Connectivity and pore accessibility in models of soil carbon cycling

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LETTER TO THE EDITOR

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In an article published recently, Waring et al. (2020) introduced a conceptual framework, named PROMISE, to explore controls on belowground carbon cycling. This "fundamentally novel approach to measuring and modeling critical carbon cycle processes" represents soil pore space as an array of possible particle locations belonging to one of three pore size classes. Several aspects of this conceptual framework raise questions about its adequacy to describe the fate of carbon in heterogeneous soils.

More than a decade ago already, Kuka et al. (2007) advocated the significance of the size of pores when modeling carbon turnover in soils and proposed a model, called CIPS ("Carbon Turnover in Pore Space"), which is not mentioned by Waring et al. (2020) even though in several respects, CIPS is very similar to PROMISE, and shares the same aims and approach. In CIPS, pores are also divided into three classes according to their size. Like PROMISE, CIPS does not assume any spatial arrangement, distance, or differences in connectivity among the three classes of pores.

The neglect of pore connectivity may have been a defensible working hypothesis in 2007. However, experimental research as well as a sizeable amount of modeling work (reviewed in Baveye et al., 2018) has since demonstrated the importance of the connectivity, size, and degree of water saturation of pores on a wide range of soil processes, including the decomposition of soil OM. PROMISE makes a small provision for the importance of pore connectivity by assuming that the probability of a particle leaving a pore of any size depends on whether the soil is dry or moist. However, this is a very crude way to take pore connectivity into account.

Another set of questionable assumptions of PROMISE concerns the probabilities of particles entering and leaving mesopores, associated with clay domains, or micropores, between individual clay platelets. Waring et al. (2020) assume a priori, without any experimental data at this stage to support it, that the probability of a monomer leaving an intraparticle pore is 200 times less than its probability of penetrating it. From that perspective, one expects that organic matter that manages to diffuse in those tiny pores remains there for extended periods of time. However, this sequestration, if it occurs at all, cannot be due to diffusion alone, without the involvement of some other process that may need to be modeled explicitly. Indeed, Dumestre et al. (2000, 2006), using Electron Paramagnetic Resonance spectroscopy to monitor the behavior of spin probes, have shown experimentally that probe molecules that had entered intraparticle pores in a suspension of bentonite clay particles could relatively easily diffuse out if a chemical reaction or consumption by bacteria, outside of the pores, decreased the concentration of spin molecules in the bulk solution. In that context, a possible alternative to pore exiguity as an explanation for the persistence of organic matter is that, because of low connectivity and high tortuosity of the pore space in soils, neither microorganisms nor even their exoenzymes can get close enough to the organic matter to prompt it to diffuse out in the open.

Another issue concerning PROMISE relates to the usefulness of a computer model that contains many parameters that can be evaluated only by fitting. In PROMISE, in addition to the uncertain probabilities of particles entering and leaving pores, the volumes associated with two of the classes of pores are also virtually impossible to determine at the moment other than via parameter fitting. Indeed, only the larger "macropores" would be detectable by X-ray computed tomography, unless one worked with exceedingly small soil samples, which creates challenges of its own, in terms of the representativeness of measurements and their upscaling to larger volumes. Mercury intrusion porosimetry could in principle be used to determine the pore size distribution down to diameters of the order of 3 nm. Unfortunately, this method suffers from a potentially severe overestimation of the volume of small pores due to connectivity-related ink-bottle and sample size effects (Moro and Böhni, 2002). Perhaps to avoid these problems, Waring et al. (2020) did not attempt to measure the volume of pore classes, but assumed instead that "the distribution of different pore size classes can be related to soil texture and mineralogy." However, soil texture and mineralogy are typically evaluated after heavy disturbance of the architecture of soils, and may therefore not be at all correlated in a straightforward manner with the pore size distribution in the original, undisturbed soil.

Before significantly more time and effort are invested in the development of the PROMISE model, it would be worth investigating the extent to which some of its key premises are sound, and in particular whether it is feasible to describe the dynamics of processes occurring in soils without taking at all into account the connectivity of their pore space.

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