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Species-specific seasonal stable carbon isotope variation in temperate deciduous leaves and implications for carbon allocation phenology and water use efficiency estimates

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Trees accumulate and store non-structural carbohydrates (NSC) for plant growth and survival. Although the NSC allocation plays an important role in terrestrial ecosystem function, the process remains poorly understood. In specific, it is unclear how NSC are allocated to growth versus maintenance, and how that changes under conditions of stress.

There is potential in using natural abundance ^{13}C to better understand seasonal carbon allocation processes. For example, Helle and Schleser (2004) observed early season enrichment of δ^{13}C values in leaves and tree rings and proposed that remobilized NSC from previous years has more enriched δ^{13}C values than recently assimilated carbon. This remobilized NSC increase and peak when resource demand is highest before leaf-out during the early season, and this process is more distinct for ring-porous trees as they build new xylem vessels before leaf-out. Thus, the mixing between old and new substrates potentially uncouples trends in δ^{13}C in plant tissues from those predicted by leaf-scale photosynthetic fractionation models. This could have implications for estimates of intrinsic water use efficiency (iWUE) controlled by leaf-level stomatal regulation, often estimated using tree ring δ^{13}C.

Therefore, we intended to understand the species-specific seasonal variations of stable carbon isotopes (^{13}C) in leaves and its implication on NSC remobilization and iWUE. We conducted our study at Morgan-Monroe State Forest (MMSF) and focused on four main species, which are sugar maple, tulip poplar, sassafras, and oak species. We analyzed seasonal δ^{13}C in leaves and annual δ^{13}C in tree ring collected during the 2011-2013, and 2017 growing seasons. Lastly, we used the same set of equations as the Community Land Model version 4.5 (CLM 4.5) and Farquhar model for photosynthetic fractionation model. The models were forced by meteorological observations at the MMSF tower site and validated by leaf-level gas exchange measurements in the field.

Our results show that, the seasonal pattern of leaf δ^{13}C is similar to the pattern in Helle and Schleser, although the pattern is dependent on years and species. In general, δ^{13}C of leaf is higher in the beginning of the growing season and decrease as the growing season proceeds. The decrease pattern is especially distinct for sassafras, a ring-porous species. Also, the δ^{13}C of leaf shows a slight increase at the end of the growing season for tulip poplar and sassafras in 2012 when the severe drought was observed. The simulated leaf δ^{13}C using the Farquhar model of photosynthetic fractionation corresponds well with the observed δ^{13}C from the middle to the end of the growing season (DOY 200-270). In contrast, the simulated leaf δ^{13}C does not match with the observation in the beginning of the season, probably due to the remobilized NSC in early season. Based on these observations, we calculated iWUE and compared with iWUE calculated using tree ring δ^{13}C. The results show that iWUE estimates may differ by 25% when using leaf or tree ring δ^{13}C.