Sustainable soil management requires a systems approach (SOIL-2017-26)

Vogl et al

Review comments J.Bouma.

General comments

In a well written paper, the authors present a relevant question: " *what can the contribution of soil sciences be to sustainable soil management"*(p2, line6). They later (p5, lines 4-5) specify a goal:"*the ultimate goal of soil research's support for sustainable soil management is to quantify and predict the impact of external forcing on the ensemble of soil functions".* And they mention the means to achieve all this:'*modeling soil as a complex, adaptive system"*(p3, lines4-5). But they also indicate that we have a long way to go:"*to truly capture the reaction of soils to external forcing through land use and climate change ..is still in its infancy"(p2, lines 17-18).* Still, *"soil scientists are working on detailed process understanding* (p4, line 9). Perhaps these, as such correct, statements could be put together in a unified storyline.

This type of paper is valuable, in my view, particularly at this point in time when soil science has spectacular opportunities as UN Sustainable Development Goals have been approved by 195 states, members of the UN, in 2015. This includes legal obligations to report progress towards 2030. Indeed, as has been observed elsewhere, in soil science subdisciplines still operate rather independantly. I fully agree with the statements on p2, lines 17-18 and p10, lines 24-27. How to cope with this is a highly relevant question.

I have a number of questions, comments and suggestions that will be articulated below. I will cite a number of publications with the only objective to better document comments made. I am aware of the recent "citation- stacking' excitement that does, of course, not apply in this context (and that is irrelevant anyway in my case because of my age).

Three overarching comments: (1) the paper is strongly soil-focused, while I feel that now more inter- and transdisciplinarity is also needed, emphasizing the word:"also", because we have to continuously develop our own science; (2) the schemes are very complex and it would have been useful to include some specific examples to increase transparency, (3) the authors correctly conclude that modelling the complete soil system with all its interconnections is still not possible but should be pursued in future. Then they jump rather abruply to defining indicators. I feel there is a way in between, to be further explored below.

Specific comments

1. P2, line 14: the main message of Keesstra et al (2016) and Bouma and Montanarella (2016) was the need to link soil functions with ecosystem services that are, in turn, interpreted to define ways to reach SDGs. Soil scientists can't do it alone, addressing the SDGs that have a strong and broad societal focus when the corresponding texts are read completely. We, and many others, have found that using dynamic simulation models of the soil-water-plant-climate system (e.g SWAP but many other models as well) is a highly effective and functional way to realize interdisciplinary interaction. The word modeling is used a lot in this paper, but what does it mean? I suggest the soil-water-plant-atmosphere modeling approach. We have lots of soil data in databases and we have to be aware of the manner in which such data are used by agronomists, hydrologists, climatologists and ecologists. There is a tendency to pick up texture, bulk density and %C, use pedotransferfunctions and assume that the soil part of soil-water-plant–climate models is being covered (and input from soil scientists is not needed anymore). This way "soil" is all too often represented very poorly. So we have

to stay involved in the modeling process, asking how soils can be represented best. The questions raised in this particular SOIL paper address this very issue.

2. The authors address the important issue how current land-use questions are being identified (p2,line19). I would be in favor of pro-active approaches by (soil) scientists, engaging stakeholders. This is further explored in two publications that were published after this SOIL paper was written. I invite the authors to consider these observations:

   Bouma, J., 2017. How Alexander von Humboldt's life story can inspire innovative soil research in developing countries. SOIL 3, 153-159. (https://doi.org/10.5194/soil-3-153-2017).

   Bouma, J., 2018. The challenge of soil science meeting society's demands in a "post-truth", "fact- free"world. Geoderma 310, 22-28.(http://dx.doi.org/10.1016/geoderma2017.09.017).

3. The „major societal concerns"(Baveye, 2015) (p2, line 23) are now well expressed by the SDGs. I would avoid the terms „services that soils provide"(p2, line 25). For clarity: soil functions contribute to ecosystem services. The „services"mentioned on p2, line 25, are soil functions (see also p3, line 26: indeed, soil functions are not the same as ecosystem services). I like the reference to the DPSIR approach (p2, line 16) but I interpret the system somewhat differently in terms of pro-actively offering options to stakeholders and policy makers, from which to choose (Bouma, 2018).
4. I wonder whether the link between social and natural sciences is clear but I certainly agree that the interface needs to be further developed. I refer again to the two papers cited above. We need, I feel, to pay particular attention to developing countries to encourage them to develop their own independant approach focusing on basic principles involved.
5. The authors take a big jump when moving from modeling interactive soil physical, chemical and biological processes (which is indeed very difficult) to indicators, to be discussed later. There is, in my view, an intermediate possibility. When we identify a given soil, we accept it as it presents itself and we describe it and measure its properties. There have been some studies that try to model soil formation, starting with the unchanged parent material and covering often thousands of years. Very difficult as is modeling of interacting soil processes associated with land use, as discussed in this paper. So why not look at the effects of different forms of land use as it presents itself in the field as a function of management, that can be traced back by questioning farmers. Sonneveld and Pullemans did so for SOC, each looking at a particular soil type and measuring soil properties at 50 locations, identified by using the soil map, while identifying past land use. They could develop regression equations that predicted %C remarkably well as a function of past and current land use:

