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Differential regulation of non-structural carbohydrate reserves in trees under carbon-limitation and -starvation

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Over the last two decades, the ecological significance of non-structural carbohydrates (NSC; i.e. starch and low molecular weight sugars) has become the focus of numerous studies on tree response to environmental stresses like drought, heat or cold conditions. The concentrations of NSC are thereby commonly used as indicators for the carbon (C) supply of trees. However, up to date there have been surprisingly few in-depth experimental efforts to explicitly investigate the dynamics of NSC tissue concentrations of trees under sustained C-limitation over several seasons, as well as the minimum NSC tissue concentrations in trees at lethal C-starvation. Here, we present two experiments that aimed to tackle the above topics.

Within a large-scale field experiment, three-year-old saplings from 10 temperate tree species (including deciduous broadleaved trees and evergreen conifers) were exposed to deep shade conditions (6 % of PPFD at unshaded conditions) for three consecutive years in order to induce continuous non-lethal C-limitation. All trees exposed to deep shade showed strongly reduced growth throughout the three-year period. In contrast, the tissue NSC concentrations of shaded trees declined strongly by about 50 % across all species only during the first season, but they recovered over the following two seasons, resulting in no significant differences of NSC concentrations between shaded and un-shaded trees by the end of the third season in most tissues and species. However, additional stress like natural or experimental defoliation led to a strong depletion of NSC and death in shaded, but not in unshaded saplings.

Within an indoor experiment with saplings of two deciduous broadleaved and two evergreen conifer species, we investigated the minimum NSC tissue concentrations at lethal C-starvation induced by continuous darkening (0% light). All species showed a fast and very strong decline of NSC within the first three weeks of darkening, but survived at least for 9 weeks under darkness with very low NSC concentrations. Darkened saplings, that were reintroduced to light before death, exhibited a fast refilling of NSC reserves prior to the resumption of growth. At mortality, all darkened trees showed NSC concentrations of less than 1 % d.m. in most tissues.

In conclusion, the two experiments revealed important information for the interpretation of the C-supply status of trees via NSC analyses. Non-lethal C-limitation by shading induced a massive and sustained growth restriction, but only a temporary reduction of tissue NSC concentrations. Thus, the absence of a reduction of NSC concentrations does not automatically also mean the absence of C-limitation for growth in trees. On the other hand, C-starvation is always indicated by a strong depletion of NSC tissue concentrations and should only be diagnosed as the reason for tree mortality, if starch and sugar concentrations are close to zero.