Validity of extrapolating field CO\textsubscript{2} experiments to predict carbon sequestration in natural ecosystems

Yiqi Luo\textsuperscript{1} and James F. Reynolds\textsuperscript{2}

\textsuperscript{1}Biology Research Center, Desert Research Institute, Reno, Nevada 89512 USA
\textsuperscript{2}Department of Botany, Duke University, Durham, North Carolina 27708 USA

Abstract One of the ultimate goals of ecosystem carbon dioxide (CO\textsubscript{2}) experiments is to infer the capacity of terrestrial ecosystems to sequester carbon (C) in a CO\textsubscript{2}-enriched world. This modeling study examines C sequestration (C\textsubscript{seq}) in natural ecosystems based on CO\textsubscript{2} experiments. Most experiments are conducted by a step increase in CO\textsubscript{2} concentration, whereas natural ecosystems are experiencing a gradual increase in atmospheric CO\textsubscript{2} (C\textsubscript{a}). To examine the effects of a step vs. gradual CO\textsubscript{2} increase on ecosystem responses, we have developed a terrestrial C sequestration (TCS) model that focuses on C and nitrogen (N) interactions in regulating C\textsubscript{seq}. We used the model to: (1) compare C\textsubscript{seq} and N demand in response to the step vs. gradual increase in CO\textsubscript{2}; (2) identify mechanisms underlying different ecosystem responses to the step vs. gradual CO\textsubscript{2} forcing; (3) examine key parameters in controlling C\textsubscript{seq}; and (4) explore three hypothesized N supply mechanisms in regulating photosynthetic acclimation and C\textsubscript{seq}.

Application of this model to simulate responses of a forest ecosystem with gross primary productivity of 1200 g C m\textsuperscript{-2} yr\textsuperscript{-1} suggested that a step increase in CO\textsubscript{2} from 350 to 700 ppm resulted in C\textsubscript{seq} of 263 g C m\textsuperscript{-2} yr\textsuperscript{-1} in the first year. A gradual C\textsubscript{a} increase led to the C\textsubscript{seq} rates of 27 and 58 g C m\textsuperscript{-2} yr\textsuperscript{-1} in 1987 and 2085 when CO\textsubscript{2} reached 350 and 700 ppm, respectively. The model predicted that N demand required to balance the additional C influx was 4.1 g N m\textsuperscript{-2} yr\textsuperscript{-1} in the step CO\textsubscript{2} increase and only 0.6 and 1.7 g N m\textsuperscript{-2} yr\textsuperscript{-1} in 1987 and 2085, respectively, in the gradual C\textsubscript{a} increase. The contrasting differences in C\textsubscript{seq} and N demand between the two increase scenarios reflected the nature of C fluxes that were controlled by the sizes of donor pools (i.e., donor-controlled system). Our modeling analysis of four ecosystems (forest with high productivity [HP]; grassland with HP; forest with low productivity [LP]; and grassland with LP) indicated that additional C influx C relaxation time are the key parameters in determining ecosystem C\textsubscript{seq}. The additional C influx varied with ecosystem productivity and N regulation, while C relaxation time differed between the forests and grasslands due to woody tissues and litter in the forests. We conclude that in spite of the fact that the step experiment is one of the most effective approaches in ecosystem studies, its results cannot be directly extrapolated to predict terrestrial C\textsubscript{seq} in natural ecosystems responding to a gradual C\textsubscript{a} increase. In order to develop predictive understanding from the step experiments, we need not only to improve experimental design and measurement plans, but also to develop new approaches, such as deconvolution and inverse modeling, for data analysis and interpretation.