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The 5C's of soil security guiding realization of ecosystem services in line with the UN-SDGs

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ABSTRACT

The UN Sustainable Development Goals (SDGs) have a deadline of 2030 so, restricting attention to agriculture, development and implementation of management measures, aimed at reaching the goals, is urgent. Even though the current 159 very broad targets and 234 indicators for the SDGs don't mention soils, soils play a key role when addressing indicators 2.4.1 and 15.3.1 aimed at "sustainable agriculture" and "degraded land", by introducing operational methods to assess soil health and interdisciplinary ecosystem services in line with the SDGs. Application of the soil security concept, combining biophysical and socioeconomic approaches, is essential for sustainability research where dominant socioeconomic considerations by stakeholders should frame the biophysical analysis. If stakeholders don't embrace SDG-inspired innovative management, nothing will materialize in the real world. Much research is still needed to address inter- and transdisciplinary sustainability issues but a plea is made at this critical point in time to also apply a relatively straightforward and pragmatic research approach, essentially based on available data and methods, to assess ecosystem services, defining indicators and thresholds, in line with five key SDGs. Reference is made to an exploratory Dutch case study in a:"Living Lab". The National Soil Health Institute in the US has already pioneered such a pragmatic approach by first emphasizing socioeconomic aspects and by incorporating the soil health analysis in regenerative farm management that is recognized by farmers. But the five ecosystem services will still have to be assessed here to maintain the link with the SDGs and the policy arena. The 5C's of soil security apply very well at farm level. The soil science profession will benefit from showing specific examples of "Living Labs" where five thresholds of ecosystem services are met, creating: "Lighthouses" showing examples of achieved sustainable development in which soil health plays a key role as demonstrated by specific measurements.

1. Introduction

Lal et al. (2021) have documented contributions by soil science to a large number of UN-Sustainable development Goals (SDG's): SDG 1 (End Poverty), 2 (Zero Hunger), 3 (Good Health and Wellbeing), 5 (Gender Equality), 6 (Clean Water and Sanitation), 7 (Affordable and Clean Energy), 9 (Industry Innovation and Infrastructure), 11 (Sustainable Cities and Communities), 12 (Responsible Consumption and Production), 13 (Climate Action), and 15 (Life on Land). Their review not only considers environmental aspects but economic and social aspects as well (be it implicitly) that are an essential part of the sustainable development concept. Clearly, soil contributions to some SDGs are more important than to others and, rather then be broadly scattered, discussions on soil science research in future would be more effective when focusing on SDGs that have a direct relation with environmental aspects of land use. For example, zero hunger (SDG2) has strong socioeconomic and political dimensions but the production of food, where soils play a key role, represents the essential starting point of the foodchain. The same holds for producing healthy foods where soil health is important (SDG3). Soil processes are also key when considering clean water and sanitation: leaching of excess fertilizer and biocides and other pollutants to ground- and surface waters(SDG6). Carbon capture by soils forms an important climate mitigation measure (SDG13) and Life on Land (SDG15) is, obviously, strongly affected by soil processes as well. Of course, poverty in rural areas (SDG1) is highly affected by agricultural conditions, certainly in developing countries, but many other factors play a role as well. The same is true for gender equality. Soils have restricted and indirect impact on industry, cities and consumption patterns. Even though biomass production can be important for affordable and clean energy (SDG7) it only represents a relatively small

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contribution to the issue at large and can be covered by the production issue in SDG2.

The largest land area in the world is used by agriculture but soils also play an important role in forestry, other nature areas and cities. Attention in this review will, however, be on agriculture and on the five SDGs, mentioned above, where soils play a dominant part when focusing on environmental issues, one aspect of sustainable development next to socioeconomic conditions. In this environmental context de concept of "ecosystem services" is important (e.g. Millennium .Ecosystem Assessment, 2005), defined as:*"services provided by ecosystems to humans"*.

SDGs are now defined by very broad "action goals", like:"achieve food security" and "ensure availability of water", and by targets and indicators. Bouma et al. (2019) reviewed the list of approved indicators and concluded that soils were not mentioned and recommended more engagement of the soil science community. This has not materialized as listings in 2023 ((https://unstats.un.org) still don't mention soils in159 targets and 234 indicators for the 17 SDGs. Only SDG 2 (7 targets, 14 indicators) has indicator 2.4.1 with a distant relation with soils:*"proportion of agricultural area under productive and sustainable agriculture"*. SDGs 3 (13 targets, 28 indicators), SDG6 (8 targets, 11 indictors), SDG 13 (5 targets, 8 indicators) don't mention soils, land or agriculture. Only SDG15 (12 targets; 14 indicators) has indicator 15.3.1.: *"proportion of land that is degraded over total land area"*. Other targets of SDG15 address biodiversity and wildlife. This listing can be rather shocking for soil scientists at first sight as it indicates that what they rightly consider to be essential input into the debate on sustainable development is as yet not being recognized in the SDG-centered debate. Soil does, however, receive substantial attention in other policy arenas, such as, for example, in Europe in the:"Soil Deal for Europe" program. Still, a basic question is evident for the soil science community: how to communicate the role of soils in a more effective manner ?

