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Interactive comment on "Sustainable soil management requires a systemic approach" *by* Hans-Jörg Vogel et al.

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We thank the reviewer for his/her critical but very constructive and valuable comments! We will follow the general suggestion and reduce the obvious redundancy at several places. We will change the title to "A systemic approach for modeling soil functions". In the following we discuss the specific points brought up in the review:

1) Specific example for application of the model required: Indeed, in the meantime we developed the model and especially the case study on compaction and recovery of soil structure further. We will extend the presentation of this case study in an additional section (2.3) to better illustrate how the model can be applied and what input is actually required. However, the numerical implementation will be part of a separate paper since

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this would blow up the paper enormously and the special focus on the underlying model concept might be diluted.

2) How do we identify functional characteristics? The starting question is: which measurable/observable properties are carrying substantial information on soil functions and provide integral information about small-scale processes and their interactions? In fact this is the question how to upscale soil process descriptions. It came out that the possible candidates of such properties coincide with properties that change at an intermediate time scale of months to years in soils (of course macro pore volume may change abruptly below a tractor wheel, but the dynamic change under natural boundary conditions and the recovery after compaction is at a much longer time scale). Moreover, what we ended up with in Tab.1 (which of course might be extended) is in accordance to a considerable body of recent literature on indicators for soil functions and own analysis published in recent review papers (Rabot et al. 2018, Wiesmeier et al. 2018). We have the impression that we are converging towards some limited number of suitable "functional characteristics“ in our modeling framework. These functional characteristics may eventually translate to indicators of soil functions.

3) How to include functional characteristics into modeling? They need to be a subset of the interacting "agents“ in the process interaction network. In fact they are slowly changing state variables in our model concept. This is in contrats to many other process models in soil where these characteristics are treated as fixed material properties. We will illustrate this by highlighting the functional characteristics on the nodes of the network for the specific example in Fig. 4.

4) How to measure or parameterize the process interactions? Indeed most of them cannot be directly measured but for many of these interactions there is substantial site-specific knowledge or lets say a reasonable hypothesis about the principle form of these interactions in the literature. There are other process interactions for which much less is known about. And we need to rely on plausible assumptions (Examples are provided along with the example in Fig. 4). An attractive perspective is that process

interactions can be updated as soon as new insight is generated. Also the model concept can be used as a “toy model” in sense of: what would be the consequences if the interaction changes from type A to B ?

5) Where does the impression comes from that our scientific knowledge is often thought to be pretty much settled? This impression is not only based on the cited papers which are focused on the need for transdisciplinarity (certainly very important) and, thus, less on requirements in the field of natural sciences. It is also based on other, often non-scientific publications in this field and events like the "soil water nexus“ and the "global soil week“ which are mainly dedicated to the question how to bring the available knowledge into practical decision support (again, also important). Yet, we feel the need to make a strong point that fundamental soil science is still required and how this could provide a substantial contribution.

6) The simplistic Fig.1 is motivated to illustrate the human-soil interface and since there is no direct societal impact on climate it is missing here. We will make a strong point in the text that from the perspective of soil systems, climate is the other essential driver besides agricultural soil management. In Fig. 2, where the focus is on the soil system, climate has already been included. We will extend the caption of Fig. 1 to refer to the more detailed Figs 2 and 3 as suggested.

7) Why do we believe that our approach is superior to a bottom up approach starting at the molecular scale? We will add a paragraph at the end of section 2.2 to summarize why we focus on observable "functional characteristics“ and where to get the information about the relevant interactions which of course can be non-linear as well. The problem of spatial heterogeneity is reduced since the model approach is focused on entire soil profiles and a stratification of functional characteristics considered to be "effective“ descriptions of soil horizons. When it comes to larger scales we face the same classical problem: how are different soils distributed in the landscape - but this is not the scope of this paper.

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8) The question how do we come to the functional characteristics has already been discussed above (2).

9) What is the importance of state variables? We definitely agree that modeling the dynamics of state variables (e.g. water content) provide highly valuable information on soil functions (e.g. water storage) - but to evaluate the capacity of a soil to store water we rather focus on the bulk density (or inferred hydraulic properties) and not on the actual water content. As indicated in Fig. 2 state variables are also highly relevant for the impact of external drivers on the functional characteristics. For example, the impact of wheel traffic on water capacity is very sensitive to the actual water content. This is why the dynamics of state variables need also be part of the proposed model concept. We will make this point more clear.

10) The focus on functional characteristics leaves us with uncertainties about impact and indicators: For sure there are considerable uncertainties at various places. However the focus on functional characteristics allows us to base the model approach on observable properties having their individual but in principle measurable variability. The uncertainty related to the impact is included in the process interactions formulated as the kernel of the model approach. Here the perspective is that the uncertainty will decrease with increasing process understanding. The indicators are thought to be a subset of the functional characteristics or derived as a combination of such a subset depending on the soil function to be evaluated. Hence their uncertainty is directly related to the uncertainty in the observation of functional characteristics. This discussion will be included in the additional paragraph (see 7).

11) What is the new research we are referring to? We agree that a lot of progress has been made in the field of plant soil interaction especially with the help of new visualization techniques (and this is very promising to support our model approach). For the specific problem described in the paper – the recovery of soil structure from compaction – the specific point we are referring to is that we need to know the affinity of plant roots to grow into existing pores or their capacity to generate new pores. We

expect this is a function of soil texture, bulk density, soil moisture (again dependent on state variables!) and it depends on the plant species as well. To the best of our knowledge there is very little experimental evidence currently available along these lines. We think that this relatively new types of questions will pop up if we try to formulate the relevant process network required to predict the dynamics of functional characteristics in response to various drivers – we think this is an exciting endeavor and will include this discussion in the more detailed description of the example (see 1).

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