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Is phosphorus export from beech forest stands transport-limited of source-limited?

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Phosphorus (P) is one of the key limiting nutrients in forest ecosystem resulting in tight P-recycling strategies in natural forests. Hydrological fluxes in the subsurface during rainfall events can however lead to a relocation and export of P from the forest stands. We present results from six large-scale sprinkling experiments on three highly instrumented experimental hillslope in the Bavarian Forest, Black Forest, and the Swabian Alb in Germany that differ in their soil P stocks. We simulated an extreme 150 mm rainstorm with intensities between 12 and 15 mm/h. The aim of these experiments was to quantify the lateral and vertical fluxes of subsurface storm flow and phosphorus under a range of input fluxes and to identify differences in the degree of nutrient retention depending on the prevailing soil properties of the three forest sites.

We sprinkled the 200 m^2, steep hillslopes with 60,000 l of isotopically (deuterium) labeled water for 11 h. Lateral subsurface flow was measured at three depths (10cm, 240cm, 300cm) at a 10 m wide trench at the bottom of the hillslope and with large zero-tension lysimeters (area of 0.6 m^2) installed at four depths into the undisturbed soil profile. This setup allowed us to quantify the lateral and vertical fluxes of subsurface flow and phosphorus concentration during the experiment in 30 min temporal resolution. We found vertical subsurface flow to dominate over lateral flow by more than one order of magnitude. We could identify a P-flashing (i.e., high P concentrations) in the first 2 hours after start of subsurface flow across all soil depths. During the rest of the sprinkling the P-concentrations were lower but did not change significantly despite further increasing subsurface flow. We explored P concentrations as a function of subsurface flow and found for all observations, except those from the litter layer, to be chemostatic. We also found no change in P-concentrations with increasing new water fraction, calculated based on a two-component hydrograph separation approach using the deuterium label as tracer. However, when calculating the internal and total P-fluxes we realized that the majority of P, that was leached from the litter layer (i.e., 0.22 kg/ha at the P-poor site and 1.17 kg/ha at the P-rich site), was retained in the mineral soil. The total vertical and lateral losses from the experimental hillslope were small (i.e., 0.07 kg/ha at the P-poor site and 0.06 kg/ha at the P-rich site during each experiment).

Therefore, our results suggest that P-poor and P-rich forest ecosystems are efficiently retaining phosphors in their mineral soils. However, as phosphorus export is transport limited but not source limited an increase in the frequency of heavy rainstorms, as predicted under future climate conditions, might still lead to a relocation of phosphorus to soil depths below the depth of tree roots or even cause increased P-export from the forest stands.