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Soil heterogeneity strongly affects fate and transport of deicing chemicals

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Large amounts of the deicing chemicals propylene glycol (PG) and formate are spread for removal of snow and ice on aircrafts and airfields every winter worldwide. Some of these organic contaminants are carried into surrounding areas, where they increase the biological oxygen demand and aquatic toxicity in the receiving waters. To evaluate the potential of the unsaturated zone to buffer high loads of deicing chemicals during snowmelt we conducted infiltration field experiments, using PG, formate, and bromide as conservative tracer. Eight undisturbed soil cores (0.3 m x 1 m, 0.071 m3) were retrieved at Gardermoen airport, Norway, and installed as non-weighable small scale lysimeters at a nearby field site. The lysimeters were equipped with electrodes for electrical resistivity tomography (ERT), tensiometers, FDR probes and suction cups for the evaluation of flow and transport in the profile. Before snowmelt in March 2010 a mix of snow containing 350 g/m2 PG, 71 g/m2 formate, and 17 g/m2 of bromide were added to the lysimeters. Following this, the lysimeters were exposed to natural weather conditions for one year. To determine the fate and transport of PG we monitored PG and its metabolites, bromide, manganese, and iron in the seepage water. Water flow and solute transport of both PG and bromide varied strongly between all lysimeters. The mean residence time estimated from the center of mass of the bromide breakthrough was 15 $\pm$ 5 days. In the lysimeters 50 % to 99 % of annual seepage water occurred predominantly during the snowmelt period from April to May. Transport heterogeneities resulted in a wide range of recovered bromide and PG loads. No PG was detected beyond July. Furthermore, almost none of the initially added formate reached the lysimeter outlet. Effects of soil heterogeneity were not only visible between different cores but also within single cores. For example, the infiltration of melt water, shown by ERT, exhibited distinct structures of preferential infiltration. Potentially, degradation is influenced by such flow behavior. On the one hand, the rapid degradation of the deicing chemicals and the detection of pyruvate and lactate in the lysimeter effluent indicate that PG and formate degradation was largely aerobic. On the other hand, the appearance of propionate, as an end product of anaerobic metabolism, and manganese, as a product of reductive dissolution of Mn(IV)(hydr)oxides, indicate partially anaerobic localities in the soil during high soil water saturation in April and May. The preliminary results show that retardation and microbial degradation of deicing compounds was very efficient. Still, flow and transport heterogeneities allow a considerable mass of PG to leave the upper, microbially most active, region of the soil. The reason for this is that effective degradation requires optimal spatial and temporal conditions. Our experiments indicate that this happens rarely, such that the resulting heterogeneity of microbial activity may lead to localized spots of considerable PG transfer into deeper layers. Consequently, a significant impact on deeper soil layers and groundwater may potentially occur. These results underline the importance to characterize the heterogeneity of the unsaturated zone, preferably assisted by non-invasive methods.