

A more vital soil science future

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By some measures, soil science is doing fine. We have gained a battery of aspiring young scientists, and became more gender-balanced although still not as diverse as we should be (Carter et al., 2021). The number of soil scientific papers and books are growing at an almost exponential rate reflecting increased research and funding and, hopefully, an expanding knowledge base. An enormous amount of soil information is available, and increasingly peer-reviewed publications are freely accessible. Soon there will be no barrier for humanity between what is known and what information can be retrieved about soil.

Soil awareness has grown among policy makers and the general public, following enduring campaigns by national and international soil organizations. It is not uncommon to hear podcasts, talks on the tv, or read articles about soil health, regenerative agriculture, or the relationships between soil management, greenhouse gases and the changing climate. Scientific disciplines ranging from medical geology to urban planning recognize the relevance of soils and have embarked on soil research.

Countless technological advances enable us to observe, measure, model and monitor soil attributes at accelerating speed (Wadoux and McBratney, 2021). The private sector and industry have entered the soil carbon market, discovered the commercial value of the soil microbiome, and continues to develop technologies to optimize soil water use. But as soil science is rapidly evolving with a particular focus to solve the grand environmental challenges, it is vital that the science is done efficiently and impactful, and that it stays well-ahead of the technology.

Some soil research approaches are holding us back. First, a lot of soil science is conducted at the fringe of traditional soil science centers and departments by a community that has not had the benefit of primary schooling in soil science. Our discipline has always been enriched by approaches and theory from other scientific disciplines but, at the same time, a lot of fundamental knowledge about our soils, knowledge that was learned the hard way, is ignored (Hartemink, 2015; Schimel and Chadwick, 2013). This particularly refers to the lack of viewing soils as a four-dimensional system that cannot be reduced to measuring a limited set of attributes in one or a few timesteps and from shallow soil depth.

Quite a lot of research purports to investigate systems and aims to derive knowledge from differences among the systems. For example, soils under different vegetation or cropping systems are sampled for certain fractions, say, soil organic carbon, and the differences are attributed to land use and management. Too often, samples are collected only from the uppermost 20 cm (Yost and Hartemink, 2020) and, in many studies, diverse vegetation or a ‘range of agricultural soils’ are sampled across the continent so as to maximize

variation. No wonder that differences are unearthed, but such studies rarely progress beyond the description of loosely connected phenomena that are hard to extrapolate, or interpolate.

With research framed within one or other grand environmental challenge (Wortman and Lovell, 2013), it remains unclear how the results translate or contribute to solving those challenges. Studying and understanding soils is no easy. The best studies are those that investigate a multitude of soils and their attributes across a range of spatial and timescales using a wide range of tools and, above all are based on a solid framework and sound theory. We need to speculate more and think deeper and longer, and require more explorations that combine measurements with modelling and predictions across time and space.

Next, there is *soil anxiety* – that might be described as the hidden apprehension of doing something new and novel. This seems to occur, for example, at the research proposal stage whereby new ideas are met with: ‘Why?’ instead of a firm: ‘Why not!’. This goes along with the lack of study whether the research has already been done: it is easier to repeat than to formulate and invent. Part of the soil anxiety is the strictly regional approach that can be summed up as: ‘We have done in North Dakota. Now we do it in South Dakota.’ Science needs verification but there is quite a limit to progress in this direction. Progress comes from tirelessly chasing of new ideas, quite often with only partial success, but the lack of ideas - equivalent to maintaining a status quo - is regressive. It is not: ‘Go big or go home’ but: ‘Do something new or go home. Dare to fail - and dare to publish it.’

And, finally, a lot more effort is needed to develop sound theory. Sound theory is the bedrock of all the soil science subdisciplines. This could be the last chapter of every PhD thesis. It is not the same thing as hypothesis formulation and testing. Research considered ‘high impact-high risk’ is no guarantee of novelty or an overture for theory development if that is not the overarching aim. Funding bodies might hesitate to support foundational soil science research but it is good to see that methodology development is advancing in most soil science subdisciplines. It seems to go hand in hand with increased technological availability.

So, soil science is thriving, but it can do better. As much of our research findings are available, we have all the more responsibility to deliver the best. The future directions of our science are by no means solely determined by funding or the environmental challenges but, in particular, by the community, its education and willingness to strive for excellence. There is surely a role for the soil science journals to weed out problematic research approaches, but it is the task of the community, research centers and universities to guarantee that the research approaches are solid, reproducible, and innovative. Innovation should be the foundation of our research and not a special program defined as ‘high risk’ or ‘quick impact’. Concerted efforts should be made to force breakthroughs, for the growth of soil science theory and frameworks, and to think about the vitality of our discipline – now and in the future. And in all that, there is no need to think outside the box. There is no box.

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