soil systems

Review

Assessing the Role of Soils When Developing Sustainable Agricultural Production Systems Focused on Achieving the UN-SDGs and the EU Green Deal

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Abstract: The general concept of sustainable development has been specified in terms of goals, targets, and indicators by the UN Sustainable Development Goals, adopted in 2015, followed by the Green Deal of the European Union in 2019. The focus on targets and indicators does, however, not address the issue as to how these goals can be achieved for land-related SDGs in the real world, and attention in this paper is therefore focused on how land management can contribute to providing ecosystem services in line with the aims of the SDGs and the Green Deal. Agricultural production systems should at least produce healthy food (SDG2 and 3), protect ground- and surface water quality (SDG6), mitigate climate change (SDG13), avoid soil degradation, and support biodiversity (SDG15). The corresponding ecosystem services are discussed with particular emphasis on the role of soils, which are characterized in terms of soil health, defined as: *contributing to ecosystem services in line with the SDGs and the Green Deal.* Appropriate management, as developed and proposed by researchers working jointly with farmers in living labs, can only be realized when it is part of sound long-term business plans, supported by independent advice that is focused on farmers' concerns based on the requirements for adaptive management. The research effort in living labs, addressing "wicked" problems, needs to be judged differently from classical linear research. As the development of successful ecosystem services requires an interdisciplinary research effort based on a systems analysis, SDG-oriented soil research in the future should be focused on: (i) presenting suitable data to the interdisciplinary effort beyond standard data to be found in existing databases; (ii) using soil types as "carriers of information" to allow extrapolation of results; (iii) providing data with a comparable degree of detail when analyzing the various ecosystem services, and (iv) revisit past experiences in soil survey and soil fertility research when contact with farmers was intense, as is again needed in future to realize ecosystem services in line with the SDGs and the Green Deal.

Keywords: ecosystem services; UN-SDGs; EU Green Deal; soil health; transdisciplinarity

1. Introduction

The iconic Brundtland report of 1988, "Our Common Future", has been instrumental in emphasizing the urgency to put the issue of sustainable development on the international policy agenda. The need to not only focus on separate economic, societal, or environmental issues when dealing with societal developments but on a challenging, integrated approach of these three issues has changed the sustainability discourse. The introduction of 17 Sustainable Development Goals by the General Assembly of the United Nations (https://sdgs.un.org (accessed on 28 June 2021)), approved by 193 countries in 2015, provided a welcome focus for the effort that was, in essence, also followed by the Green Deal of the European Union of 2019 (https://ec.europa.eu/greendeal (accessed on 28 June 2021).

Several SDGs are strongly affected by soil conditions and processes [1]. When focusing on agriculture, primary attention should not only be on the traditional role of producing healthy food (SDGs2 and 3), but also on maintaining a suitable quality of ground- and surface water (SDG6), on limiting greenhouse gas emissions, and increasing carbon capture for climate mitigation (SDG13) and on avoiding soil degradation and preserving biodiversity supporting life on land(SDG15). In addition, energy use (SDG7) and sustainable production and consumption (SDG12) are relevant. In other words: a need for multifunctional land use. In turn, contributions to each of these SDGs can be expressed in terms of services provided by ecosystems to mankind ("ecosystem services"), as proposed by the Millennium Ecosystem Assessment of 2005 (https://www.millenniumassessment.org (accessed on 15 June 2021)) Four types of ecosystem services are distinguished: (i) provisioning (e.g., production of food or clean water); (ii) regulating (e.g., control of climate or disease); (iii) supporting (e.g., nutrient cycling); and (iv) cultural (e.g., heritage, recreation). Man is only a preferably humble recipient of these services that can only be provided if appropriate land management is applied.

Each SDG is specified by targets and indicators (https://unstats.un.org/sdgs/metadata (accessed on 10 June 2021). These targets and indicators are intended to apply worldwide and are general in nature. For example, see the following targets: *"end hunger, universal access to clean water; integrate climate change measures in national legislation, restore degraded land . . . ."*. All to be achieved by 2030. Next, Indicators have to show by % to what extent these targets have been reached. The UN agreement on SDGs does thereby not address operational methods and procedures by which these targets can be reached in the real world. This is a gap, and without the development and introduction of appropriate management measures, the goals may remain "lofty". With regard to the role of soils, this problem can be addressed by a focus on methodology to characterize and improve soil functions contributing to ecosystem services that, in turn, are linked with the SDGs, with particular attention to the role of soil management [2,3]. So far, soil scientists have not been involved when defining SDG targets and indicators [4]. The aim of this review paper is to stimulate an active engagement of the soil science community based on a practical focus on realizing a set of ecosystem services by developing successful soil management practices. Where to start? Turning attention to realizing the SDGs will only succeed when land users embrace management procedures that result in providing multiple ecosystem services. The record in Europe is not good. A total of 60–70% of soils in the EU are degraded for various reasons that inhibit the provision of significant soil contributions to ecosystem services [5]: pollution by chemicals, poor soil structure due to compaction, depletion of soil carbon leading to low biological activity, loss of biodiversity and occurrence of erosion. However, these processes have been studied for decades by soil scientists and proposed alternative forms of soil management have apparently not been convincing to most farmers lacking convincing evidence for more efficient use of production factors and more robust and reliant business models [6,7]. Therefore, when aiming for sustainable agricultural production systems, new research approaches are needed to engage farmers, a broad conclusion that applies way beyond the soil science discipline [8]. Questions and demands by farmers as well as the drivers for their options and mechanisms that foster or restrain change need serious attention, and research on such questions needs to be integrated into soil science research if science outcomes are to support the needed changes in management [9].