There are, however, still excellent opportunities in the SDG debate, to do justice to the profession as will be explored in this paper. Note, for example, that it remains undefined what is meant by *"productive and sustainable agriculture"* or:*"land degradation"*.Also, the presented very broad indicators don't mention thresholds, in terms of critical percentages of areas occupied, allowing important distinctions between "good" and: " not yet good enough". This is what land users need to know! The SDG target and indicator scheme presents a highly abstract, bureaucratic wish-list (as such, valuable compared with having nothing at all) that should urgently be specified as farmers and other stakeholders are confused and increasingly irritated about lack of clear action-oriented down-to-earth rules and regulations to be provided by the policy arena.

The Soil Security concept (Koch et al., 2013; Field et al., 2017) can provide an important guide at this point in time as it advocates consideration of both biophysical and socioeconomic aspects of sustainable development. This is essential to connect science, including soil science, with society presenting one of the most important challenges for the science arena at this point in time.

The following issues will therefore be discussed in this paper: (i) the role of soil functions and ecosystem services in line with the SDGs; (ii) determination of ecosystem services and their thresholds contributing to: *"sustainable agriculture"* and *"land degradation"*, covering the condition, capability and capital dimensions of soil security, and: (iii) the need for effective interaction with the land user and policy arena considering socioeconomic conditions, thereby covering the connectivity and codification dimensions of soil security.

2. The role of soil functions feeding into ecosystem services in line with the SDGs

Soil functions have been defined by the European Commission (EC, 2006) and recently reviewed by Evangelista et al. (2023) proposing the listing of Table 1. What happens in the real world for each of these functions depends, of course, on management practices, input by other scientifc disciplines and socioeconomic considerations. For example,

Table 1
Soil functions (Evangelista et al., 2023).

1 to produce food and biomass.
2 to store carbon.
3 to provide a habitat for, and of, biodiversity.
4 to store and regulate nutrients.
5 to store, purifier and regulate water.
6 to filter and remediate contaminants.
7 to be a source of raw materials.
8 to be an archive of archæological artefacts.

food and biomass production is, aside from economic aspects, a function of input by, at least, agronomic, climatic and hydrological expertise. Dynamics of the nutrient and substances regime are also a function of soil hydrology, while the habitat and carbon pool are affected by nature management where ecologists play a key role. Whether or not the archaelogical heritage is realized depends on archeologists and on societal initiatives or funding by governmental agencies.

Restricting attention for the moment to environmental aspects of sustainable development, ecosystem services in line with the various SDGs serve to express the impact of the external input factors mentioned above. Soils contribute to interdisciplinary ecosystem services that are defined as:"*services provided by ecosystems to mankind"*. (Millennium Ecosystem Assessment.2005). By defining threshold values for each service a distinction is possible between:"good" and "not yet good enough" (the latter avoiding the demotivating term:"bad"). Ecosystem services can apply to regions but also to business units, like farms. Attention for the latter is particularly important to reach and connect with practicioners. Four types of ecosystem services are distinguished: (i) provisioning (e.g. food, fresh water, wood, fuel); (ii) regulating (e.g. climate, floods, disease, water purification); (iii)supporting (e.g.nutrient cycling, habitat preservation, primary production), and (iv) cultural (aesthetics, spiritual, educational, recreational). Note clear links with the various soil functions as was also mentioned by Evangelista et al. (2023) except that ecosystem services have an interdisciplinary character. .

Again, soil functions have a distant relation with various SDGs and their primary role is:" *to contribute to ecosystem services in line with the SDGs"*. (e.g. Keesstra et al., 2016, Veerman et al., 2020). Soils cannot do it alone! Linking the discussion in this manner to the SDG context allows connection with the worldwide scientific and policy arena which favorably broadens the scope of the discussion potentially contributing to improved recognition of the soil science profession. Soil science would be well advised, like all other professions, to not only strengthen its own bubble but to also move beyond.! The term "soil-ecosystems" is too short to clearly express the relations between soil functions, ecosystem services and the SDGs as articulated above. Next to soil functions and soil ecosystem services, Evangelista et al. (2023) also suggest that soil threats should be judged seperately applying the 5C's. This could, however, also be represented by different Living Labs on a given soil type (the genoform), that have experienced different threats, realizing that threats may have quite different effects in different soils. Living Labs with eroded soil, low carbon, soil structure decline etc. This way a set of characteristic phenoforms can be distinguished with associated ecosystem services, with indicators to be judged by the thresholds for that particular genoform. This will right away provide information on and allow judgements on the associated forms of management. Clearly, Living labs will have to be established first but the advantage of this approach would be that the overall straightforward procedure of assessing ecosystem services would remain unchanged, providing clarity.

As an aside, one could argue that the term ecosystem services seems to imply a submissive relation between ecosystems on the one hand and mankind on the other, in which mankind is being served and is in charge. Of course, modern insights acknowledge that mankind is subject to ecosystem processes that he or she can only affect to an often unknown and limited extent. Would it therefore not be more realistic to talk about:"Ecosystem favors"? The already complicated sustainability debate is, however, not being served by yet another discussion about terminology but mankind, including scientists, would be well advised to internalize their limited role justifying humble modesty. .

3. Defining ecosystem services and their thresholds

Some ecosystem services will now be discussed in more detail for the five SDGs and to provide a specific focus, reference is made to an exploratory case study on ecosystem services and soil health made on a Dutch "Living Lab".(Bouma, 2022; Bouma et al., 2022), located in Southern Flevoland. The soil at the "Living lab" was a well drained, fine, mixed, mesic Typic Fluvaquent (Soil Survey Staff, 2014).

