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Field and Laboratory Analysis of Snowmelt Partitioning and Quantification of Preferential Flow in Frozen Prairie Soils

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Summary

Seasonally frozen soils in cold regions control the distribution of snowmelt within the hydrological cycle and have a major influence on surface water flows, soil moisture, and groundwater recharge. The partitioning of snowmelt between infiltration and runoff on cropland and grassland fields is not well understood due to the influence of antecedent soil moisture conditions, macroporosity, midwinter melt events, and flow dynamics during spring melt. This project investigated the infiltration-runoff dynamics in frozen prairie soils during melt events and how hydrologic behavior might differ between croplands and grasslands. Fluorobenzoic acid tracers (FBAs) were applied on cropland and grassland field sites prior to spring melt, and a parallel set of tracer infiltration experiments were completed on frozen soil cores in the laboratory. At the onset of spring melt, ponded water samples showed high tracer concentrations although only 50-60% of tracer mass was recovered which indicates snowmelt infiltration was prevalent while the soil was still partially frozen. Infiltration and preferential flow were influenced by soil water content before freezing, and the number of midwinter melt events. The soil core experiments demonstrated that midwinter melts changed soil moisture conditions, potentially blocking macropores, which influenced frozen soil infiltration. Both the field and laboratory experiments suggest that wetter soil conditions reduce preferential flow in frozen soils while drier conditions encourage it.

Introduction

Depression-focused recharge plays a key role in replenishing groundwater in the prairies. This occurs when snow melts and collects in small, local depressions formed by past glaciers and then seeps down to the water table. Preferential flow and runoff in frozen soils have been explored historically and in more recent studies (Pittman et al., 2019; Mohammed et al., 2018; Grant et al.,2019), but these processes and their influence on water movement remain difficult to predict. A large portion of the prairies consist of croplands, which have not been studied as intently as natural prairie grasslands (Morgan, 2019). Cropland and grassland constitute the majority of the landmass in southern Alberta, so it is important to understand their hydrologic function and the influence that different land uses have on groundwater recharge. In order to predict and quantify any potential changes it is important to study all the different components of the prairie hydrological cycle (Pittman et al., 2019).

Methods

In the field, conservative FBA tracers were applied on parallel strips at different topographic positions upgradient of a local depression. Tracers were applied to both cropland and grassland sites prior to melt events while there was still snow on the ground. Snow surveys were conducted to monitor the snowpack and any melt events. Snowmelt runoff samples from the depressions and soil samples from the site were analyzed for tracer concentrations.

For the laboratory experiments, large soil cores were instrumented with temperature and moisture probes and placed in a freezer. A series of melt events were simulated on the frozen cores by adding a "meltwater" mixture of FBA tracer and dye. Flow-through was collected from column outflow and submitted for FBA tracer analysis. The cores were dissected in order to analyze preferential flow paths after the infiltration tests were completed.

Results

Water samples from the local depression showed high tracer concentrations during early spring when snow was melting rapidly. Temperature probes showed the ground had only partially thawed, which suggests that the large amount of tracer could be due to more melt travelling overland instead of infiltrating. Even though the soil samples showed no signs of tracer, the tracer mass balance indicated that roughly 40-50% of the tracer must have infiltrated into the soil profile upslope of the depression. This suggests that infiltration was fairly prevalent compared to runoff during spring melt while the soil was still partially frozen. The bulk mass of tracers applied on the topographic high did not arrive in the depression until the soil had thawed completely. This could be due to the initial meltwater infiltrating and freezing in the pore spaces and being released after the soil had thawed. The cropland depression had greater runoff and less infiltration compared to the grassland. This is because the cropland has fewer macropores than grasslands in terms of depth and density and had a higher soil moisture content in the fall prior to freezing.

In the soil core experiments, water from the midwinter melts froze in the cores, reducing the amount of water exfiltrating out the bottom. This was similar to the field experiments when infiltrating water would block macropores and created a barrier that prevented further infiltration and increased runoff. The dye patterns in the dissected frozen cores showed the transport pathways through the core and how fluid transport was limited by the depth, density and connectivity of the macropores.

Conclusions

Fall soil moisture conditions and midwinter melt events seem to influence infiltration-runoff dynamics on croplands and grasslands, thereby affecting snowmelt distribution. As climate change continues to change our environment, it is necessary to study these effects on frozen soils and use the results to improve our understanding of the global hydrological system.

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