To offer an alternative approach to developing effective management procedures, research is proposed in living labs (LL), where scientists and farmers work jointly to develop and implement innovative management systems aimed at realizing a set of optimized ecosystem services [5]. "Lighthouses" demonstrate successful efforts in terms of suitable practices. In LL's soil, scientists need to work with colleagues in agronomy, hydrology, climatology, ecology, economics, sociology, and others, all members of an interdisciplinary team. The concept of living labs is not new. For example: The ENoLL represents the European Network of Living Labs (https://digital-strategy.ec.europa.eu (accessed on 10 July 2021), and DESIRA describes 20 LL's in different European countries. (https://desira.2020.eu (accessed on 10 July 2021). Successful studies have been reported on the farm level in the context of the LANDMARK program [10,11], emphasizing soil functions [12] but with as yet not a link with SDGs. In the LL context, a new approach is proposed for LL's in which land users work with scientists on realizing ecosystem services. [5] and they introduce the concept of soil health as a guiding principle for soil science, defined as: "*the continued capacity of soils to contribute to ecosystem services in line with the SDGs and the Green Deal*". This definition emphasizes soil contributions to achieving ecosystem services in an interdisciplinary context.

In summary, the objective of this review paper is to explore: (i) the farmer perspective as a guiding principle when developing sustainable agricultural production systems; (ii) the development of an operational approach toward the provision of ecosystem services, to be provided by Living Lab research, as a contribution toward the realization of land-related SDGs (iii) the position of soil science in an interdisciplinary context; and: (iv) implications for future research and environmental rules and regulations.

2. The Farmer Perspective as a Guiding Principle

Modern farmers face major challenges when confronted by multifunctional land-use demands, discussed above. They have to react to largely unpredictable weather and economic and regulatory conditions that govern their operational, tactical and strategic management. Operational management refers to daily scheduling, while tactical management covers seasonal plans, and longer-term strategic management is often associated with the write-off of substantial capital investments [13]. Multifunctional management by farmers is considered by some to be nearly impossible under current conditions [13]. However, if this would be true, how realistic is it to aim for multifunctional management to reach the lofty goals of the SDGs and the Green Deal? But we do not have the luxury to stop attempts to realize multifunctional management, which is crucial for sustainable development [14]. When exploring possibilities for multifunctional land use, we should therefore interact more closely with farmers internalizing their concerns and starting from there. A review of the literature indicates farmer's views on the future [13,15–20]. In summary, some items dominate: (i)Serious concerns about low prices at the farm gate and their economic future; (ii) confusing top-down environmental regulations reflecting a basic lack of understanding practical conditions; (iii) lack of independent advice that makes it difficult to assess the value of new management approaches, thereby strengthening existing path dependencies; (iv) worries about climate change. The recently introduced concept of soil security links the "hard" technical aspects of soils (condition, capability, capital) to the more "soft" aspects (connectivity and codification), and this reflects farmers' views, as mentioned here [21]. Elements of soil security can be well related to the UN-SDGs and are, therefore, a significant contribution to the study of sustainable agriculture [22].

The four views by farmers can be discussed in more detail as follows:

Ad(i) At least 30 actors were directly or indirectly engaged with sustainable soil management, and actors have widely different views [21]. Economic considerations were dominant for farmers in The Netherlands when discussing sustainable management., while others emphasized environmental conditions or various technical aspects in the food chain. Prices of agricultural products are low, which is partly due to world-market surplusses and to the supermarket cartel focusing on low consumer prices. Recommendations to raise consumer prices are hardly realistic, and not all farmers can produce "niche" products that fetch higher prices. Even though climate change may lead to food shortages within a few decades and higher prices, this is of no support at present. However, the provision of ecosystem services following particular forms of effective management for different types of soil (to be adopted from literature or to be developed at living labs) can and should be expressed in financial terms as they represent so far “free” services to society. Why should society only pay for the production of healthy food? Current conditions represent, in fact, a “tragedy of the commons”. Payments for achieving effective multifunctional land use represent a service to society by delivering a set of ecosystem services, and that is as yet not covered. Such land-use acts de facto as a life insurance policy for society and is therefore fundamentally different from governmental subsidies for, e.g., steel producers or airline companies. The Common Agricultural Policy of the EU for the next years (2021–2027) is considering allocating part of its funds to pay for ecosystem services. While this is a positive strategic development that could represent an important future financial impuls, the national implementation plans to guide CAP application in the member states is still under preparation and risk lagging behind the intended goals.

