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The increasing relevance of soil science and soil security in a changing agricultural policy environment

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ABSTRACT

Following a new definition of modern soil science and a focus on the 5C's of soil security can provide a scientific basis for sustainable development, in line with recent high-level reports on the future of agriculture by the European Union. This requires a focus on indicators and thresholds of ecosystem services, including soil health. A recent case study on farm level showed that methods are available but attention is needed to define appriopriate regional threshold values for ecosystem services while field work to test modeling and measurement assumptions remains essential. This can establish a rejuvinated soil science profession that lives up to its central role in sustainability studies as the most permanent component of any ecosystem.

A challenge to the science community by the policy arena

Much is happening recently in both the agricultural policy and stakeholder arena . The European Union recently published a high-level strategic dialogue on the future of agriculture (EU, 2024). Though focused on 27 EU countries, this dialogue can have woldwide implications as it was initiated by the CEO of the European Commission, ms. van der Leyen, in her "State of the Union" address of 2023 and was written by leading members of various agricultural stakeholder organizations (11), -NGO's (8), -industry (9) and only two scientists. The dialogue thus expresses a strong stakeholder and industry perspective covering the entire production chain: "from Farm to Fork"! . When addressing knowledge in the dialogue, emphasis is on better access and sharing, not necessarility on generating new knowledge. An intriguing if not alarming signal for the scientific community which is in line with current highly critical, populistic approaches to research funding in several countries. But the research community is challenged in a positive manner when the strategic dialogue emphasizes: *"the need for sustainable farm management and harmonization of methodologies for on-farm sustainability assessment"* with: "*common metrics and indicators"* aiming at the objective:"*to determine where each farm stands"*. Also: *"provide quantifiable ecosystem services using robust indicators"*. This strategic dialogue was followed by a report of the European Commission on the Future of Agriculture (EC, 2025). also embracing:"*on-farm sustainability assessment",* in the context of:"*an agro-food system that is economically, socially and environmentally sustainable"*. This involves:' *contributions to climate mitigation, providing clean water and air, soil health and biodiversity preservation"*.

This are welcome signals as some current environmental regulations for agriculture focus only on implementation of management measures that are assumed to contribute to sustainable development without any supporting documentation, while soil contributions are ignored (Bouma and Scrope, 2024).

Soil science and sustainable development

A recent fascinating discussion on the evolving definitions of soil science (Hartemink and Mc Bratney, 2025) proposed a definition that fits well into the discours on the future of agriculture in the European Union: "*soil science is the study if the soil of the Earth and other planets, using evolving theories and knowledge to understand its role in sustaining ecosystem functioning, tackling environmental challenges and supporting humanity"*. Rather than a more traditional focus on soil physical, -chemical and -biological processes as such, and (digital) soil mapping, a much wider scope is proposed. So do the 5C's of soil security that not only address the more traditional soil condition, (C1), -capability(C2), and -capital (C3) issues but also connectivity(C4), with land users and codification (C5) focused on rules and regulations (Field et al., 2017). This allows an operational connection with sustainable development as articulated by the UN-Sustainable Development Goals of 2015. (Bouma, 2023).

A recent case study (Reijneveld et al., 2024) showed that methods are available to assess ecosystem services on farm level by measuring

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indicators and associated thresholds. including soil health as an ecosystem service. To be able to show this, the authors had to take a step back and not emphasize what we don't know (as is usual in research) but what we know. Stepping back is difficult for scientists who prefer to aim for cutting-edge research and the associated publications that support their careers. The transfer of scientific knowledge to stakeholders and the policy arena requires hard work with often relatively meager measurable output. But it is more than ever needed to face demands of modern society. A two-track future approach is therefore desirable: (1) cutting-edge basic research, and: (2) field research, based on working and communicating with land users contributing their tacit knowledge. This knowledge can also function to partly guide basic research of track 1. Establishing effective links between the two tracks forms a real challenge for future research.

The case study showed that field research is still needed to check assumptions made when applying simulation models, making measurements, and when using existing database-data. For example, partly compacted soil showed rooting patterns that did not correspond with modeling assumptions. The need for field research is particularly relevant as AI becomes more prominant . Wadoux (2025) concluded that: *" AI aids only minor parts of scientific soil research mainly under human supervision"* and:: *"running out of quality data"* calls for continuing creative field research. .

