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# Soil security as a roadmap focusing soil contributions on sustainable development agendas

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ABSTRACT

Long a rather abstract concept, sustainable development has since 2015 been defined by the United Nations in terms of goals (SDGs), specified by targets and indicators.Soils play an important role in several land-related SDGs by their contribution to ecosystem services that, in turn, contribute to biomass production (SDG2), water quality (SDG6), climate mitigation (SDFG13) and biodiversity preservation (SDG15). These goals have been adopted by the European Union when defining their Green Deal. However, sustainable development will only be achieved when stakeholders adopt appropriate management measures that result in a satisfactory level of all four ecosystem services. Adoption, however, is not only a function of technical considerations but is also highly affected by socioeconomic and even psychological factors. The soil security concept that considers both: “hard”and “soft” criteria, is therefore well suited to act as a roadmap towards a sustainable future, focusing soil contributions to ecosystem services and the SDGs. A storyline is proposed starting with *connectivity,* defining interaction processes among all partners involved in the sustainability debate, followed by *condition,* and *capability* that can be defined by a recently proposed quantitative expression of soil health. *Soil Capitol* expresses soil contributions to ecosystem services in financial terms and thus contributes to *connectivity* when examples show that non-soil contributions are much more expensive. Environmental laws and regulations, expressed by *codification,* ideally link soil performance to societal relevance but the tension between individual desires and societal demands requires modern forms of *connectivity* in terms of willingness to: “joint-learning”, supported by modern communication theory. Following the complete storyline of the 5C’s, as proposed by the soil security concept, can make future soil research much more effective from a societal and political point of view.

## 1. Introduction

Soils receive increasing attention by the international policy arena. For example, the new research and innovation program: “Horizon Europe 2021–2027″ of the European Union with a proposed budget of 80 billion €, is based on five so-called Missions, among them:”Soil Health and Food” (Veerman et al., 2020). These Missions have a particular focus on: *maximizing the impact of EU support to research and innovation, demonstrating its relevance for society and citizens”*. This new focus on Missions reflects a certain frustration with more traditional research that has, according to EU politicians, too often remained invisible and therefore irrelevant to EU citizens. Clearly, the research community is being challenged to rise to the occasion. How to proceed is no less than an existential question, also for the soil science discipline.

Of course, the fact that soils form one of the topics of the Missions implies a welcome correction of the fact that in the past only water, air and nature received particular attention in environmental research while soils were largely ignored. This change does, however, present a major challenge to the soil science profession. This review will argue that the 5 C’s of the soil security concept are an important beacon for the soil science profession to face the challenge ahead for a number of reasons: (i) quantitative and reproducible expressions for the first 3 C’s: soil capability, condition and capital are crucial as contributions to both effective interdisciplinary research and to communication with the policy arena and citizens at large; (ii) the last 2 C’s: connectivity and codification are essential elements to be always added to the first three as they will determine whether or not research will have relevance for society and citizens. So far, major emphasis in soil research (and in many other environmental disciplines) has been on technical aspects as embodied for soils in the first 3C’s. But always considering the complete 5 C’s as a general research framework, would, in the opinion of the author, be essential for future soil research. This does, of course, not exclude the possibility to focus basic research on certain aspects of one of the 5C’s, where existing knowledge is lacking, but the way in which such research fits into the overall picture should always be considered and explained.

The objective of this paper is to explore implications for future soil research when executed in a general context of soil security, by discussing: (i) the overall research goal; (ii) the link with SDGs. (iii) the role of the 5C’s of soil security, and (iv) a discussion on what could

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be a future roadmap for soil security activities aimed at realizing the SDGs.

