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Forest's carbon cycle under drought – insights from 13C-pulse labelling experiments

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Drought limits the metabolic activity of plants and soil organisms, but drought effects on forest's C cycle will ultimately depend on the resilience of forests to drought – the ability of forests to recover from and to adapt to drought. Here, we synthesize various studies on the effects of drought on the forest C cycle at different time scales: (1) In 13C-pulse labelling experiments at the tree level in young and mature forests, we have tracked the fate of recent assimilates in ecosystems during drought and the recovery phase following rewetting. (2) In a naturally dry pine forest, we have conducted a 15 year long irrigation experiment to study how long-term water limitation affects C-pools and fluxes.

At the annual time scale, photosynthesis and soil respiration were strongly suppressed by drought. Following rewetting, however, both C fluxes recovered rapidly and even exceeded C fluxes of the permanently moist control, almost compensating for the reduced C fluxes during drought. The 13C pulse labelling experiment in young model forests tracking recent assimilates from leafs to the soil revealed that during drought C allocation to the belowground was strongly reduced. In contrast, after rewetting in the recovery phase, substantially greater amounts of 13C were allocated belowground indicating that trees primarily invested their assimilates into their rhizosphere, probably to regain root functions after drought. In the mature pine forest, tracing of a 13C pulse for one year indicated a similarly sensitive response of ecosystem C cycling to soil moisture. Allocation of recently assimilated C to the belowground showed a tipping point at soil moisture contents around 15%, which is also the critical soil moisture for microbial activity in the soils. This finding strongly suggests that the moisture dependent C use by rhizosphere communities drives tree's utilization of recent assimilates.

In the 15 year long experiment in the dry pine forest, irrigation strongly increased forest productivity and more than doubled C accumulation in forest biomass. Soil carbon fluxes were also strongly increased: C inputs by litterfall but also C outputs by soil respiration increased by a factor of two to three. The accelerated C cycling in the soil was also mirrored by compositional shifts in the soil microbiome. Irrigation promoted bacteria and fungi with more copiotrophic life style strategies. Determination of soil organic matter pools revealed a C loss in the organic layer under irrigation but a C gain in the mineral soil, resulting in small net effects.

Overall our results show that C fluxes in the forest ecosystem respond very sensitive to drought with distinct tipping points. Rewetting following drought leads to a recovery of forests. Nevertheless, in the long-term, C accumulation in biomass is suppressed by repeated summer drought, while net effects on C balance of soils are much smaller.