Ad(ii) In Europe, the EU Water Guideline [23] already presents legal indicators with threshold values for water quality, requiring certain management practices. This has offered problems for farmers because practical implications of proposed rules and regulations were insufficiently considered. Rather than focus on direct measurements of water quality, required management measures were introduced, such as maximum fertilization rates of 170 kgN/ha, ignoring different processes in different soils, and possible favorable effects of split applications of fertilizers. In addition, costly application methods of manure involving injection of manure slurry were prescribed without clear data on N-deposition in nature areas, the reason for this measure. Nature quality is not only determined by nitrogen deposition as climate change also has an increasing impact [24]. In the future, direct measurements of greenhouse gas emissions, carbon contents of soils, and assessment of biodiversity should be preferred over prescriptions of certain forms of management. Direct bottom-up involvement of land users when developing such indicators is therefore essential to facilitate a smooth introduction.

Ad(iii) Farmers often receive advice with a commercial focus. This often leads to less efficient farm use of resources, as commercially attractive but costly solutions are adopted [25]. Independent advisory needs to be anchored on scientific knowledge, permanently up to date, and detached from the supply of production factors. Furthermore, it requires novel approaches in research so that it replies to the complexity faced by farmers and evolves according to such complexity.

An example of suitable advisory practices was described in Italy [26], where farmers suffered from drought and were besieged by advisers that either promoted drought-resistant crop varieties or smart irrigation equipment. The study showed different reactions of different soils as a basis for making rational choices. Farmers welcomed these results as they did not provide a single recommendation but, rather, a series of “options” from which a rational choice could be made. This approach, in line with real-world problems and complex decision processes by farmers, deviates from classical linear research where a question is defined and where a specific solution is worked out based on a selected methodology, leading to the outcome of one single pathway to be applied in practice. Research for multifunctional land use faces “wicked” problems and can only define a series of land use “options” as conflicting demands for different ecosystem services require tradeoffs [8,27]. Farmers have to make choices that reflect their personal farming style. So far, the dominant scientific discourse on judging research still follows the linear approach. Within this approach, research results obtained in living labs may not be considered scientifically convincing due to a lack of replicates allowing statistically significant conclusions. However, every farm and even every field in a Living Lab is unique, and it will never be possible to have “exact” replicates in the real world. However, if we focus on the exact measurement of indicators defined for each of the ecosystem services concerned, each one with sufficient replicates and spatial coverage to be scientifically sound, then scientific quality can be achieved in the Living Lab context. Many measurement techniques are available [28]. Furthermore, management can best be communicated by producing "storylines" that are more effective as a communication tool than data as such or abstract, sophisticated models [29].

Ad (iv) Effects of climate change are already present in terms of extended dry periods and heavy showers, but future scenarios of the International Panel of Climate Change (IPCC) are quite alarming as many areas in the world will become too dry and hot for agriculture in future while fertile soils near rivers and seas may flood due to sea-level rise. (IPCC, 2020: Climate Change and Land—www.ipcc.ch (accessed on 10 July 2021)). The Mediterranean basin will be highly impacted with severe reduction in water availability and an overall increase in average temperature, affecting many production systems, not least the most recent intensive permanent cultures of wine, olives, and dry fruits [30].

Within a few decades, this could be favorable for farmers in northern latitudes with moderate climates, but "green" colored areas in Northern Canada, Greenland, and Siberia cannot contribute to food production if only because there is no infrastructure. Only simulation models can provide valuable exploratory data on future effects of climate change. So far, surprisingly few studies have been made focusing on soil and the effects of climate change [31–33].

Most important: multifunctional land use can only be realized when farmers are enabled to develop sound business plans, including a realistic strategic compound. These strategies need to be worked out jointly between researchers and farmers so that requirements for the needed ecological transition are assessed for each different context and each farm situation. If the research and regulatory arenas will ignore this need and keep following their own scenarios, any attempt to reach multifunctionality in the future is doomed. Let us be candid: if farmers, all farmers, do not team up with the long parade of experts and policymakers, the emperor will wear no clothes.

3. Ecosystem Services

A number of crucial ecosystem services in which soil contributions play a major role can be distinguished to reach the land-related SDGs discussed above. The following ecosystem services are relevant:

3.1. Ecosystem Services Contributing to Production of Healthy Food

Obviously, producing healthy food (which is already a simplification of the original titles for SDGs2 and 3: *zero hunger and good health and well being,* respectively) has a much broader scope than primary production on land as agronomic and economic aspects play a key role, but a focus on primary production is justified in this discussion about soils. Soils provide water and nutrients and an aerated environment to plants, and soil structure should be such that roots can reach a depth that corresponds with their genetic character. Soils should also be free of chemical pollutants and contain sufficient organic matter and nutrients.

