000	1.443
y-intercept	-0.489	-8.387
R^2	0.892	0.703
4) f_{CHL}		
Slope	0.928	1.088
y-intercept	0.443	0.955
R^2	0.867	0.632