"Living labs", proposed by the European Commission in their:"A Soil Deal for Europe": program (EC,2021) are defined as: *"spaces for co-innovation, through participatory, transdisciplinary systemic research"* that "*contribute to Green Deal targets for sustainable farming, climate resilience, biodiversity and zero-pollution"* .The EU Green Deal corresponds with the world-wide UN-SDGs. "Living Labs" reflect the need for researchers to work closely with stakeholders developing practical solutions for environmental problems that form barriers to sustainable development. When successful, "Living Labs" become "Lighthouses", defined as: "*single sites, like a farm or a park, where to showcase good practices. These are places for demonstration and peer-to-peer learning.*"

To reach an overall judgement for the business unit (the farm) being considered, the "one-out", "all-out" principle is applied. Only when all ecosystem services meet their threshold, the farm qualifies in terms of contributing sufficiently to environmental aspects of sustainable development. Additional judgements about socioeconomic conditions allow an overall judgement as to whether or not the farm contributes to sustainable development and can act as a:"Lighthouse". Farmers and politicians like the clarity of this straightforward procedure which does, however, include many shortcuts from a scientific point of view that need to be justified, as will be discussed hereafter. The procedure also allows a specific focus on areas that need additional research.

3.1. Ecosystem service: providing healthy food (SDG 2&3)

Soil moisture regimes are crucial factors determining agricultural production levels that affect SDGs 2 and 3. Lin et al., 2006 and Bouma, 2023, have, amongst others, therefore advocated joint work of pedologists and soil phycisits in hydropedology when addresing the role of soils in agricultural production. This approach presents one procedure to increase the visibility of the soil science profession by teaming up with colleagues in an other discipline. As mentioned by Bouma (2023), "soil and water" have last year been accepted by the Dutch government to guide land development.

Crop yields and contents of possible pollutants can be measured, determining whether ro not legal health limits are exceeded. Simulation models are widely available to estimate production levels as a function of climate conditions and are an ideal vehicle for interdisciplinarity as all participating scientific disciplines have to contribute basic data. (e.g. White et al., 2013, Van Ittersum et al. 2013, Kroes et al., 2017, Holzworth et al., 2018). Models require basic soil physical characteristics such as hydraulic conductivity and moisture retention (Reynolds et al., 2002), that can be estimated by pedotransferfunctions derived from soil survey databases (Bouma, 1989, Van Looy et al., 2017). Unfortunately, many of these databases also contain values of so-called:"available water', arbitrarily defining water contents between "field capacity"(set at 0.3 bar) and "wilting point"(set at 15 bar). These concepts date from the 1930′s and more recent work has shown that "field capacity"and "wilting point" vary strongly as a function of soil type, crops being studied and environmental conditions. Dynamic models, using hydraulic conductivity and moisture retention data as well as crop-specific "sink-terms" for root uptake of water should therefore be used now, avoiding the old "available water" concept. (e.g. Kroes et al., 2017, Bouma, 2018a).

Relations between pollutants in soil and uptake by plants that can affect human health are complicated and the subject of new research as new pollutants appear (e.g. Brevik et al., 2020). Pesticides form a particular problem that requires more research resulting in meaningful thresholds.(Geissen et al., 2021).

Results of the case study Living Lab (table 2): Yields were measured and they were in line with the 80% water-limited yield as proposed by van Ittersum et al., 2013 as a possible threshold. Soils at the Living Lab were not polluted to be explained as they did not receive city compost, as a possible source of pollutants. Reduced and on-site precision application of biocides resulted in relatively low soil contents that did not adversaly affect crop quality.

Conclusion: the ecosystem service scores meet the thresholds of both SDGs 2, 3,13 and 15 (soils).

3.2. Ecosystem service: providing clean water and sanitation (SDG6)

Soils can be effective in removing pollutants from percolating solutes by adsorption, filtration or oxidation processers. Purification is a direct function of travel times associated with application regimes of liquid waste or infiltration of rain mixed with surface applied solid waste. For example, pathogenic viruses were removed in 60 cm of sand when applied at 5 cm/day while they moved beyond that depth at 50 cm/day. (Bouma, 1979).Every soil has a characteristic critical flow rate, above which purification of percolating liquid waste is inadequate. Of concern are soils with macropres where rapid downward movement of pollutants may occur (e.g. Bouma, 2023). Critical thresholds for water quality are well defined in many countries. The EU Water Guideline defines thresholds for nitrate levels in groundwater, N and P levels in surface water and for pollutants.(EC,2000) Recent concerns about the content of pesticides in groundwater call for new research resulting in meaningful thresholds.

Results case study Living Lab (table 2): Ground- and surface water quality was not yet measured on- farm. Nearby measurements were below the thresholds but this cannot present a positive result for the Living Lab. Application of innovative, automatic measurement techniques was recommended to facilitate operational measurements.

Conclusion: this ecosystem service cannot be judged but future measurements are quite feasible.

3.3. Ecosystem service: limiting greenhouse gas emissions (SDG13)

Greenhouse gas emissions are a complex function of carbon dynamics (e.g. Smith et al., 2020). Rates are currently estimated with modeling, based on IPCC criteria, allowing rough estimates at farm level (Arets et al., 2021). Even though no formal thresholds have been defined, emissions of mineral clay soils are relatively low. In addition, to be discussed later in the section on soil health, soils in this Living Lab have higher organic matter contents than similar soils elsewhere,

Table. 2
Ecosystem services determined for a:"Living Lab", an arable farm on calcareous light clay soils in Flevoland, the Netherlands (from Bouma et al., 2022). For SDG13 empirical considerations result in a probable positive result. When based on the "one-out, all out" principle this "Living Lab" does not yet qualify as a:"Lighthouse".

