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Exploring Operational Procedures to Assess Ecosystem Services at Farm Level, including the Role of Soil Health

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Abstract: Reaching the land-related UN Sustainable Development Goals (SDGs) and similar goals articulated by the EU Green Deal (GD) by 2030 presents a major challenge and requires a pragmatic approach focused on joint learning by land users (mostly farmers), researchers and other stakeholders in "Living Labs" and system experiments at experimental farms of research organizations. Defining specific indicators and thresholds for ecosystem services in line with land-related SDGs is crucial to establish "Lighthouses" that can act as inspiring examples if they meet the various thresholds. This exploratory paper discusses indicators and thresholds for an arable farm operating on marine, calcareous light clay soils in the Netherlands. Studies of a system experiment are used to discuss and test operational methodology to be widely applied when characterizing many "Living Labs" in future, as planned by the European Union. The important role of soils in contributing to ecosystem services is discussed in terms of soil health. Recommendations are made for innovative methodology to be associated with all land-related SDGs. Satisfying the thresholds of ecosystem services, which will vary by soil type, region and farm type, can be the basis for farm subsidies, such as the Common Agricultural Policy (CAP). Research on Living Labs and in system experiments has to be judged by different criteria than those associated with traditional linear research. The important contributions of soils to achieve ecosystem services are framed in terms of soil health and are the most effective way to promote soil science in a by now widely desired inter- and transdisciplinary context.

Keywords: sustainable development; modeling; interdisciplinarity; SDG; green deal

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1. Introduction

1.1. Sustainable Development Goals

The Brundtland report of 1988, "Our Common Future", has been instrumental in emphasizing the urgency of putting the issue of sustainable development on the international policy agenda, as the concept has remained rather vague. The need for an integrated approach combining economic, societal or environmental issues when dealing with societal development has changed the sustainability discourse. The introduction of seventeen sustainable development goals by the General Assembly of the United Nations (https://sdgs.un.org, assessed on 20 February 2022), approved in the 2030 Agenda for Sustainable Development by 193 countries in 2015, provided a welcome focus for the sustainability effort that was, in essence, also adopted by the Green Deal of the European Union of 2019 (https://ec.europa.eu/greendeal, assessed on 20 February 2022). Both policy documents emphasize the need for a practical approach resulting in visible results.

Green Deal targets and land-related SDGs are strongly affected by agricultural practices, and soils play an important role [1]. When focusing on agriculture, primary attention will not only be on the traditional role of producing healthy crops to combat hunger (SDG2 and SDG3), but also on clean ground and surface water (SDG6) on increasing carbon sequestration and limiting greenhouse gas emissions for climate mitigation (SDG13) and on the reduction in land degradation and biodiversity preservation (SDG15). Additionally, energy use (SDG7) and sustainable production and consumption (SDG12) are relevant, where the latter has much in common with SDG2 and SDG3. The indicators and thresholds of the Green Deal and the SDGs specify the required "clear and concrete objectives" of [2]. They are strongly interrelated. Some form of multifunctional soil use and management therefore has to be realized in agriculture, and this can be assessed in "Living Labs", which will certainly be very different in different regions.

Focus on the SDGs serves to connect with the international discourse on sustainable development. Each of the five major land-related SDGs can be reached when adequate ecosystem services are provided that are defined in terms of "services provided by ecosystems to mankind", as first proposed by the Millennium Ecosystem Assessment of 2005 (https://www.millenniumassessment.org, assessed on 10 January 2022)). Soil functions contribute to ecosystem services in line with the SDGs [3,4]. Man is a recipient of such services, which cannot be taken for granted. Adequate levels can only be reached by applying appropriate management measures. Ecosystem services can only be reached by an interdisciplinary effort, involving agronomists, hydrologists, climatologists, ecologists, economists, sociologists and others in addition to soil scientists. This represents a key message for all disciplinary researchers involved in the sustainability effort.

Each SDG is so far specified in terms of targets and indicators (https://unstats.un.org/sdgs/metadata, assessed on 20 February 2022) that do not, however, address operational methods and procedures by which these targets can be reached in the real world, presenting a key challenge to not only the scientific arena but also to society at large.

Where to start? The SDGs will only be reached when land users, most of them farmers, are willing to embrace management procedures that result in providing ecosystem services in line with the SDGs. Farmers have been interviewed many times and their questions, concerns and demands need particular attention before new activities are started. Their major concerns are about unsure economic prospects and unclear and dysfunctional environmental rules and regulations in their perception, as well as about not receiving independent advice [5–7]. These economic prospects are significantly affected by the Common Agricultural Policy (CAP) of the European Union, supporting farmers with EUR 350 billion for the period 2021–2027, including a provision now that 25% of the funds, and perhaps more in future, will be allocated to support the realization of ecosystem services. This justifies the need for an operational assessment of ecosystem services allowing a functional link with the CAP.

