Geophysical Research Abstracts
Vol. 20, EGU2018-12004-2, 2018
EGU General Assembly 2018

Subsurface hydrologic connectivity and functioning in a high–elevation Andean hillslope: Soil moisture dynamics, transit times, and processes conceptualization

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Water moving through hillslope soils influence the hydrological, ecological, and biogeochemical functioning at larger scales. However, our understanding on how soils mediate the transport and mixing of water through hillslopes remains limited. To improve this situation, we investigated how the soil's hydrophysical conditions influence the subsurface hydrologic connectivity and functioning in a tropical alpine grassland hillslope (3,913–4,006 m .a.s.l) located in south Ecuador.

Our experimental hillslope (208 m in length) was instrumented at three positions with soil moisture content (SMC) probes and wick samplers installed at four different soil depths varying between 5–75 cm. SMC and rainfall amounts were recorded every 5–min and rainfall and soil water samples were collected weekly for water stable isotopes (WSI) analysis during the period April 2014–January 2017. We analyzed the temporal variability of SMC, the hillslope water storage during a drought, and estimated the mean transit times (MTT) of soil water using the WSI signals.

Through the characterization of the physical and chemical properties of the soils, which included the soils' types and depths, texture, carbon content, root content, saturated hydraulic conductivity (ksat), and moisture release curves, we identified two distinctive soil layers: a little developed (< 50 cm) highly organic layer with a clay loam texture, underlain by a little developed (< 65 cm) mineral layer with low organic matter content, a sandy loam texture, and higher ksat than at the organic layers.

In the organic horizon, results showed that the shallow rooted zone (5 cm depth) rapidly responded to precipitation inputs, presented high water storage losses during the monitored drought, and had the lowest MTTs (2 weeks); whereas the deeper and unrooted layer (20 cm depth) showed virtually no response to precipitation inputs, maintained a high water storage near saturation conditions even during the observed drought, and presented longer MTTs (4 weeks). These differences in SMC dynamics and storage are likely related to the abrupt change of ksat –and related capillary dynamics– between the rooted (1.73 cm3/hr) and unrooted (0.29 cm3/hr) organic layers, which favor a faster mobilization of water in the former.

Interestingly, in the mineral horizon (75 cm depth), our results also showed a rapid SMC response to precipitation dynamics and a rapid loss of high water storage during the monitored drought, but the longest MTTs (6–9 months). Observations that likely result from the presence of high amounts of coarse material and the sandy loam soil texture, which favors an enhanced subsurface connectivity of longer flow paths in the soils' mineral horizon.

Overall, our findings evidence rapid lateral connectivity of water draining within the rooted organic layer towards the bottom of the hillslope, most likely influencing the flashy response of discharge at the catchment scale. The high water storage capacity and diminished loss of moisture storage of the deeper and unrooted organic horizon likely helps sustain and regulate discharge, particularly during drought periods.