Ecosystem service	Indicator	threshold	result
SDG2: food production	local yields and Yw	80%Yw	positive
SDG3: healthy food	EU &local reg.	EU & local reg	positive
SDG6: water quality	EU& local reg	EU & local reg	negative
SDG13: greenhouse gas em	modeling em	not defined	prob. positive
SDG15: biodiversity pres	not defined	not defined	negative
SDG15: land degradation	soil health	see Table 3	positive

indicating positive carbon capture, contributing to mitigation processes.

Results case study Living Lab (table 2): this ecosystem service meets the threshold based on empirical considerations as a formal threshold has not yet been defined. This is unsatisfactory indicating the need for new focused research including measurements.

3.4. Ecosystem service: supporting biodiversity and soil health (SDG15)

Biodiversity at Living Lab level is difficult to assess as it should be judged at a regional level. In the Netherlands 162 nature areas have been established in the EC- NATURA 2000 program (https://www.natura2000.nl). Biodiversity is determined periodically in each area but there is a fundamental disagreement among ecologists as to which methods are to be used and how thresholds should be defined. Define a condition at a given year to be selected or define the types of plants and animals that should occur given environmental conditions? The latter can result in unrealistic "wishful thinking". More important is the effect of expected climate change (IPCC, 2023). Their latest report concludes with "high confidence": ".*widespread adverse impacts and related losses and damages to nature by climate change."* Nature is dynamic: static pictures of the past cannot represent the future. In the Netherlands climatic conditions in 2050 are projected to correspond with current conditions in central France and this should be reflected in realistic indicators and thresholds for nature in future. Innovative research is urgently needed.

Of course, negative environmental effects of farming, such as pollution of water and air, can affect the quality of nature areas nearby. As such emissions do not occur in the Living Lab being analysed, this can be seen as an indirect positive contribution to biodiversity. But,as discussed, for above ground biodiversity, indicators or proxies are still lacking as current political discussions in the Netherlands still struggle to find common ground between agricultural- and nature-oriented interests. .

Soil Health is presented here as part of SDG15 and illustrates the integration process of soil science in the SDG context. Soil biodiversity is part of soil health, as defined by the EU Mission Board of Soil Health and Food (Veerman et al., 2020). Soil health indicators are defined based on the needs of growing roots: (i) lack of pollutants; (ii) good soil structure; (iii) relatively high organic matter contents, (iv) high soil biodiversity, (v) favorable soil moisture regimes (newly added) and (vi) favorable soil fertility. As mentioned above, the soil at the Living Lab was not polluted. Soil structure was judged by bulk densities and penetrometer resistances and values were below proposed thresholds. Soil biodiversity presented a problem as a standard methodology, let alone thresholds were not available. The relatively high organic matter content of the soils was taken as a proxy for soil biodiversity. Soils were well drained presenting a favorable soil moisture regime. A long list of required soil nutrients, as used in other soil health determinations and in early publications of the National Soil Health Institute in de USA, was avoided by the requirement that a soil test followed by fertilization advice should be provided by a registered laboratory. And recommendations should be followed up! For further details reference is made to Bouma et al. (2022).

Considering the above results, soil health for this Living Lab was considered to be positive as all indicators were satisfied, be it with what seemed to be reasonable empirical assumptions on soil biodiversity. (Table 3).

Next to soil health, also the term soil quality is still widely being used and this confuses outsiders. Some authors suggest that both terms have the same meaning but why have two terms for the same item? Bonfante et al. (2019) suggested to restrict the term soil health to actual conditions, comparable to a patient visiting the doctor and receiving a judgement. Soil quality would represent the range of soil health values (as expressed by soil health indicators) for a given soil as a function of past and present management, comparable to provide health values for certain cohorts of people (15–25 years old, 75+, males, females etc.). This implies consideration of a series of phenoforms of a given soil genoform (Droogers and Bouma, 1997; Rossiter and Bouma, 2018) reflecting effects of soil threats or of poor management practices.

Table 3
Soil health indicators for the "Living Lab" described by Bouma et al. (2022). Conclusion: this soil is healthy and offers a positive entry pointy for SDG 15 in table 2 . Note that soil biodiversity still uses what seems to be a reasonable proxy value as general methods and thresholds have not yet been defined.

Soil-health indicator	actual value	threshold	result
Soil pollution	EU& local reg.	below thresholds	positive
Soil structure: bulk density Soil structure: bulk density	1.35 g/cm3,sd 0.08	1.55g /cm3	positive
Organic matter content	2.9%, sd 032	2.0%	positive
Soil biodiversity :	% org matter as proxy	2.0%	positive
Soil moisture regime	well drained	meets requirements	positive
Soil fertility: regime based on required soil testing			positive

Results case study Living Lab: this ecosystem service scores above the threshold for soil health (Table 3) but biodiversity is still undefined for the "Living Lab". (Table 2)..