Soil conditions are described by the soil health concept with a limited number of indicators that are focused on conditions that address and directly affect root growth [5]: (i) lack of excess chemical pollutants and salts; (ii) adequate carbon stock; (iii) favorable soil structure; (iv) favorable soil biodiversity, and (v) adequate nutrients. In contrast to other soil health programs [34–36], a limited number of indicators has been proposed for operational reasons. Defining 20 or even 30 costly indicators that require time-consuming laboratory measurements hardly allows effective operational procedures. Indicator (v) is quite variable for fertilized agricultural soils during the year and widely used fertilization programs, based on soil sampling, define this indicator. The other indicators still need research defining innovative methodology and characteristic threshold values for different soils.

When considering the role of soils when contributing to ecosystem services aimed at the primary production of food, a number of issues need attention:

(i) Polluted soils are a major source of polluted food and should be excluded from food production. This includes the need for reliable threshold values for the various pollutants and more information on the uptake process of pollutants by plant roots [1].

Assessing the occurrence of soil pollution and its effect on food quality is a key contribution of soil science to ecosystem services contributing to the production of healthy food [37–39].

(ii) Soil scientists should work together with agronomists and hydrologists to characterize the dynamic character of the soil-moisture-nutrient system contributing to plant growth. Widely available and well-tested simulation models of the soil-water-atmosphere-plant system [40–42] are ideal vehicles to realize interdisciplinary cooperation focused on important societal issues such as water management [43]. Such models also allow an estimate of the specific effect of soils on primary production as they can distinguish between potential production Yp (determined by radiation and temperature assuming the optimal supply of water and nutrients and absence of pests and diseases), water-limited yield (Yw) as Yp but expressing the effects of real soil water regimes and Ya = actual yield. A real yield corresponding with approximately 80% Yw is considered as a realistic threshold for primary production [44–46]. Simulation models are instrumental in assessing the role of (non-polluted) soils with different degrees of degradation in achieving primary production. Italian studies have shown the specific effects of compaction, erosion, and varying organic matter contents on Yw [31–33]. They also proposed to simulate such a range of Yw values for a given soil type, which is characteristic for any given soil, as a measure of soil quality while soil health reflects the actual condition of a given soil at a given time in accordance with the suggested indicators, discussed above. This distinction would be welcome if there is now a confusing mixed use of the terms soil health and soil quality. The contribution of soil data to interdisciplinary modeling studies will be discussed later in more detail in the section on soils acting in an interdisciplinary context.

In summary: soil contributions to ecosystem services aimed at SDGs2 and 3 focus on: (i) defining and excluding polluted soil with particular attention to the uptake process by plants; (ii) contributing appropriate soil data to interdisciplinary simulation models for the soil-water-atmosphere-plant system; and (iii) assessing primary production levels using an 80%Yw threshold value for that particular region.

3.2. Ecosystem Services Contributing to Clean Water and Sanitation

The combination of clean water and sanitation in SDG6 may be surprising at first sight, but it does reflect the important function of soils to filter, adsorb and oxidize organic and inorganic pollutants, thereby purifying the liquid waste or rainwater as it moves downwards through the soil. Different soils have different capacities to adsorb chemicals because of different textures and organic matter contents, but also flow rates are important. Purification only occurs during unsaturated flow when travel times are relatively low, increasing the contact time between the percolating liquid and the soil particles while larger pores are filled with air [47]. In contrast to other SDGs, threshold values for ground- and surface water quality have been defined by legally binding regulations at the EU level, as discussed above. Surface water quality can be negatively affected by the erosion of surface soils. Simulations of soil-water-nutrient dynamics can result in recommendations for optimal application regimes of fertilizers or biocides aimed at minimizing leaching, maximizing uptake of fertilizers, and improving the efficiency of biocides. This has been applied in studies on precision farming where (in addition to protecting groundwater quality) savings of up to 25% of fertilizer and biocide expense were achieved applying site-specific precision management [48]. This is important for farm management as cutting costs is as important as increasing yields in determining net income. Finally, many studies have been made to combat erosion by management measures, such as a permanent vegetational cover of surface soil or tillage that results in soil structure allowing adequate infiltration of water into the soil.

In summary, soil contributions to ecosystem services aimed at SDG6 focus on defining soil-specific precision application regimes of agrochemicals and fertilizers that reduce pollution of ground—and surface water and optimize plant uptake. Each soil type has different optimal water- and nutrient regimes, illustrating that soil types are suitable "carriers of information". In addition, combating erosion can contribute to lower pollution of surface waters.

3.3. Ecosystem Services Contributing to Climate Action

The term: "climate action" for SDG13 covers a wide spectrum of issues and possible activities covering both climate mitigation and adaptation. Restricting attention to soils, carbon capture by soils is seen as a significant climate mitigation measure. All soils in the world contain approximately 1500 Gt of carbon, which is twice as much as carbon in the atmosphere and three times as much as carbon in all vegetation. French scientists have proposed their: "4per1000" proposal at the climate conference in Paris in 2015, suggesting that only a small yearly increase in soil carbon of 0.04% could mitigate carbon emissions on the world level. Many publications have appeared about the feasibility of this proposal [49]. An excellent recent review on carbon capture and emission of CO_2 was presented [50]. They suggest developing an MRV platform, defining standard procedures for measurement, reporting, and verification because now many different procedures and models are used in different countries as the research effort expands rapidly. Research focuses on measurement and modeling methods for organic matter capture and greenhouse gas emissions, where proximal and remote sensors offer new measurement opportunities. Methodologies and data for greenhouse gas emissions for Dutch conditions are already presented [51].