## 2. What is the overall research goal?

When restricting for now attention to land-based agriculture, there appears to be a research focus on particular farming systems that are considered to be ideal in terms of achieving sustainable development. For example, biological farming that does not allow application of agrochemicals, regenerative farming focusing on natural dynamic processes, circular farming that focuses on local input of resources, precision farming that uses modern technology to fine-tune management procedures to environmental conditions or nature-inclusive agriculture such as agroforestry. This often results in excellent research and highly relevant contributions to the soil management literature, but it also can lead to exclusive claims with even ideological overtones: "my system is best!" It would be preferable to define a general focus based on indicators that would allow an objective environmental evaluation of any particular agricultural production system, allowing comparisons among systems. Of course, the concept of sustainable development would be quite suitable but even though universally embraced, it has remained rather abstract until the UN Sustainable Development Goals (SDGs) with targets and indicators were accepted in 2015 by 193 governments with a committment to deliver by 2030. (https:www.un.org/sustainabledevelopment-goals). The European Green Deal follows closely the UN-SDG approach (https://ec.europa.eu.info/strategy/european-green-deal). We propose, therefore, to apply the targets and indicators of the SDGs when defining different agricultural production systems and the role of soils. Three components, covered by the SDGs, are always important when considering sustainable development: economy, society and environment. Only covering one or two of the three components does not cover the sustainability concept! Although emphasis in this review will be on environmental aspects, the other two will certainly be considered.

## 3. SDGs as a guideline for sustainable development

Soils play an important role when realizing a number of SDGs. Most prominent are SDG2 (zero hunger), SDG6 (clean water and sanitation), SDG13 (climate action) and SDG 15 (life on land). But also SDG3 (good health and wellbeing) and SDG7 (affordable and clean energy) apply. There is no direct link between soils and the SDGs. Soils contribute to ecosystem services that, in turn, contribute to the SDGs (Bouma, 2014; Keesstra et al., 2016). So far, soil scientists have not contributed to defining targets and indicators for SDGs (Bouma et al., 2019) but this can be changed and a link with soil security could then be effective. Ecosystem services can only be defined by interdisciplinary activities involving several scientific disciplines and the challenge for soil science is to generate relevant data and input into the interdisciplinary effort, requiring active participation thereby avoiding indiscriminate " shopping" in soil databases by third parties (Bouma, 2020) .

## 4. The 5C's of soil security in relation to the SDGs

Numerous contributions have been reported to not only define the 5C's of the soil security concept but to also report specific applications (Field et al, 2017 and Richer-de-Forges, 2019). The following discussion of the 5C's is intended to add to this by including soil health, a recent report by the EU Mission Board of Soil Health and Food (MBSHF) (Veerman et al., 2020) and recent literature on land use and interaction processes.

### 4.1. Soil condition

Studying physical, chemical and biological soil conditions has been one of the most common themes of soil research since the start of the science in the 19th century. In recent years the need for a specific measure of a given soil condition, to be obtained by operational indicators, has been increasingly evident, considering that other environmental disciplines covering water, air and nature developed such indicators while soil indicators were lacking. Soil quality has been studied for many years but these studies have not resulted in a standard operational procedure to be applied everywhere (Bünemann et al., 2018). This has not been changed by the recent shift to soil health that can be used as a measure to express a given soil condition. Numerous indicators for soil health have been defined but combining them into a single indicator for soil condition has so far been elusive (Moebius-Clune et al., 2016; Norris et al., 2020; National Resources Conservation Services (NRCS) of the US Dept, 2019). Of course, the common "one-out, all-out"system allows distinction between healthy and unhealthy soils but with up to 30 indicators in most systems, hardly any soil will qualify anymore as being healthy. Also, these various indicators have different significance and importance. Recently, a proposal has been made to define a limited number of soil health indicators for agricultural soils based on characterizing the root environment and to obtain an integrated expression by applying a soil-water-atmosphere-plant simulation model, fed, in fact, by the soil health indicators (Bonfante et al., 2020). A unique advantage of modeling, aside from producing a single soil health number, is the opportunity to explore effects of climate change, considering IPCC (Int.Panel of Climate Change) scenarios up to the year 2100. The modeling method distinguishes plant physiological concepts that allow a quantitative and reproducible scientific focus, such as Yp which represents the potential yield of a given crop as determined by climate conditions in terms of radiation and temperatures, assuming that water and nutrients are adequately supplied and pests and diseases don't occur; Yw= water-limited yield, like Yp but now the actual soil water regimes are considered. Finally, Ya is actual yield. A soil health index for a given soil is obtained by: (Ya/Yw) x 100. (Bonfante et al., 2020; van Ittersum et al., 2013). Of course, Ya is not only determined by soil processes even though they play a dominant part. Still, the analysis also allows an independant evaluation of several soil degradation effects such as erosion and compaction, while also effects of a hypothetically increased organic matter content can be explored (Bonfante et al., 2020). This procedure also allows a distinction between actual soil health for a given soil at a given time and for inherent soil quality expressing the range of soil health values that a particular soil can possess at different locations as a function of management, as expressed by phenoforms (Rossiter and Bouma, 2018). Soil classification focuses on constant or stable soil features and should, therefore, not change following different short-term management practices. But these practices cannot be ignored when considering land evaluation and that's why phenoforms are distinguished linking soils with land use objectives.The modeling procedure also allows comparions among soils in regions, countries and the world at large (Bonfante et al., 2020). Finally, a clear distinction between the soil quality and soil health concepts is desirable as both terms are now used without indicating differences between the two terms, causing confusion.