4. Condition, capacity and capital in relation to the SDG indicators

The 5C's of the soil security concept refer to soil but can also be well applied at "Living Lab" level, which is of most interest to farmers and to the policy arena. We propose to do so.The *condition* of the "Living Lab" being discussed can be expressed by the assessment of the six ecosystem services, analysed above. Four ecosystem services meet their threshold but two others do not. The discussion in Section 3 suggests additional activities or research to fill the gaps. When all ecosystem services would meet their threshold, the "Living Lab" would be sustainable from a biophysical point of view, allowing a judgement for indicator 2.4.1., as discussed in Section 1. Judging different Living Labs in an area will allow estimates of the proportion of land occupied by sustainable farms, satisfying bureaucratic requirements.The successful Living Laboratories Initiative in Canada consists of groups of farms constituting a Living Lab, allowing this type of evaluation (https://agriculture.canada.ca.livinglabs).

As discussed in Section 3.4, soils in the Dutch "Living Lab" were healthy, implying lack of degradation, thereby answering indicator 15.3.1 as discussed in Section 1. Again, proportions of land can be determined when assessing different farms in a given area with similar soils. Farmers income was above the economic threshold value, allowing an overall positive judgement.

The *capacity* ("what can this Living Lab do?") is close to its *condition.* This is reflected by the Dutch tax system that defines land prices for 65 regions in the Netherlands defining the agricultural value. Soils in this particular Living Lab score by far the highest of all land in the country at 147,900 €/ha, while values for other land start at 50,000€/ha with an overall average of appr. 70,000€/ ha. Clearly, the *capital* value of this "Living Lab" is very high.

In this analysis the original terms "condition" and "capacity" were used, as in Evangalista et al. (2023) and not the term "capability" combining both (Mc Bratney et al., 2019). The two separate terms appeal to land users as they address "what is" versus "what could be".

5. Connectivity and codification

The introduction of the soil security concept (Koch et al., 2013; Field et al., 2017) has been quite significant for the soil science profession because for the first time, attention was not confined to the usual technical considerations, as expressed by condition and capability, but was extended to capitol, connectivity and codification expressing the need to structurally link soil science with the stakeholder and policy arena (e.g. Bouma, 2015). The latter is important as trust in government is low in many countries. A recent survey in the Netherlands reported that 80% of dairy farmers did not trust government! Topdown imposed environmental rules and regulations and lack of a coherent vision for the future create much resistance in an evermore articulate stakeholder environment. But how to improve this? How to frame the *connectivity* concept in "post-truth", "fact-free" times ? (Bouma, 2018b).

The European Union has proposed:"Living Labs" to encourage bottom-up efforts to realize sustainable development but the science arena seems so far to be primarily engaged in discussing theoretical definitions and procedures. The National Soil Health Institute in the US (www.soilhealthinstitute.org) has chosen a different and successful approach that by now has resulted in perhaps less publications in scientific journals but in a series of reports and videos on internet that address farmer concerns in a truly engaging and successful manner. Also effective contacts have been established by agrobusiness and advisory bodies, e.g. the National Cotton Council, Cargill, Walmart and others. When discussing the impact of the national Soil Health Institute program, two aspects stand out:

(i) they have broadened the soil health issue by incorporating it in an assessment of agricultural management of a given farm enterprise, expressed by regenerative agriculture. Farmers have more affinity with that concept than for abstract targets and indicators, the favorite subject of researchers (including the author of this paper). Sustainable development can only be based on an interdisciplinary approach: soil is not the only game in town! The Institute also made thorough economic studies of 100 corn and soybean farms, showing that, following regenerative practices, yields were appr. 70% higher when compared with traditional systems, costs were lower and net incomes increased by approximately 50$/acre. Farmers run an economic enterprise and only data like this are truly convincing (even though some conservative farmers still stick to traditional management, demonstrating how difficult it is to change well established traditions). Of course, the key ingredients of regenerative agriculture (cover-crops and reduced tillage) have been known for many years but the message came to life again in this new frame, inspired by the soil health concept. Why not, if it works?

(ii) (ii)Studies showed that soil health was higher in fields with regenerative management as compared with traditional management. Realizing that tests for soil health were complicated, costly and time consuming they proposed to strongly reduce the number of tests, restricting it to only measure%C, C-mineralization and aggregate stability and by calculating water holding capacity with pedotransferfunctions (Bagnall et al., 2022). This development is in line with Doran and Zeiss (2000) and Schoenholz et al. (2000) that recommend indicators to be easy to measure, inexpensive, sensitive to variation in management, relevant across sites and time and useful and comprehensible for different stakeholders. These principles also guided the Bouma et al. (2022) study.

Whether or not this reduction of indicators by the national Soil Health Institute is justified, the US experience shows that incorporating the soil health concept into well defined management systems, that are bound to differ in different regions, may be most effective to connect with farmers and realize sustainable development in the real world. This is important as, again, there is no time to loose!

The effort of the National Soil Health Institute to simplify procedures and to connect with the know-how and visions of farmers is in line with the effort of Bouma et al. (2022) to explore application of a relatively simple procedure to assess ecosystem services for a "Living Lab", be it that emphasis on a given farming system may result in less emphasis on ecosystem services associated with the five SDGs (where soil health is part of SDG15) and this may hamper the sustainability analysis. Defining indicators and thresholds, allows (after an economic evaluation) a conclusion whether or not a given "Living Lab" is sustainable. Determination of thresholds still needs much more attention by the research community. Values will not only be different for different soils but also for different regions because of climatic differences. The procedure is transparent and straightforward, allowing clear communication with farmers, citizens and the policy arena. Soil-centered approaches, that are scientifically highly relevant and necessary to expand our understanding (e.g. Evangelista et al., 2023) will, in contrast, be more difficult to communicate It should be clear that the author is in favor of an interdisciplinary approach where soil science contributes to ecosystem services in line with the SDGs.. A two track procedure may be desirable at this point in time: pragmatic, operational approaches as realized by the National Soil Health Institute and explored by Bouma et al. (2022) on the one hand and continuing explorative scientific studies on the other hand. The first track is needed now as there is no time to lose!