Among the suggestions of [50] is the use of soil surveys at different points in time to document changes in organic matter contents. This may be difficult because changes take many years to materialize. An example from Switzerland is, however, presented [52], where this has been done for a 30-year period. They report an increase in %C but only after the year 2000 when legislation was introduced requiring cover crops and minimum tillage. These results not only show the feasibility of carbon capture by soils but also the impact of appropriate legislation.

But soil maps can also be used in a different way focusing on particular soil types and document the effects of different forms of long-term land use on organic matter contents. Thousands of defacto experiments are waiting to be discovered out there in the field, as shown for major clay soil in The Netherlands [53], followed by a study for a major sandy soil [54]. They could relate current % organic matter to past and present land management with a surprisingly high correlation. The range of organic matter contents was 1.7% to 5.0% for the clay soil and 4.8% to 9.1% for the sand soil, corresponding for both soils with conventional arable land and permanent grassland, respectively. These ranges of % organic matter as a function of land use are characteristically different for the two soils (and for different soils in general), and this type of analysis can be useful to define a pragmatic first approach establishing the range of organic matter contents in a given soil type as a function of management, followed by defining a threshold value. Management that has resulted in exceeding the threshold for that particular type of soil could be recommended for that particular type of soil, recognizing that carbon transformation processes are dynamic balancing input and output of carbon from the soil system. Relatively high contents can only be maintained when organic matter is continuously applied by (green) manure, crop residues, or compost. Results discussed relate to soils in moderate climates. Increasing the organic matter content of soils in arid regions may be more difficult, although some promising results have been reached by applying agroforestry.

In summary, soil contributions to ecosystem services aimed at SDG13 focus on organic matter contents of soil and the generation of greenhouse gases that can be measured and estimated by modeling. Different soils vary in their capacity to adsorb CO2 as a function of past management. Only soils low in carbon offer potential for an increase. Threshold values for organic matter content can be defined for different soils, and this can be the basis for a pragmatic approach to defining suitable management schemes that not only define management increasing carbon contents above the threshold but also management that maintains such contents. One may question whether the rapidly expanding and highly fragmented research field of soil carbon dynamics, focusing on basic processes, will result in relatively simple, operational methodologies. The latter will be crucial to realize adoption in practice, which, in turn, will determine whether or not the emphasis in the EU-CAP on payment for ecosystem services will be achievable.

3.4. Ecosystem Services Contributing to: Life on Land

The SDG15 focuses on a large number of broad goals that all involve soils, among them: to halt and reverse land and forest degradation, desertification, and biodiversity loss and preserve landscape heterogeneity and functionality, as well as the cultural heritage in each region. There is a clear link with the SDGs2, 3, 6, and 13 because adequate ecosystem services, discussed in that context, provide specific contributions in terms of suitable water quality and carbon capture and reduction in greenhouse gas emissions that are important for, among others, biodiversity [55]. However, there is a strong link with management procedures and policy issues, all of them with not only a local but also a landscape and regional character. This also applies to the EU Green Deal [56]. The biodiversity issue can, however, directly be related to individual soils as living soils are more biologically diverse, having higher organic matter contents. The soil health indicator (iii) is therefore useful as a proxy value for soil biodiversity. Testing soil health at particular locations is important when assessing SDG15 issues because positive indicators are a contribution to achieving effective ecosystem services that for SDG15 relate particularly to providing favorable soil conditions supporting vital natural vegetation. Here, indicator (v) covering soil fertility has a different meaning as compared with agricultural soils because natural vegetations react strongly to inherent chemical soil conditions. Nitrogen deposition, originating from traffic and agriculture, has a strong effect on natural vegetations but solutions to this problem are largely beyond soil control, except when liquid manure is inserted into the soil to reduce ammonia emissions [24]. Then, groundwater quality (SDG6) may be negatively affected by the increased leaching of nitrates. Besides the effects of local management, soil health is affected by processes in the overall landscape context, and measurements and observations at the landscape scale need to be included in the overall assessment. A mosaic landscape where land use considers the carrying capacity of every component is key for securing hydrological cycles, avoid erosion and land degradation and contribute to the preservation of soils while preserving landscape heterogeneity and functionality, as well as the cultural heritage of a given region.

In summary, soil contributions to ecosystem services related to SDG15 can be well expressed by the soil health indicators, with particular emphasis on natural soil chemical conditions required by natural vegetation. Soil functioning should be considered in a landscape context.