### 4.2. Soil capability

This dimension recognizes that different types of soil have different possibilities to contribute to a range of ecosystem services, that, in the context of this paper, relate to SDGs. "a clay can never function as a sand"; it has different capabilities. In this context, Yw would be a proper measure for soil capability, as it reflects not only climate conditions but also the soil moisture regime while it makes the reasonable assumption that management will supply adequate nutrients and will avoid pests and diseases. In fact, Yp is the same for all types of soil in a given area! As Ya/Yw will usually be lower than 100, the practical question will arise as to what type of soil management is needed to raise Ya. Traditionally, emphasis has been on agricultural production (SDG2), Prices for agricultural products determine whether or not farmers can thrive. But in the SDG context also, SDGs 6,13 and 15 are relevant and whether or not these goals are achieved is a function of good soil management, that will be different for different soils in different years. Reducing fertilization rates by precision techniques can avoid pollution of ground- and surface water (SDG6); increase of organic matter contents of soil can be achieved by applying manure, compost or applying green manure or suitable cover crops (SDG13). Biodiversity (SDG15) can be increased in the soil by higher organic matter contents and in fields by suitable crop rotations or forms of agroforestry. This represents services to society for which the farmer receives no payments and this needs to be changed (see codification section).

### *4.3. Soil capital*

Placing a value on assets that contribute to human wellbeing can be effective to “secure” an asset, such as a soil. Assets with high values are likely to be less challenged than the ones that are considered to have lower values (Robinson et al., 2009). But values are not only determined by the production of food, which is the only one ecosystem service directly linked with markets and financial yields, but also by other provided ecosystem services. Dominati et al. (2016) have made pioneering calculations for New Zealand soils to illustrate this principle. Comparing two soils, the Horotiu silt loam and the Te Kowhai silt loam, they showed that when considering 14 ecosystem services, the first soil yielded 16,415 $/ha/yr and the second 12,144 $/ha/yr. Of these amounts only 4795$ and 3620$ related to the value of agricultural products, demonstrating that only 25% of ecosystem services provided were financially compensated for the farmer. Calculations compared services provided by soils with technical alternatives with the same results. For example, removal by soils of N and P and pollutants was compared with the cost of constructing reed-wetlands used for purification purposes. Obviously, the soil is a lot cheaper. This would also apply when comparing carbon capture by soils with removing CO2 from factory stacks or burrying it in the subsoil: a promising future topic for soil research! Even though the technical alternatives being presented sometimes stretch the imagination, they clearly illustrate the societal value of soil in addition to the well known production function. Such calculations are very important to illustrate otherwise rather abstract soil contributions to ecosystem services: money talks!

### *4.4. Connectivity*

Connectivity is concerned with the decision making of the people that manage land (Field et al, 2017), as determined by many socioeconomic factors and forms of communication: (i) the economic relation with markets: how to produce the right products at the right time; (ii) the relation with the research community, picking the right advise from an ever increasing amount of data, accessible from internet, (iii) the relation with citizens that act not only as critical consumers but some of them also as active and vocal members of environmental action groups, violently questioning modern forms of agriculture, and (iv) adopting management to changing environmental rules and regulations . How to devise a trajectory that satisfies all these often contrasting requirements and demands? How to communicate the right things at the right time the right place to the right person? Recent discussions in Europe in the context of the Soil Health and Food Mission, mentioned above (Veerman et al., 2020), focus on the need to first select enterprises, particularly farms, that operate in an economically viable manner and that deliver a range of ecosystem services, relating to food and water quality (SDG2,6), climate mitigation (SDG13) and biodiversity preservation (SDG15) in ways that seem to satisfy environmental threshold values. Such “lighthouses” or:”Living Labs” can be the basis for continuing onsite research focused on documentation of the ecosystem services by measurement and monitoring (such data are often not available) and by fine tuning and testing current and alternative management procedures. Joint learning between land users and scientists is essential to allow this process to evolve into productive procedures. Favorable results are to be communicated in two ways: first to colleague land users and second to the public at large that is currently exposed to much negative publicity about modern agricultural practices. Communication to colleague land users can be facilitated by modern Decision Support Systems but also interpersonal communication in study groups remains very important (Schulte et al., 2019; O'Sullivan et al., 2017; Ingram et al., 2010; Reed, 2008; Bouma, 2018). Modern communication using social media is needed to reach the public at large and will require professional assistance.