Codification, finally, is served by developments described above. If regenerative or other well tested practices are well defined they could be the basis for agricultural subsidies but it would be desirable to document the associated ecosystem services, as presented above for a "Living Lab". If not, the definition of any particular management system could be too vague while the link with the five major SDG issues,and thereby the link with the policy arena, would be lost. This is relevant for Europe where their massive Common Agricultural Policy provides subsidies to farmers with a budget of 350 billion € for the period 2021–2027. A decision has been made to direct 25% of the subsidies to achieving ecosystem services, a percentage that is bound to increase in future. Obviously, to qualify, farmers will have to provide documentation as to the status of their ecosystem services.

Another important reason for the need to define ecosystem services is the fact that other farming systems than regenerative farming may meet the ecosystem thresholds (e.g. Stavi et al., 2016). For example: organic-, circular-, nature inclusive- and high-tech precision farming. Farmers should have the freedom to adopt whatever farming system fits best with their interests, capabilities and entrepreneurial spirit. The government should define specific goals to be met and provide financial support when needed, but should not prescribe the type of management to be followed.

Another, and different *codification* aspect was realized in South Africa where a hydropedological survey is required now when submitting land-use plans. (van Tol et al., 2021; van Tol and van Zijl, 2022). The University of Free State and other institutions developed the science, some of which funded by the Water Research Commisssion (WRC) which is the research funding institution of the Department of Water and Sanitation (DWS). Departmental officials were nominated to serve on reference groups to help guide the research to ensure that the science and tools developed would be appropriate for assessment requirements through the legislative framework for water use authorization. This was a lengthy process but now tools are available and DWS has adopted them, compelling applicants to use these standardised tools and guidelines in the assessment process. In terms of soil security, *codification* is therefore assured!

With due respect, lawyers, governance- and communication experts, that tend to increasingly populate governmental agencies in many countries, as "hard" scientists retire, cannot be asked to judge technical biophysical requirements when judging and regulating land use plans. In South Africa a hydropedologist was a member of the reference group, acting as a crucial "anchor", linking biophysical science with the policy arena. Such "Anchors" are essential to advance the soil mission, where hydropedology in this instance turned out to be an effective tool. "Anchoring" the concept of ecosystem services in broad policy discussions is also very much needed, requiring policy careers of at least some biophysical scientists!

Conclusions

- The soil security concept, combining biophysical and socioeconomic characterizations, presents an excellent frame for the study of sustainable development where genuine stakeholder participation is crucial to meet the SDG deadline of 2030. As stakeholders are particularly motivated by socioeconomic impulses, biophysical research should be framed in that particular context.
- The seventeen UN Sustainable development Goals have by now 159 targets and 234 indicators, none of them mentioning soils. The initial alarm about this is unjustified as indicators are very broad and providing specific data for two of them ("productive and sustainable agriculture" and "degraded land") offers excellent opportunities to demonstrate the crucial role of soil health. Linking soils to internationally established protocols, like the SDGs, increases the potential for visibility and recognition of the soil science profession.
- Sustainable development is a highly complex issue that needs continuing thorough research. Still, the 2030 SDG-deadline is near and a plea is made to also focus now on a pragmatic approach, using available data, emphasizing values and thresholds of ecosystem services in line with five key environmental SDGs. Reference in this context is made to an exploratory Dutch study in a ":Living Lab", as defined by the European Union, with the objective to improve interaction between science, stakeholders and the public and policy arena.
- In line with the previous bullit, the National Soil Health Institute in the US has successfully followed a stakeholder-oriented approach right from the start, first emphasizing economic aspects and integrating the soil health concept into the regenerative farming system. This has not only resulted in broad acceptance by farmers but also by agrobusinesses that increasingly provide funding for Institute activities.
- Even though regenerative farming systems may be quite suitable in certain areas to result in ecosystem services meeting their thresholds, farmers should have the freedom to adopt whatever farming system fits best with their interests and capabilities. The government should therefore define specific goals, in terms of indicators and thresholds of ecosystem services to be met, but is and will remain unqualified to prescribe the type of management to be followed.
- Using both soil quality and soil health terminology is confusing for outsiders, unless soil health can be restricted to actual conditions while soil quality can refer to the range of soil health values (expressed by indicators and thresholds) for a given soil type as a function of different threats and associated soil management. Results of such threats can be expressed as phenoforms of a given soil type (the genoform).
- More research is needed to define thresholds of indicators for ecosystem services, that will vary among soils and regions with different climates. Thresholds will allow a distinction of ecosystem services that are "good" versus the ones that are "not yet good enough". Land users need this information for their business plans.

Declaration of Competing Interest

The author has no specific commercial or other interests associated with this review.

Data availability

No data was used for the research described in the article.

References

Arets, E.J.M.M., van der Kolk, J.W.H., Hengeveld, G.M., Lesschen, J.P., Kramer, H., Kuikman en, P.J., Schelhaas, M.J., 2021. Greenhouse gas reporting of the LULUCF sector in the Netherlands. Methodological Background, Update 2021. WOt Technical Report 201. Statutory Research Tasks Unit for Nature & the Environment (WOT Natuur & Milieu), Wageningen UR, Wageningen, The Netherlands. https://edepot.wur.nl/539898.