4. Soils Science Acting in an Interdisciplinary Context Aimed at Realizing Ecosystem Services

Discussions so far have been summarized in the flow chart of Figure 1. Soil science fits in the disciplinary research box, contributing to interdisciplinary systems- research focused on the questions raised in the living labs by land users, expressing their expertise. Ecosystem services, in line with the land-related SDGs, are identified and characterized as well as the management procedures that have been followed that are part of the business plans of the farmer. Soil health plays an important role here and is also directly connected with society to express the major effect of soil health on food quality. When all ecosystem services meet characteristic threshold values that have been determined for the region concerned, a lighthouse can be established as an example as to how SDGs at a particular location can be realized by particular forms of management. This requires new research establishing such indicator values. When the ecosystem services don't meet the thresholds, additional research is needed. In the end, effective communication to the public, the land users, and the policy arena is essential [39] and can best be based on specific examples.

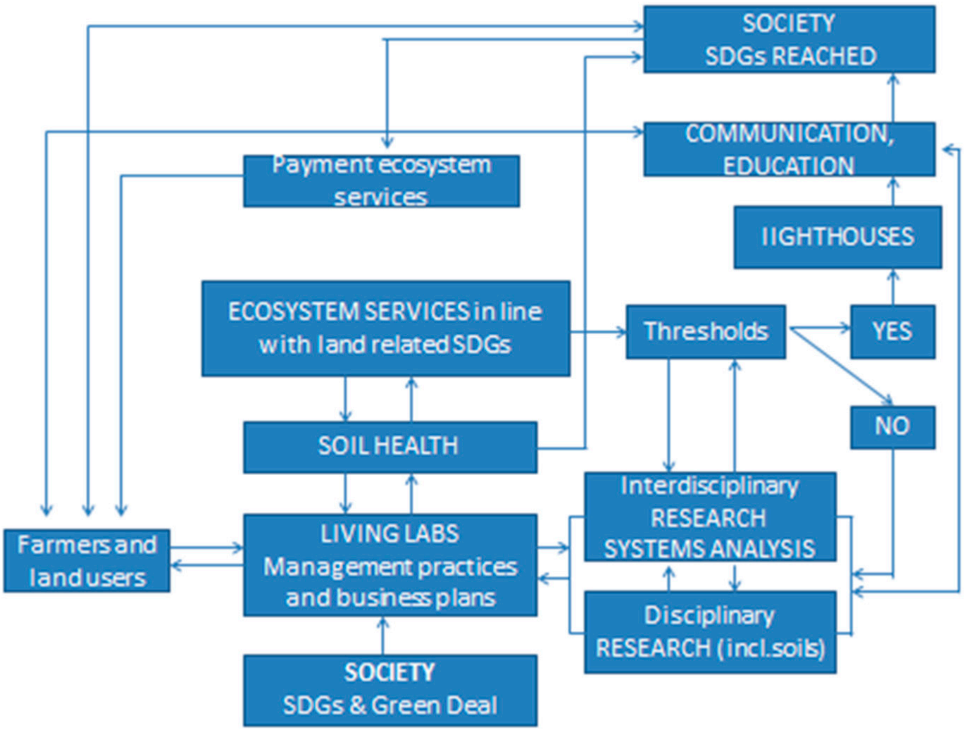

Figure 1. Schematic representation of procedures discussed in this paper, linking farmers' experience with research in living labs focused on achieving ecosystem services in line with the SDGs and the Green Deal (see text).

Some may question the exclusive emphasis on the cooperation of farmers with scientists, as visualized in Figure 1, because many other societal partners are involved in achieving sustainable development, and should they not be involved right from the start as partners in the LL's? Thirty actors were identified in The Netherlands that were directly and indirectly involved in sustainable soil management [20]. Practical experience has shown that involving all actors in all discussions may result in time-consuming, wide-ranging, and often controversial discussions with a paralyzing effect. At least two considerations led to the chosen approach of Figure 1: (i) Emphasis on the SDGs and the Green Deal already implies consideration of societal factors, directly affecting land-related SDGs. The latter provides a welcome focus for the overall discussions, and: (ii). By proposing specific and jointly developed viable management practices that can satisfy at least five ecosystem services while specifying the role of soils, it is a solid, separate, and independent contribution to the overall discussions also covering other SDGs.

The important contributions of soil science to systems analysis have been described in the previous sections. This type of contribution is much more effective to show the importance of soils for achieving sustainable development to the outside world than just elaborating on the importance of soil as such [1]. However, to ensure continued effective contributions of the profession in the future, attention should be paid to a number of aspects:

(i) Contributing to studies on the uptake of pollutants by plants and on determining regional threshold values for the various ecosystem services considered, including assessment of the contribution of soil health;