Effective connectivity between the various participants in the societal debate is crucial to achieve the SDGs in future. If the research community stays within its bubble, if the public cannot be convinced to move beyond sterotype ideas about food and agriculture, the SDGs may remain elusive. That leaves the role of the government, expressed by codification.

### *4.5. Codification*

Codification acknowledges the need for government policy and regulations to ensure that environmental quality is established and maintained. Such policies always strongly affect soil management. Problems encountered when initiating and enforcing a particular regulation will be discussed analysing the EU Water Framework Directive (2000/60/EC) that defines critical limits of N and P content of ground- and surfacewater. Ground- and surfacewater quality was below standard in the Netherlands in the 1970′s and therefafter (Bouma, 2011, 2016) Nitrate concentrations in groundwater were higher than 200 mg/l in sandy soils with general legal thresholds of only 50 mg/l. Also surface water concentrations of N and P were higher in several locations. This was due to high fertilization rates with manure and chemical fertilizers just focusing on production and ignoring environmental side effects. The Framework Directive defined means to improve water quality by requiring maximum application rates of 170 kg N, derived from manure. This was successful in reducing nitrate levels in groundwater for most areas in the Netherlands. However, once a rule has been established it turns out to be difficult to change it. Increasingly, farmers would prefer to have clear goals, as shown by indicators for water quality, to be reached by their own favorate form of management. This not only would refer to water quality but also to the release of greenhouse gasses and ammonia, carbon capture in their soils and biodiversity, the latter probably expressed in a regional context. A possible shift to clear goals to be faced by each farm, is facilitated by the development of new measurement and monitoring equipment based on proximal and remote sensors (Viscarra Rossel et al., 2010). Progress in realizing sustainable development will be hampered when governmental rules and regulations don't shift from emphasizing means to reach environmetal objecties to defining clear indicators for such objectives in terms of ecosystem services. This will allow land users to mobilize their creativity.

## 5. A future roadmap

Linking soil condition, - capability and – capital to soil connectivity and – codification, as a key element of the soil scurity concept forms a solid and unique base to develop pathways to sustainable development. Just considering the first three C's is scientifically interesting and can be the source of excellent publications but is inadequate to reach sustainable development in the real world that requires genuine commitment and engagement by stakeholders and the policy arena which operate in a different environment than the research community. On the other hand, only input by the last two C's is ineffective as well because without hard data, actions defined by the last 2C's are likely to remain speculative and inconclusive when not supported by soil science expertise. The question remains as to how to proceed. A storyline was proposed linking the five C's (Bouma, 2019). With a slight modification: *Considering a given type of soil, how and by whom is the soil being managed? What are user goals and their questions? Which outside forces affect management* *("connectivity")? What is the soil "condition" in terms of its health and its contributions towards ecosystem services and what might potentially be possible? ("capability"). How does this soil compare with other soils in terms of its contributions ("capital") and are its condition, capability and capitol properly addressed in societal and legal frameworks ("codification")?* This storyline approach corresponds with a proposal Bouma (2020) to also frame our soil discours more in terms of:" every soil has a story to tell and it's up to soil scientists to listen, observe and measure and try to express this magnificent story in primitive human language"

This line of reasoning has at least two implications:

