BELOWGROUND EFFECTS OVER ABOVEGROUND IMPACTS – FOREST TREE-RHIZOSPHERE RESPONSES TO CHANGING SITE CONDITIONS

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Setting the stage: Soils and their respiration govern carbon (C) pools and fluxes in forest ecosystems, as mycorrhizae substantially drain C gains belowground. Still, response processes belowground to environmental impact as such by climate change are initiated aboveground. This is the case not only for warming and associated drought, but also atmospheric CO_2 accumulation, which upon impacting on foliage becomes effective through altering whole-plant and rhizospheric C relations. Anthropogenic ozone (O_3) with its currently enhanced regimes similarly acts in the lower troposphere, being recognized today as an intrinsic component of climate change, but hardly understood in ecologically meaningful ways for forest sites. Mediated by precursor formation from natural sources, fuel combustion and forest burning, O_3 is climate-effective, spread at hemispheric scales and, if high influx passes stomata, incites toxicity in plants. Although not destroying trees rapidly (as posed by forest decline discussions of the 1980s), enhanced O_3 uptake chronically weakens tree and ecosystem-level C fixation and storage. O_3 only indirectly acts belowground, depending on plant-internal response pathways originating from aboveground impact.

What do we actually know about belowground O_3 effects in forest trees and ecosystems in view of climate change? Knowledge is scarce despite a plethora of indoor and outdoor chamber O_3 fumigation studies since the 1940s, as findings (mostly aboveground and short-term) from well-watered and fertilized juvenile, typically potted and single trees, and inevitably affected by micro-climatic bias, are not transferable to prevalent forest site conditions. Only two prolonged experiments were conducted in tree plantations (AspenFACE, USA) and in a maturing beech/spruce forest (*Fagus sylvatica/Picea abies*, Kranzberg Forest/Germany), both making use of novel free-air O_3 canopy fumigation technology. We will highlight the Kranzberg Forest experiment, referring to O_3/drought interactions also that had occurred during the dry summer of 2003.

O_3 belowground effects: : A conspicuous impact of canopy-level O_3 was an increase in soil respiration around beech and spruce trees under the experimentally enhanced O_3 regime. The effect was associated with stimulated fine-root production (in consistency with findings from AspenFACE) and increased density but altered fungal community structure of ectomycorrhizae (ECM), in particular, on beech. Reduced specific N uptake was attributed to ECM-mediated O_3 influence and corroborated through ^{15}N soil labelling. Notwithstanding, the number of vital ECM on beech was increased under enhanced aboveground O_3 exposure, and so was the number of ECM types and fungal species richness. In spruce, shifts had occurred from “medium” and “long-distance” towards “short-distance” and “contact” ectomycorrhizal exploration morphotypes after eight years of elevated O_3 treatment. Aboveground O_3 impact led to loss in mycelial soil volume occupation, which represents decline in belowground resource exploration capacity, and hence, in tree competitiveness, if space-related resource turnover is similarly crucial as along aboveground organs.

Largely vague remained potential influences by O_3-stressed trees on soil microbial communites including ECM. Extracellular enzyme activities in mycorrhizosphere soil integrate activities from roots, fungi and associated as well as free-living microorganisms. Indications may be biased, however, by plant age and tree species, as O_3-driven enzyme stimulations in the mycorrhizosphere of adult forest trees was not confirmed in juvenile trees. Given that soil bacteria may promote nutrient mobilization and provide beneficial capacities in general (“helper bacteria”), holobiontic understanding of O_3-incited interference with

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belowground tree, fungal and bacterial interactions poses a challenge for research. The challenge implies focus on such mutualistic interaction networks that may turn to parasitic relationships under O_3 stress.

O_3/drought interaction: During the extraordinarily dry summer of 2003, the stimulating O_3 effect on soil respiration rate vanished under spruce, in consistency with decreased fine-root production by a factor of six, reflecting some kind of dormancy, whereas fine root production stayed unchanged in beech. $\delta^{13}C$ of newly formed fine roots was consistent with stomatal limitation by O_3 in beech. Overall, drought had the capacity of overriding the stimulating O_3 effects on fine-root dynamics and soil respiration in both tree species. Autotrophic soil respiration (SRa) was drought-sensitive, as total SR (SRt) ceased in spruce to follow the seasonal course of soil temperature. SRa rather than heterotrophic SR (SRh) was sensitive to changes in soil temperature and plant-available soil water.

Explanatory model of O_3 belowground effects: O_3-induced stimulations in soil respiration, fine-root growth and mycorrhization were accompanied by a dramatic decline in stem productivity by annually 44 % in beech (spruce with incipient tendency). The effect related to leaf-level phytohormonal disturbance inflicted by O_3, while effects on photosynthesis stayed minor. Leaf-level destruction of cytokinins (CK) incited drain via xylem from roots, where CKs, if accumulating under non-limiting N soil availability (as was the case at Kranzberg Forest), typically impose growth inhibition. The impeded CK accumulation evoked fine root production and created a belowground C sink that outcompeted that posed by the stem. Hence, aboveground O_3 impact pretended belowground N limitation, misguiding fine root response.

Ecological significance: Modelling approaches have shown substantial loss in C fixation of forest ecosystems worldwide since 1900, although parameterization and validation are inadequate and limited, respectively. Kranzberg data are supportive regarding the O_3 response of adult beech. Radiative forcing of the atmosphere appears to lesser extent to be caused by photosynthetic limitation under O_3 stress than by belowground shift in whole-tree C allocation and increase in soil respiration. Belowground O_3 effects in forest ecosystems demand for attention during the post-Kyoto debate.

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