(ii) Working in interdisciplinary teams with simulation models raises the question as to the specific input of each of the participating disciplines. Soil inputs are defined by the soil types being considered in terms of the occurrence of different soil horizons and textures and by the soil health indicators. Values for texture, bulk density (BD) (as a measure for soil structure). Organic matter content is important and can be found in widely available soil databases. Modeling soil water regimes also requires information on basic soil physical parameters of soil water retention and hydraulic conductivity. They can be measured but also estimated by regression analysis using texture, BD, and % organic matter, yielding widely used pedotransferfunctions (ptf) [57,58]. Soil scientists face the risk that their expertise is bypassed by others using soil input only based on ptfs and basic data copied from soil databases, and this can produce poor results because separate data points cannot express the complex behavior of soils in a landscape context. Pedological expertise is essential to provide this type of information, but soil scientists should not wait until being invited to contribute but should act in a pro-active mode. A comparable challenge has been described for agricultural economics [59]. The issue is relevant because simulation models implicitly assume that soils are homogeneous and isotropic. They are not. Occurrence of particular soil horizons or large soil pores, such as cracks or root- and worm channels can significantly change flow patterns in soils by causing stagnation of downward water movement or by: "bypass-flow" where free water moves rapidly downwards in the soil, bypassing an unsaturated soil matrix. Pedologists are familiar with such processes (e.g., [57], with an example for clay soils). Testing and validating modeling results by observing vegetational reactions to environmental conditions is still a high research priority to test the validity of models. New remote sensing techniques provide new opportunities for model validation [48]. Furthermore, also exploratory modeling of the economic viability of different business models is needed, considering tradeoffs between soil regeneration and immediate income while modeling alternative land-use options. In addition, changes in the food value chain can require a change in management practices at the farm level. This requires novel approaches, integrating the expertise of different production-oriented disciplines, such as soil science and agricultural economics and policy analysis [59,60];

(iii) Procedures suggested could imply that investigations at any new Living Lab would start from scratch. However, soil survey interpretations in the past were based on the principle that results obtained at a given site with a particular soil type could be extrapolated to new sites with the same soil type, using soil types as "carriers of information". Traditional soil survey interpretations were empirical in nature (a given soil has "moderate limitations for arable farming"). This does not suffice for modern, SDG-oriented applications. However, every soil: "has a unique story to tell," and this not only can but also should include modern model-derived information [31–33,43,47]. Using soil types that can be well visualized as "carriers of information" also facilitates communication of research results to land users, politicians, and the public at large using modern methods of "storytelling". South African studies demonstrate this well for regional hydrological modeling studies [61]. Effective communication becomes ever more important in a confusing information environment with "post-truth", "fake news", and "alternative facts" [62];

(iv) Effective interaction with farmers in living labs is crucial, as discussed. Soil scientists and particularly soil surveyors and fertility specialists have a long tradition of working with farmers. Soil surveyors, when walking the fields, when making the surveys and being invited for coffee, fertility specialists collecting samples and communicating results in terms of fertilization recommendations. Traditional soil surveys are finished in most countries, and soil fertility procedures have been automated with less direct contact between farmers and specialists. Going back to the roots of the profession when interacting with farmers is necessary and can create a special role of soil scientists in the interdisciplinary research team studying ecosystem services;

(v) As discussed, modern agriculture has to satisfy the demands of multifunctionality as expressed by different ecosystem services: producing safe and healthy food, protect water quality and biodiversity, reduce greenhouse gases and capture carbon. This requirement offers a major challenge to the level of detail by which assessments of the various ecosystem services are made. The various methods should preferably have a corresponding degree of detail. Very detailed knowledge for one ecosystem service is difficult to combine with poor knowledge for another and may lead to over-emphasizing certain ecosystem services.

For example: detailed knowledge is available on the effects of soil pollution on safe and healthy food in terms of food quality, but new pollutants arrive, and this research field is highly dynamic and as yet incomplete while research on the uptake of pollutants by plants lacks attention. In addition, attention should be paid to the effect of pollutants on the soil biome, which plays a central role in soil functioning. An example is a study on the effects of glyphosate on the soil biome [63] (SDG2 and 3). Optimal application regimes of agrochemicals in different soils and climate zones to avoid groundwater pollution have so far received little emphasis in research in contrast to the study of soil erosion contributing to surface water pollution (SDG6). Carbon capture and greenhouse gas emissions are widely studied following different approaches but are a relatively new topic with as yet no agreement on implementation protocols [50]. A first-step pragmatic approach using soil survey data was proposed above (SDG13). Land degradation has been studied for many decades and has produced effective results. Biodiversity has, in contrast, been studied by plant scientists with relatively little connections with other scientific fields, such as soil science. Much is yet unknown about the relations between biodiversity as a function of natural soil conditions (SDG15).

When considering the effects of management on achieving a combined set of ecosystem services, different levels of knowledge have to be combined in a systems analysis, and it will be important to not over-emphasize certain services with a relatively high knowledge level.

However, the organic matter content of the soil in combination with favorable soil structure and soil moisture regimes presents a unifying goal when considering soil contributions to the different ecosystem services as higher organic matter contents are associated with: (a) a higher adsorption capacity for nutrients, which is favorable for plant growth and for protecting groundwater quality, (b) a better soil structure for root growth and higher structural stability, when properly managed, which is suitable for plant growth and to combat erosion, (c) carbon capture, but higher carbon contents are associated with higher emissions of greenhouse gases. The two need to be balanced, and: (d) a higher soil biodiversity.

In summary: developing soil management schemes that increase organic matter contents while preserving favorable soil structure and soil moisture regimes is an effective overall soil strategy to improve the capacity of agricultural soils to contribute to ecosystem services.

