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Terrestrial carbon-cycle feedback to climate warming: experimental evidence

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Feedback between global carbon (C) cycles and climate change is one of the major uncertainties in projecting future global warming. Coupled carbon-climate models all demonstrated a positive feedback between terrestrial C cycle and climate warming. The positive feedback results from decreased net primary production (NPP) in most models and increased respiratory C release by all the models under climate warming. Those modeling results present interesting hypotheses of future states of ecosystems and climate and are yet to be tested against experimental results.

This presentation will provide two lines of experimental evidence on terrestrial carbon-cycle feedback to climate warming. One is based on a comprehensive review of experimental results across studies (Luo 2007) and the other is based on detailed analysis of major carbon processes as affected by an experimental warming in a North American tallgrass prairie (Luo et al. 2008).

Experimental results across many studies showed that the responses of C uptake and release processes to temperature changes are extremely variable. Experimental warming caused increases, decreases, or no change in photosynthesis, plant growth, primary production, soil respiration, and NEP. The highly variable results from field experiments may not have generated the necessary insights on ecosystem responses to climate warming to the detriment of model improvement. Nevertheless, experiments have suggested that the kinetic sensitivities of photosynthesis and respiration, although fundamental to models, are usually overridden by other processes. Those major processes that regulate responses of ecosystem C processes to climate warming include changes in phenology and the length of growing seasons, species composition, nutrient dynamics, and ecohydrological processes (Fig. 1).

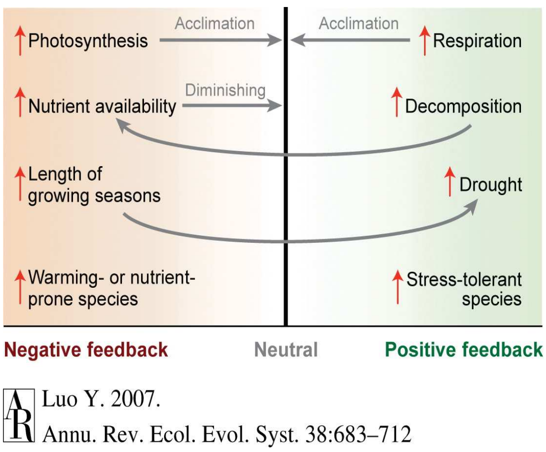

Figure 1 Schematic summary of major regulatory mechanisms that lead to either positive or negative feedbacks of terrestrial C cycles to climate warming. Climate warming instantaneously stimulates photosynthetic C uptake and respiratory release. Acclimation can neutralize their kinetic responses. Warming-stimulated decomposition of soil organic matter is associated with respiratory C release and increases nutrient availability that stimulates plant growth and ecosystem C uptake. The warming-induced increases in nutrient availability may be diminishing over time. Warming extends growing seasons and lengthens C uptake periods. Extended growing seasons and warming in combination can exacerbate drought stress and limit net ecosystem C uptake in some regions. Warming-induced changes in species composition can result in either positive or negative feedbacks of C cycles to climate warming, depending on which species adapt to the new environment.

We have conducted a warming and clipping experiment in a North America tallgrass prairie to examine ecosystem C balance and its major components at ambient and elevated temperature. We have used infrared heaters to elevate soil temperature by approximately 2^{o}C continuously since November 1999. Clipping once a year was to mimic hay or biofuel feedstock harvest. We have synthesized data from 2000 to 2005. On average over 6 years, estimated NPP under warming increased by 14% without clipping ($P < 0.05$) and 26% with clipping ($P < 0.05$) in comparison with that under control. Warming did not result in instantaneous increases in soil respiration in 1999 and 2000 (Luo et al. 2001) but significantly increased it by approximately 8% without clipping ($P<0.05$) from 2001 to 2005. Soil respiration under warming increased by 15% with clipping ($P < 0.05$) from 2000 to 2005. Warming-stimulated plant biomass production, due to enhanced C_4 dominance, extended growing seasons, and increased nitrogen uptake and use efficiency, offset increased soil respiration, leading to no change in soil C storage at the experimental site (Fig. 2). However, biofuel feedstock harvest by biomass removal resulted in significant soil C loss in the clipping and control plots but was carbon negative in the clipping and warming plots largely because of positive interactions of warming and clipping in stimulating root growth.

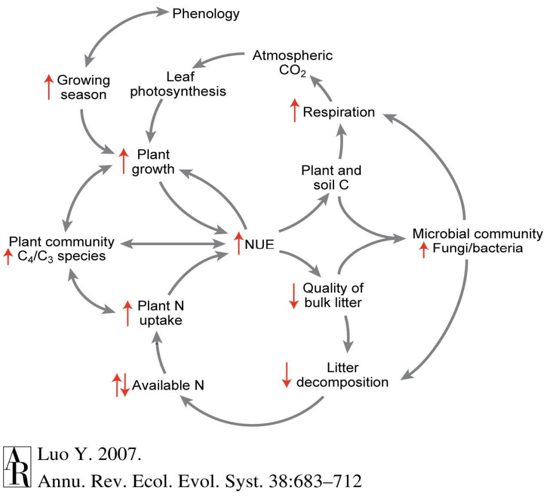

Figure 2 Illustration of regulatory mechanisms of ecosystem temperature sensitivity using results from an Oklahoma warming experiment. Major carbon (C) and nitrogen (N) processes are affected by warming in complex ways. Warming extended growing seasons, shifted species composition toward C_4 plants, and increased plant biomass growth. The increased growth was associated with increased plant N uptake and N use efficiency (NUE). Warming also increased soil respiration, which was roughly balanced by increased C uptake via plant growth, leading to little change in soil C storage, although warming accelerated almost all the rate processes. Owing to the increased dominance of C_4 plants in the grassland, the quality of bulk litter decreased under warming, which likely leads to diminished or even decreased soil N availability over time, although warming may initially increase N availability.

In summary, although coupled carbon-climate models reported in the literature all demonstrate a positive feedback between terrestrial carbon cycles and climate warming, field experiments suggest much richer mechanisms driving ecosystem responses to climate warming, including extended growing seasons, enhanced nutrient availability, shifted species composition, and altered ecosystem-water dynamics. The diverse mechanisms likely define more possibilities of carbon-climate feedbacks than projected by the kinetics-based models. It is essential to benchmark future development and improvement of coupled carbon-climate models against experimental and observational data.

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