Quantification of CO_2 exchange in grassland ecosystems of the world using tower measurements, modeling and remote sensing

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Keywords: nontropical grasslands, gross primary production, ecosystem respiration, net CO_2 flux partitioning, light-use efficiency

Introduction Grasslands cover significant areas in nontropical regions, perform essential biogeochemical functions and represent important natural and agricultural resource. Nevertheless, in contrast to forests and agroecosystems, no flux measurement-based global summary of their CO_2 exchange, sequestration potential, and role in mitigation of the greenhouse effect were available.

Materials and methods Data sets of continuous CO_2 flux measurements at 32 towers from nontropical grasslands in North America, Europe and Asia were analysed to estimate the major parameters for CO_2 exchange and light-use efficiency. Tower-derived net CO_2 exchange (F_c) was partitioned into gross primary productivity (P_g) and ecosystem respiration (R_e) components ($F_c = P_g – R_e$) by using physiologically-based analysis of ecosystem-scale light-response functions (Gilmanov *et al.*, 2003; Gilmanov *et al.*, 2004). Methods of nonlinear multivariate analysis were used to identify relationships between P_g, R_e and the normalised difference vegetation index (NDVI) and other factors.

Results Maximum daily rates of P_g and R_e achieved values of 63 g $CO_2/m^2/d$ and 54 g $CO_2/m^2/d$, respectively and were approached not only in highly productive tallgrass prairies, but also in southern arid grasslands in years with high precipitation. Maximum values of annual P_g (5200 g $CO_2/m^2/a$) and R_e (4700 g $CO_2/m^2/a$) were observed in tallgrass prairies of Oklahoma and Texas, respectively. The lowest P_g (< 400 g $CO_2/m^2/a$) was recorded on the grazed mixed prairie in Montana during a drought year. The lowest R_e (< 500 g $CO_2/m^2/a$) was estimated for the semidesert grassland in Uzbekistan. Depending on weather conditions and management (grazing, fire), net ecosystem CO_2 exchange of grasslands varies from +2800 g $CO_2/m^2/a$ (early post-fire succession in tallgrass prairie, strong sink) to less than –1500 g $CO_2/m^2/a$ (grazed mixed/tallgrass prairie during a drought year, a strong source). Maximum values of daily light use efficiency $\varepsilon = P_g/(\text{incident PAR})$ were achieved in warm temperate grasslands of Europe and eastern U.S. (ε_{max} = 34 – 40 mmol CO_2/(mol incident PAR)), followed by tallgrass and mixed prairies (ε_{max} = 32), while the lowest light use efficiency values were recorded in the semidesert of Uzbekistan (ε_{max} = 9). Grassland CO_2-flux data showed significant correlation (r) between P_g and R_e and NDVI, with r in the range 0.55 to 0.92 for P_g and NDVI, and 0.45 to 0.94 for R_e and NDVI. Maximum r-values were achieved in ecosystems with highest phytomass (tallgrass prairies, warm temperate grasslands). For some sites statistically significant relationships $P_g = f(\text{NDVI}, X_{i1}, \ldots, X_{in})$, $R_e = g(\text{NDVI}, X_{j1}, \ldots, X_{jm})$ were established, where X_i represents some aspect of climate, soils or vegetation. The R^2 for these relationships in many cases achieved values higher than 90%.

Conclusions Superposition of these functions on GIS data layers of NDVI and X_i for areas ecologically similar to the tower sites represents a defensible method for scaling-up tower CO_2 flux measurements allowing regional quantification of CO_2 balance on grasslands with implications for continental and global carbon budgets (Gilmanov *et al.*, 2004; Wylie *et al.*, 2004).

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