(i) Start with a focus on land use systems and its farmers as discussed in Section 4.4. A modern farmer is confronted with multiple challenges: he has to deliver products to the market place and do so in a way that is financially sustainable. At the same time he has to deal with requirements of laws and regulations, among them environmental ones on water quality and biodiversity. Most likely rules will follow in future relating to carbon management in the context of climate mitigation. A farmer is like a juggler in the circus, trying to keep five balls in the air at the same time. Interviews with 473 farmers in the European LANDMARK project (Schulte et al., 2019) showed common concerns about adverse climate conditions, too strict environmental policies and, most important, declining incomes. Farmers requested better access to reliable knowledge on soils to be shared with them by independant experts, rather than by commercially motivated "advisers". They prefer personal interaction over operating clinical Decision Support Systems on internet. Comparable results were obtained by an inquiry in the Netherlands (https://youtu.be/AdNrijtP6yg) and by student research in the context of a challenge by Wageningen University focused on "Making all soils healthy again". (www.wur.eu/soilchallenge). It seems, though, that by now a limit is reached when approaching stakeholders. Their opinions are clear and it is time now to act. The research community should not continue to follow the political agenda:*"tell me where my people want to go so I can lead them!"*

To take a next step the EC Mission Board of Soil Health and Food (MBSHF) (Veerman et al., 2020) has advised to establish Living Labs on farms where, following particular forms of management, a range of ecosystem services is provided that are evaluated based on thresholds defined by legislation. When they meet all thresholds such farms can become "Lighthouses"! Working with farmers in a joint-learning mode, soil health can be established with methods described above and innovative measurements can be made documenting the degree to which ecosystem services in terms of water quality, greenhouse gas emissions, carbon capture and biodiversity preservation are met. There are many claims by several types of farming systems but measurements of ecosystem services are often lacking and this muddles debates.

There is one additional advantage to focus on measuring ecosystem services: means-based rules and regulations can be changed into goal-based procedures: thresholds for water (SDG6), greenhouse gass emission and carbon capture (SDG13) and biodiversity (SDG15). SDG2 on food is dealt with by market forces. Different production systems can now be characterized by objective means and compared. Farmers would really like that.

The shift to on-farm research is controversial to some. Would this type of "applied research" not lead to less "basic" research, thereby devaluating the soil science profession? The author does not believe this. We should acknowledge that much soil information is already available after a hundred years of research. When we are candid, we have to admit that we know quite well what to do about various forms of soil degradation. But.. it is not being done and that's why the MBSHF still claims that 60% of European Soils are unhealthy for various reasons, despite all that research. Claims based on the 60% number are attractive when asking for financing research but if we don't change our still rather disciplinary, silo-research, into an interdisciplinary and transdisciplinary approach, there is little perspective for change. Asking for fonds in 2025 may then be quite a bit harder. Besides, the plea to first apply existing knowledge and then base new research on gaps that show up when doing so(and there will be numerous gaps), leaves much room for new research that is bound to be more effective than when it is only "curiosity driven". This: "focused curiosity driven" approach will also be attractive to the policy arena and the public at large.

(ii) stop for a while asking stakeholders what they think and desire. We have a good idea about that by now. Focus on what can be done about their questions in the real world, a new focus for "connectivity". This needs more emphasis in our professional deliberations in the near future. Some suggestions: (a).Changing rules and regulations from a means-based approach to a "goal-based"approach as discussed in Section 4.5. (b). improve knowledge transfer from the research to the stakeholder arena. Beautifil folders, flashy video's and computer systems cannot replace personal interaction with specialists with inter- and transdisciplinary expertise. We need to educate such specialists. (c) explore real possibilities to ensure financial sustainability of entrepreneurs dealing with soil. For example, in Europe, 350 billion € will be available in the period 2021–2027 for the Common Agricultural Policy and the new Green Deal of the EU intends to spend at least 40% of its substantial funds on climate issues. Carbon capture by soil is therefore a top issue not only for research, as it is already right now, but also for farmers who could request funding to increase the%C of their soils. A case can be made for payment of ecosystem services but farmers will need guidance by the research community and by lawyers to frame their request in an effective format. Of course, conditions for finance will not be so positive in other continents but possibilities to reward farmers for ecosystem services provided to society are relevent everywhere. (d) apply modern communication techniques, framing and presenting well documented succesful examples of sustainable agricultural enterprises as a counterweight to negative tendensies by some environmentalists and members of the press framing agriculturalists as environmental villeins. Farmers suffer from this and feel helples to cope. There is a real job to do.

## Declaration of Competing Interest

No conflict of interest.


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