Partitioning CO_2 fluxes with isotopologue measurements and modeling to understand mechanisms of forest carbon sequestration

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The interaction between forest carbon dynamics and climate is a large source of uncertainty in earth system model predictions of the future. We are investigating the mechanisms controlling carbon sequestration at the Harvard Forest by integrating stable carbon isotope analyses with a suite of measurement approaches including eddy covariance, soil chambers, plot trenching, and minirhizotrons. The data are being integrated in—and used to refine—the Ecosystem Demography 2 (ED2) model.

At the whole-ecosystem level, we used a novel 3-year timeseries (2011-2013) of ^{13}C-based isotopic partitioning of NEE into GPP and ecosystem respiration to distinguish the influences of soil water, temperature, and phenology on GPP and daytime ecosystem respiration. We consistently see large suppression (relative to nighttime) of daytime ecosystem respiration during the first half of the growing season, which we think represents the first direct detection, at the ecosystem scale, of the so-called "Kok effect" (light suppression of mitochondrial respiration in leaves, heretofore only observed by ecophysiologists at the leaf-scale). At the same time, we found that GPP responded consistently to light throughout the growing season, whereas conventional estimates show an anomalous peak in photosynthetic light-use efficiency early in the growing season.

At the aboveground-belowground interface, we used automated chamber measurements in trenched (i.e. no live roots) and untrenched plots to partition belowground respiration into its autotrophic (root) and heterotrophic (soil) components. The expected lower total belowground respiration in the trenched plot (due to absence of autotrophic respiration), observed in 2013, was unexpectedly reversed during a period of low precipitation in 2014. Evidently, the lack of transpiration-driven water removal in the trenched plot (detectable as wetter soil) elevated heterotrophic respiration sufficiently to compensate for the lack of autotrophic respiration. These results help us determine the separate controls on autotrophic and heterotrophic respiration.

Belowground C allocation by red oak (*Quercus rubra*), white ash (*Fraxinus americana*), and eastern hemlock (*Tsuga canadensis*) was positively correlated with temperature, though root growth occurred in multiple flushes while respiration was unimodal. Deciduous hardwood stands allocated C belowground earlier in the season and more to root growth, relative to coniferous eastern hemlock, which allocated C later and more to exudation than root growth. These results highlight the importance of accurate modeling of C delivery to the microbial community via roots.

These observations enabled us to develop an isotope-enabled version of the Ecosystem Demography 2 model which is now being tested against the isotopic and C allocation measurements (e.g. ^{13}C and ^{18}O fluxes from eddy covariance and soil surface chambers). We plan to apply the eventual isotope-optimized model to data from Howland Forest (a different Northeastern forest site) to test the generality of the model's improved representation of mechanisms of C allocation and storage.