Our case study (Reijneveld et al., 2024) showed that methods are available to assess indicators for ecosystem services but representative thresholds, seperating the "good" from the "not yet good enough", are still lacking for most indicators and their definition forms a major scientific challenge where soil science can make crucial contributions.

Going beyond scientific disciplinarity

The scientific community, including soil science, has been rather ineffective in addressing environmental challenges with integrated inter- let alone transdisciplinary approaches that are needed to effectively assess ecosystem services. The "" scientific disciplines involved such as agronomy, hydrology, climatology, ecology and soil science as well as economics and social sciences, have been rather self centered while interconnections are essential when facing the sustainability challenge, characterizing ecosystem services. Even within soil science soil physics, - chemistry, – biology and -mapping often followed and follow seperate pathways. None of the seperate scientific disciplines can by itself define ecosystem services . The term soil-ecosystem services is therefore misleading and should not be used. Soils contribute to ecosystem services as is reflected in the definition of soil health as used in the European Union: "*the continued capacity of soils to support ecosystem services"*.(EC, 2023). Soil contributions are essential when assessing ecosystem services such as: producing healthy food, improving water quality, climate adaptation and biodiversity preservation, Showing this with specific examples is the best way to promote soil science rather than pontificate about the importance of soils in general terms.

No mistake: extending the boundaries of knowledge is the essential function of scientific research but scattered disciplinary scientific activities have so far not yielded interdisciplinary, operational methods for assessing ecosystem services. It is not: "either-or" but we need both disciplinarity and interdisciplinarity, and the latter should not be stigmatized as being:"applied". There is a vast body of knowledge and expertise after decades of research, even though questions will, of course, remain. Here: "The better is the enemy of the good". So rather than critise regulatory agencies for focusing on various management measures that are supposed to contribute to sustainable development (e.g. Bouma and Scrope, 2024) the scientific community would be well advised to instead question the limited scope of their research practices. If we would have produced operational methods to assess ecosystem services they would most likely have been applied by regulatory agencies. The latter are being pressured by the policy arena to show results and can't afford to wait . But that's not all: interdisciplinarity is not enough either. The major input of agricultural stakeholders in the EU Strategic Dialogue indicates that transdisciplinarity, truly involving stakeholders, must be essential in future activities. This stiil requires attention.The Living Lab approach, as proposed by EC(2023) is therefore focused on individual farms and is intended to engage farmers. The paper reporting a recent Living Lab sustainability study (Reijneveld et al., 2024) included farmers as co-authors.

The US Soil Health Institute is pragmatically focusing, and rightly so, on promoting loosely defined regenerative agriculture as they report that so far only 5 % of US farmers apply cover crops, a key aspect of this form of agriculture. Increasing that number produces results that are convincing to the political and stakeholder arena's that are increasingly unwilling to wait for the science arena to deliver. Existing research has convincingly demonstrated the value of cover crops for improving soil health and for reducing the erosion hazard. Would an exclusive future focus on this type of research be desirable? It is time for a reality check: perhaps suggesting measurement of indicators and thresholds for ecosystem services may be beyond what land users are willing to accept at this point in time. But if soil science intends to remain vital and relevant in future it would be well advised to make a structural link with broad sustainability studies allowing basic research to continue in a context that is recognized by the policy arena and society at large.

But others believe in different farming systems than the regenerative variety and often also with messianic fervor: organic, nature-inclusive, circular, precision and others. If the transdisciplinary scientific arena can define operational methods to assess indicators and thresholds for ecosystem services, a unifying procedure can be defined for all types of agricultural production systems and this would, at least, avoid time consuming discussions among adherents of the different approaches. Rather than react to topdown regulatory proposals focused on desirable management practices farmers, can and should preferably follow a proactive approach focused on achieving ecosystem services.

Adopting the proposed definition of modern soil science and the 5C's of soil security can result in operational methods to assess ecosystem services in agriculture with indicators and thresholds, providing a modern quantitative scientific basis for sustainable development. This way a rejuvinated soil science profession can live up to its central role in sustainability studies as the most permanent component of any ecosystem.

CRediT authorship contribution statement

Johan Bouma: Writing – original draft, Formal analysis, Conceptualization.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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