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Validity of extrapolating field CO_2 experiments to predict carbon sequestration in natural ecosystems

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Abstract One of the ultimate goals of ecosystem carbon dioxide (CO_2) experiments is to infer the capacity of terrestrial ecosystems to sequester carbon (C) in a CO_2-enriched world. This modeling study examines C sequestration (C_{seq}) in natural ecosystems based on CO_2 experiments. Most experiments are conducted by a step increase in CO_2 concentration, whereas natural ecosystems are experiencing a gradual increase in atmospheric CO_2 (C_a). To examine the effects of a step vs. gradual CO_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_{seq}. We used the model to: (1) compare C_{seq} and N demand in response to the step vs. gradual increase in CO_2; (2) identify mechanisms underlying different ecosystem responses to the step vs. gradual CO_2 forcing; (3) examine key parameters in controlling C_{seq}; and (4) explore three hypothesized N supply mechanisms in regulating photosynthetic acclimation and C_{seq}.

Application of this model to simulate responses of a forest ecosystem with gross primary productivity of 1200 g $C \cdot m^{-2} \cdot yr^{-1}$ suggested that a step increase in CO_2 from 350 to 700 ppm resulted in C_{seq} of 263 g $C \cdot m^{-2} \cdot yr^{-1}$ in the first year. A gradual C_a increase led to the C_{seq} rates of 27 and 58 g $C \cdot m^{-2} \cdot yr^{-1}$ in 1987 and 2085 when CO_2 reached 350 and 700 ppm, respectively. The model predicted that N demand required to balance the additional C influx was 4.1 g $N \cdot m^{-2} \cdot yr^{-1}$ in the step CO_2 increase and only 0.6 and 1.7 g $N \cdot m^{-2} \cdot yr^{-1}$ in 1987 and 2085, respectively, in the gradual C_a increase. The contrasting differences in C_{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_{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_{seq} in natural ecosystems responding to a gradual C_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.