5. Implications for Environmental Rules, Regulations, and Policies

5.1. Implications for Environmental Rules and Regulations

As discussed, farmers are concerned about rules and regulations that change periodically and focus on means to reach goals rather than on the goals themselves. Introduction of the ecosystem services approach can address this problem by defining goal-oriented thresholds for each of the services., as discussed above and visualized in Figure 1. The implementation of the Common Agricultural Policy of the European Union (2021–2027, with a budget of 350 billion €) contains a proposal for new agro-environmental measures (Pillar 2 of the CAP) to increasingly focus on payment for achieving specifically measured ecosystem services rather than on bland payments per ha or for practices that are not linked to delivering such services. Each member state should explore procedures allowing the practical realization of this change of paradigm that represents an excellent development because it represents a direct link with the SDGs and the Green Deal and thereby to the sustainability debate.

A second justification for a focus on ecosystem services is the rather confusing array of proposed management systems and types of agriculture that are currently being promoted by various groups or by self-appointed experts, including smart websites and high activities on social media: "biological, biological-dynamic, nature-inclusive, circular, regenerative, high-tech precision, enriched . . . ". These multiple proposals create a fuzzy picture on possible pathways toward sustainable development and are confusing and misleading for farmers and land users, let alone for the public at large. By judging each system in terms of ecosystem services provided presents an ideologically neutral yardstick for judgment. Of course, the various approaches can be inspiring to farmers, and the focus on soil biology in most of the systems fits well with the general need to increase the soil organic matter content and soil biological activity.

5.2. Implications for Research Policy

The link of science with society and the need to progress through uncertainty with flexible approaches has been classified as Mode 2 Science [64]. Working in living labs, studying "wicked" problems without single solutions, cannot follow the traditional linear research approach where well-defined experiments testing a clear hypothesis are repeated several times with the objective to obtain statistically valid results. However, every Living Lab is unique and cannot be "repeated", and studies do not produce a single answer but, rather, a set of options from which the farmer has to make a choice., as discussed [26] Some scientists may therefore consider results obtained in living labs as being unscientific. This issue has to be resolved by: (i) applying the linear model to indicators for ecosystem services and soil health, as discussed above. Well-defined measurement methods and replications in space are needed. Many innovative methods are available [28] (ii) options can be articulated as "storylines" [29] linked to experiences in different living labs on particular types of soil. "Learning by doing" in a series of case studies corresponds with the successful Harvard method of research dissemination [65]. Farmers are individualistic by nature and will probably only adopt certain aspects of the storyline. The scientific literature should accept this approach as a scientifically sound expression of new ways to link science with society.

The central position of living labs in the approach being advocated in this paper is increasingly supported by recent developments in the international scientific arena, where attention seems to be shifting away from supporting unconditional basic research to research that focuses on specific goals with clear benefits for society. A reason is a substantial time that researchers spend now on writing proposals that have a low chance of being funded while the bureaucracy involved may be stifling. The goal-oriented approach has much lower administrative costs. In the USA, an Innovation and Competition Act will be introduced, defining ten "key" technology focus areas. Germany will establish a Federal Agency for Disruptive Innovation (SPRIN-D). The U.K. forms an Advanced Research and Innovation Agency. Japan establishes a "Moonshot" Research and Development effort. The latter is in line with the five Missions of the European Union in the context of the EU Soil Horizon Research and Innovation program 2021–2027.

Aiming for the realization of living labs and lighthouses clearly fits in the second category focusing on clear benefits for society.

6. Conclusions

- The UN-SDGs and the EU Green Deal provide an attractive "point-at-the-horizon" for developing sustainable agriculture, replacing a wide array of current approaches with less defined, often partial goals;
- Farmers are not only challenged in the future to produce healthy food (SDG2 and 3) but to also protect the quality of surface—and groundwater (SDG6), bind carbon, and reduce the emission of greenhouse gases for climate mitigation (SDG13) and combat land degradation and preserve biodiversity (SDG15). This presents "wicked" problems that require a special research approach, focused on joint work in living labs that, when successful, can function as inspiring: "lighthouses". Research protocols for "wicked" research need to be developed. A new research approach is needed because traditional, often disciplinary, research has not adequately reached the land users;

- Published targets and indicators for the SDGs do not mention specific management measures needed to reach the goals. A focus on developing and achieving a series of successful ecosystem services in line with the SDGs is therefore needed to realize innovative management practices in the real world;
- Simulation models for the soil-water-atmosphere-plant system can perform a systems analysis characterizing the combined effect of a number of ecosystem services. They need, however, continuous validation to correctly represent heterogeneous soil conditions. Other models dealing with decision processes and business plans also have a key role to play so as to make progress toward developing decision support tools that can be used in practice;
- Adoption of developed management procedures by a large number of farmers is essential to reach significant results worldwide. The socio-economic context in which farmers operate and their specific questions and expertise should therefore be leading in joint research developing innovative forms of management in living labs;
- The importance of soils in contributing to sustainable development can best be demonstrated by showing the impact of contributions to interdisciplinary teams working in living labs, focusing on providing ecosystem services rather than by working in isolation.

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