   Pulleman, M.M., J. Bouma, E.A. van Essen and E.W. Meijles. 2000. Soil organic matter content as a function of different land use history. Soil Sci. Soc. Amer. J. 64: 689-694.

   Sonneveld, M.P.W., J.Bouma and A.Veldkamp. 2002. Refining soil survey information for a Dutch soil series using land use history. Soil Use and Management 18: 157-163.

   So:go back to the field and observe soils that have been subjected to particular forms of land use. Establish effects by measurements and this way obtain a characteristic range of properties as a function of land use for any given soil type (even though the underlying interacting processes are unknown in detail but often in a general way).
6. Indicators are indeed important (p5, line 14). Soil health is mentioned here in passing but this needs more attention as the topic is quite "hot"in the USA. Recent developments (Moebius-Cloene etal 2017) define, aside from the traditional chemical indicators , also soil physical ones and, dominantly, soil biological ones. These authors also feel that soil characterization has focused too much on chemistry in the past. They define numbers for physical, chemical and biological soil health and put them together but in a rather

unclear manner, that certainly does not represent the "dynamic"approach that Kibbleworth etal2008 mention. :

Moebius-Cloene et al, 2017. Comprehensive assessment of soil health. The Cornell Framework. (http://www.scs.cals.cornell.edu) . See also: www.soilhealthinstitute.org

7. I fully support the introduction of "threshold"values, also called "tipping points". They have successfully been defined for ecosystems and are quite relevant for soils. I can't resist to quote the following paper, introducing pedotransferfunctions (later –pedo was added) and threshold values:

   Bouma, J. and H.A.J. van Lanen, 1987. Transfer functions and threshold values: from soil characteristics to land qualities. In: Quantified Land Evaluation. Proc. of a workshop by ISSS/SSSA. ITC-Publication no. 6. p. 106-111.

   Indeed, identify tipping points by process studies but, I would suggest, also by field observations! Yes, the authors are quite correct that the dynamics of soil functions needs to be determined, but that can also be done by making multiple field observations at critical points in time. Yes, when is compaction so severe (threshold bulk density) that roots cannot penetrate the plowlayer and are there sites where farmers have deep-plowed and seeded deeprooting plants etc. The authors mention that a deep understanding of the underlying processes is needed (p5, line 33) but this a hard call because compaction and sheer forces interact in a quite complicated manner. So, keep investigating the processes, certainly, but also observe the effects defining thresholds , most probably of critical water contents, corresponding to the lower plastic limit (lacking a better measure than this one from 1915). A specific example:

   Droogers, P., A. Fermont and J. Bouma. 1996. Effects of ecological soil management on workability and trafficability of a loamy soil in the Netherlands. Geoderma 73: 131-145..

   Also, indeed, what is a critical SOC value etc. Resilience is briefly mentioned (p7, line 18). Important as well. Some soils are more resilient than others! I still remember well young volcanic soils in Costa Rica (Andisols) that recovered rapidly from compaction after deforestation, while old volcanic soils (Ultisols) did not:

   Spaans, E., J. Bouma, A. Lansu and W.G. Wielemaker, 1990. Measuring soil hydraulic properties after clearing of tropical rain forest in a Costa Rican soil. Tropical Agriculture 67: 61-65.

8. Soil types and soil classification are mentioned on page 8, lines 106. That is too late in my view. I strongly believe that soil types (soil series in the US) have a characteristic "story to tell" and that stratification by soil type is meaningful, if not essential, in creating a systematic approach. In an attempt to express the (characteristic) range of properties of a given soil type as a function of different forms of management , we defined genoforms (the classification name based on what you call inherent soil properties) and phenoforms that express the effects of management (your functional characteristics):

   Droogers, P. and J. Bouma. 1997. Soil survey input in exploratory modeling of sustainable soil management practices. Soil Sci. Soc. Amer. J. 61: 1704-1710.

Conclusion: the discussion being initiated by the authors is relevant for soil science at this crucial point in time. I suggest that the author consider comments made above to broaden

the scope of their analysis.