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# The water vapor adsorption by dry soils potentially links the water and carbon cycles: insight from a semiarid crusted ecosystem

**Clément Lopez-Canfin**[1], Roberto Lázaro[2], and Enrique P. Sánchez-Cañete[1,3]
[1]University of Granada, Faculty of Science, Applied Physics, Granada, Spain (lopezcle@gmail.com)
[2]Experimental Station of Arid Zones (EEZA-CSIC), Desertification and Geo-Ecology, Almería, Spain
[3]Inter-University Institute for Earth System Research (IISTA-CEAMA), Granada, Spain

The process of water vapor adsorption (WVA) by soil (i.e. water vapor movement from atmosphere to soil, forming liquid water on soil particles) is likely a substantial contributor to the water cycle in drylands. However, several gaps remain in our knowledge of WVA: (1) continuous *in situ* estimates of WVA are still very scarce; (2) the underlying mechanisms involved in its temporal patterns are still not well constrained, and (3) the understanding of its coupling with the carbon cycle and ecosystem processes remains at an incipient stage.

Here, we aimed to (1) identify periods of WVA and improve the understanding of the underlying mechanisms involved in its temporal patterns by using the gradient method (GM); (2) characterize a potential coupling between water vapor and $CO_2$ fluxes, especially expected in drylands due to the water-limitation of ecosystem processes. In particular, we assumed that the nocturnal soil $CO_2$ uptake increasingly reported in those environments (including at our study site) could come from WVA enhancing reactions with $CaCO_3$; (3) explore the effect of soil properties and biocrusts ecological succession on fluxes.

To this end, in the Tabernas Desert (Almería, Spain), we measured continuously during ca. 2 years the relative humidity and $CO_2$ molar fraction in soil and atmosphere, in association with below- and aboveground variables, in microsites representative of the biocrusts ecological succession. We estimated water vapor and $CO_2$ fluxes with the GM, and cumulative fluxes over the study. Then, we used linear and non-linear statistical modelling to explain relationships between variables.

Our main findings are (1) WVA during hot and dry periods, and a new insight into the micrometeorological conditions triggering those fluxes; (2) a diel coupling between water vapor and $CO_2$ fluxes (including the uptake of both gases by soil at night) and between cumulative fluxes, well predicted by our models; and (3) cumulative $CO_2$ influxes increasing with specific surface area in early succession stages, thus mitigating $CO_2$ emissions. We suggest that the GM is a suitable approach to monitor WVA *in-situ* since it offers several advantages such as providing direct low-cost measurements of water vapor fluxes with good spatio-temporal resolution and low soil disturbance. Over a year, the WVA represented between ca. 0.2% and 2.8% of the precipitation amount, depending on the microsite and the diffusion model that was used to estimate the fluxes.

Therefore, WVA constituted a non-negligible input of liquid water in this dryland. In particular, during summer drought, as WVA was the main water source, it probably maintained ecosystem processes such as microbial activity and mineral reactions. We propose that the nocturnal $CO_2$ uptake reported in this dryland may arise from (i) WVA enhancing geochemical reactions involving $CaCO_3$ and/or biological dark $CO_2$ fixation; (ii) the co-adsorption of $CO_2$. Further research is now needed to (1) disentangle those processes; (2) monitor soil water vapor and $CO_2$ uptake by soils as those sinks could grow with climate change; (3) improve the accuracy of the water vapor fluxes estimated with the GM, for example by calibrating the GM with lysimeters.