Bagnall, D.K., Morgan, C.L.S., Cope, M., Bean, G.M., Cappellazzi, S., Greub, K., et al., 2022. Carbon sensative pedotransferfunctions for plant water. Soil Science Soc. Amer.J. 86 (3), 612–628. https://doi.org/10.1002/saj2.20395.

Bonfante, A., Terribile, F., Bouma, J., 2019. Refining physical aspects of soil quality and soil health when exploring the effects of soil degradation and climate change on biomass production: an Italian case study. SOIL 5, 1–14. https://doi.org/10.5194/soil-5-1-2019.

Bouma, J., Beatty, M.T., Petersen, G.W., Swindale, L.D., 1979. Subsurface applications of sewage effluent. In: Planning the Uses and Management of Land. Agronomy, 21. ASA-CSSA-SSSA, Madison Wisc. USA, pp. 665–703.

Bouma, J., 1989. Using soil survey data for quantitative land evaluation. In: Stewart, B.A. (Ed.), Advances in Soil Science, 9. Springer Verlag, New York, pp. 177–213.

Bouma, J., 2015. Reaching out from the Soil-Box in pursuit of soil security. J. Soil Sci. Plant Nutr. 1–10. https://doi.org/10.1080/00380768.2015.1045403.

Bouma, J., 2018a. Letter to the Editor. Comment on Minashy and Mc Bratney, 2017. Limited effect of organic matter on soil available water capacity. Eur. J. Soil Sci. 69, 154. https://doi.org/10.1111/ejss.12509.

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

Bouma, J., 2022. Transforming "Living Labs" into:"Lighthouses": a promising policy to achieve land-related sustainable development? 2022. SOIL 8, 751–759. https://doi.org/10.5194/soil-8-751-2022.

Bouma, J., 2023. The role of hydropedology when aiming for the UN Sustainable Development Goals. Vadose Zone J. (in press).

Bouma, J., Montanarella, L., Vanylo, G.E., 2019. The challenge for the soil science community to contribute to the implementation of the UN Sustainable Development Goals. Soil Use Manag. 35 (4), 538–546. https://doi.org/10.1111/sum.12518.

Bouma, J.J.J.de Haan, Dekkers, M.S., 2022. Exploring operational procedures to assess ecosystem services on farm level, including the role of soil health. Soil Syst. 6 (34) https://doi.org/10.3390/soilsystems6020034.

Brevik, E.C., Slaughter, L., Singh, B.R., Steffan, J.J., Collier, D., Barnhart, P., Pereira, P., 2020. Soil and Human Health: current Status and Future Needs. Air Soil Water Res 13, 1178622120934441.

Doran, J.W., Zeiss, M.R., 2000. Soil health and sustainability: managing the biotic component of soil quality. Appl. Soil Ecol. 15 (1), 3–11.

Droogers, P., Bouma, J., 1997. Soil survey input in exploratory modeling sustainable soil management practices. Soil Sci. Soc. Am. J. 61, 1704–1710.

EC, 2006. Thematic strategy for soil protection. communication from the commission to the council. Eur. Parliament, Eur. Econ. Soc. Cie the Cie Regions. COM(2006) 0231final. Brussels.

EC. European Commission, 2021. European missions. communication from the commission to the European parliament. The Council, European. Economy and Social Cie and the Committee of the Regions. COM, Brusssels (2021), 609 final.

EC (European Union), 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy. EU, Brussels.

Evangelista, S.J., Field, D.J., Mc Bratyney, A.B., Minashy, B., Ng, W., Padaria, J., Doberco, M.R., Wadoux, A.M.J.C., 2023. A proposal for the assessment of soil security: soil function, soil services and threats to soils. Soil Secur. 10 https://doi.org/10.1016/j.soilsec.2023.100086.

Field, D.,J., Morgan, C.L.S., Mc Bratney, A.B., 2017. Global Soil Security. Progress in Soil Science. Springer Internat. Publishing, Switzerland.

Geissen, V., Silva, V., Lwanga, E.H., Beriot, N., Oostindie, K., Bin, Z., Pyne, E., Busink, S., Zomer, P., Mol, H., Ritsema, C.J., 2021. Cocktails of pesticide residues in conventional and organic farming systems in Europe: legacy of the past and turning point for the future. Environ. Pollut. 278, 116827 https://doi.org/10.1016/j.envpol.2021.116827.

Holzworth, D., Huth, N.I., Fainges, J., Brown, H., Zurcher, E., Cichota, R., Verrall, S., Herrmann, N.I., Zheng, B., Snow, V., 2018. APSIM Next Generation: overcoming challenges in modernising a farming systems model. Environ. Model. Softw. 103, 43–51. https://doi.org/10.1016/j.envsoft.2018.02.002.

IPCC (Intergovernmental Program on Climate Change), 2023. Climate change 2023. Synth. Rep. https://www.ipcc.ch.

Keesstra, S.D., J.Bouma, J.Wallinga, P.Tittonell, P.Smith, A.Cerda, L.Montanarella, J. Quinton, Y.Pachepsky, Putten, W.H.van der, Bardgett, R.D., Moolenaar, S., Mol, G., Fresco, L.O., 2016. The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals. Soil 2, 111–128.

Koch, A., McBratney, A., Adams, M., Field, D., Hill, R., Crawford, J., Minashy, B., Lal, R., Abbott, L., O'Donnel, A., Angers, D., Baldock, J., Barbier, E., Binkly, D., Parton, W., Wall, D.H., Bird, M., Bouma, J., Chenu, C., Bulter-Flora, C., Goulding, K., Grunwald, S., Hampel, J., Jastrow, J., Lehman, J., Lorenz, K., Morgan, C.L., Rice, C. W., Whitehead, D., Young, I., Zimmerman, M., 2013. Soil security: solving the global soil crisis. Glob. Policy. https://doi.org/10.1111/1758-5899.12096.

Kroes, J.G., Van Dam, J.C., Bartholomeus, R.P., Groenendijk, P., Heinen, M., Hendriks, R. F.A., Mulder, H.M., Supit, I. and Van Walsum, P.E.V, 2017.: Theory description and user manual SWAP version 4, http://www.swap.alterra.nl, Wageningen [online] Available from: www.wur.eu/environmental-reseach.

Lin, H., Bouma, J., Pachepsky, Y., Western, A., Thompson, J., van Genuchten, R., Vogel, H., Lilly, A, 2006. Hydropedology: synergistic integration of pedology and hydrology. Water Resour. Res. 42, WO5301. https://doi.org/10.1029/2005WR004085.

McBratney, A.B., Field, D.J., Morgan, C., Huang, J., 2019. On soil capability, capacity and condition. Sustainability 11, 3350. https://doi.org/10.3390/su11123350.
Millennium Ecosystem Assessment, 2005. Ecosystems and Human well-being: Synthesis. Island Press, Washington D,C. USA.
Lal, R., Bouma, J., Brevik, E., Dawson, L., Field, D.J., Glaser, B., Hatano, R., Hartemink, A., Kosaki, B., Lascelles, B., Monge, C., Muggler, C., Ndzana, G.M., Norra, S., Pan, X., Paradelo, R., Reyes- Sánchez, L.B., Sandén, T., Singh, B.R., Spiege, H., Yanai, J., Zhang, J., 2021. Soils and Sustainable Development Goals of the United Nations (New York, USA): an IUSS perspective. Geoderma Reg. 25 https://doi.org/10.1016/j.geodrs.2021.e000398. June 2021.
Reynolds, W.D., Elrick, D.E., Youngs, E.G., Booltink, H.W.G., Bouma, J., 2002. Saturated and field-saturated water flow parameters. In: J.H. Dane and G.C. Topp (Eds). Methods of Soil Analysis. Part 4: Physical Methods. Soil Science. Society of America Book Series, pp. 797–879. no.5.
Rossiter, D.G., Bouma, J., 2018. A new look at soil phenoforms-definition, identification and mapping. Geoderma 314, 113–121. https://doi.org/10.1016/j.geoderma.2017.11.002.
Schoenholz, S.H., van Miegroet, H., Burger, J.A, 2000. A review of physical and chemical properties as indicators of forest soil quality: challenges and opportunities. For. Ecol. Manag. 138 (103), 335–356.
Smith, P., Soussana, J.F., Angers, D., Schipper, L., Chenu, C., Rasse, D.P., Batjes, N.H., van Egmond, F.G., McNeill, S., Kuhnert, M., Aries-Navarro, C., Olesen, J.E., Chirinda, N., Fornara, D., Willenberg, E., Fuentes, J.A., Sanz-Cobena, A., Klumpp, K., 2020. How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal. Glob. Change Biol. 26, 219–241. https://doi.org/10.1111/gcb14815.
Soil Survey Staff, 2014. Keys to Soil Taxonomy, 12th Ed. USDA-Nat.Resource Conservation Service, Washington DC, USA>.
Stavi, J., Bel, G., Zeedy, E., 2016. Soil functions and ecosystem services in conventional, conservation and integrated agricultural systems: a review. Agron. Sustain. Dev. 36, 32. https://doi.org/10.1007/s13593-016-0368-8.
Van Ittersum, M.K., Cassman, K.G., Grassini, P., Wolf, J., Tittonell, P., Hochman, Z., 2013. Yield gap analysis with local to global relevance: a review. F. Crop. Res. 143, 4–17.
Van Looy, K., Bouma, J., Herbst, M., Koestel, J., Minasny, B., Mishra, U., et al., 2017. Pedotransfer functions in Earth system science: challenges and perspectives. Rev. Geophys. https://doi.org/10.1002/2017RG000581.
Van Tol, J., Bieger, K., Arnold, J.G., 2021. A hydropedological approach to simulate streamflow and soil water contents with SWAT+. Hydrol. Process. 35, e14242. https://doi.org/10.1002/hyp.14242.
Van Tol, J.J., van Zijl, G.M., 2022. South Africa needs a hydrological soil map: a case study from the upper uMngeni catchment. Water SA 48 (4), 335–347. https://doi.org/10.17159/wsa/2022.v438.i4.3977.
Veerman, C., Bastioli, C., Biro, B., Bouma, J., Cienciala, E., Emmett, B., et al., 2020. Caring for soil is caring for life - Ensure 75% of soils are healthy by 2030 for food, people, nature and climate, Independent expert report. Eur. Comm. Publ. Office of the Eur. Union, Luxembourg.
White, J.W., Hunt, L.A., Boote, K.J., Jones, J.W., Koo, J., Kim, et al., 2013. Integrated description of agricultural field experiments and production: the ICASA Version 2.0 data standards. Comput. Electron. Agric. 96, 1–12. https://doi.org/10.1016/j.compag.2013.04.003. , 2013.