Considering the role of soils in this broad ecosystem context, soil health was defined in terms of: "the continued capacity of soils to contribute to ecosystem services in line with the SDGs and the Green Deal" [8]. At first sight, this may seem to be a rather politically inspired definition, but it rather emphasizes two key aspects: (i) soils cannot contribute to ecosystem services alone. Their importance is determined by their contributions, and (ii) By referring to the SDGs and the Green Deal, all environmental objectives beyond the classical production function are considered.

1.2. Research on Wicked Problems

To reach the thresholds derived from SDGs, farmers need to adapt their management to fulfill at least five ecosystem services while also having to adapt to changing weather conditions that are unpredictable beyond at most a ten-day period. This is why farms are complex systems where no simple solutions are available to solve problems, but only a set of alternative options that produce acceptable overall results. The problems encountered when researching such complex systems are "wicked". Studying "wicked" problems cannot follow the standard linear research protocol that produces a single answer based on reductionistic experiments with sufficient replicates to allow a statistical analysis resulting in "significant" results. The standard protocol has many shortcomings. As an example, in the comparison of ploughing and non-inversion tillage, many more differences are relevant than only replacing the plough with a cultivator. The timings of operations are different, but other aspects such as crop rotation, choice of cover crops, weed control and fertilization levels also need to be adapted to the new tillage method. It is not possible to take all aspects in to account in factorial experiments.

The European Commission recognizes the need for other forms of research by supporting the establishment of "Living Labs" and "Lighthouses" at the farm level, following the advice of the Mission Board of Soil Health and Food [8]. "Living Labs" 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", and "Lighthouses" are 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".

In Living Labs, farmers, researchers and other stakeholders are jointly creating knowledge [2,8] to develop suitable field-tested management methods that result in achieving several ecosystem services. Moreover, Living Labs function to inspire colleague farmers to adopt certain management options that fit their particular farming style.

In Living Labs, the practical feasibility of management options can be well-tested. However, possibilities for experiments on commercial farms are highly limited for financial and operational reasons. This aspect has not received adequate emphasis when promoting the "Living Lab" concept. Links with existing experimental farms of research organizations and universities can therefore be highly effective in designing and executing relevant experiments, including the development of operational monitoring methods that can be applied at the farm level. Next to more classical research, research projects and experiments on integrating management options into farming systems are important to test the feasibility of individual measures within systems and to assess the effects of the system on various ecosystem services. This can be carried out with more accuracy and precision on experimental farms than on commercial farms in "Living Labs". In this type of research, farmers and other stakeholders also need to be involved in the set up and execution of the research. Methodologies for these types of research already exist in, e.g., the prototyping methodology [9,10]. In addition, the value of the combination of research on experimental farms together with commercial farms has been described previously [11]. These system experiments are also important in the dissemination of knowledge through field days, excursions and open discussions.

1.3. Objective of This Paper

The objective of this exploratory paper is to present: (i) a case study on reaching the targets of the SDGs and the Green Deal for arable farming on prime agricultural soil in the Netherlands and assessing the role of soils; (ii) a discussion of operational methods and criteria to define and measure indicators for ecosystem services and soil health, including threshold values; (iii) possible future developments in terms of innovative research in "Living Labs" focused on alternative management practices that can improve ecosystem services; and (iv) implications for research, research communication and environmental policy. All of this is conducted considering the agreed SDG deadline of 2030.

2. Materials and Methods

2.1. Characterizing Ecosystem Services and Corresponding Thresholds

Studying ecosystem services at the farm level involves several steps, summarized in Figure 1. Attention is focused on the level where management decisions are made; that is, the business unit: the farm. Ecosystem services are distinguished and indicators, measurement techniques and thresholds have to be determined, allowing a judgment as to whether or not the ecosystem services provided are adequate. Targets are described in general terms in the SDG protocol, while thresholds define boundary values for ecosystem parameters in terms of "good" or "not good enough". If ecosystem services do not meet the threshold, the farming system must be re-evaluated, redesigned and the judgement procedure has to be repeated [9,10]. Thresholds should have a regional character as they are influenced by climate and local conditions, as will be discussed in the following sections.

Note that not only soils determine ecosystem services at the farm level, as many other factors and processes are involved. The major role of soils can, however, be assessed, as explored in this paper, in terms of their contribution to ecosystem services.

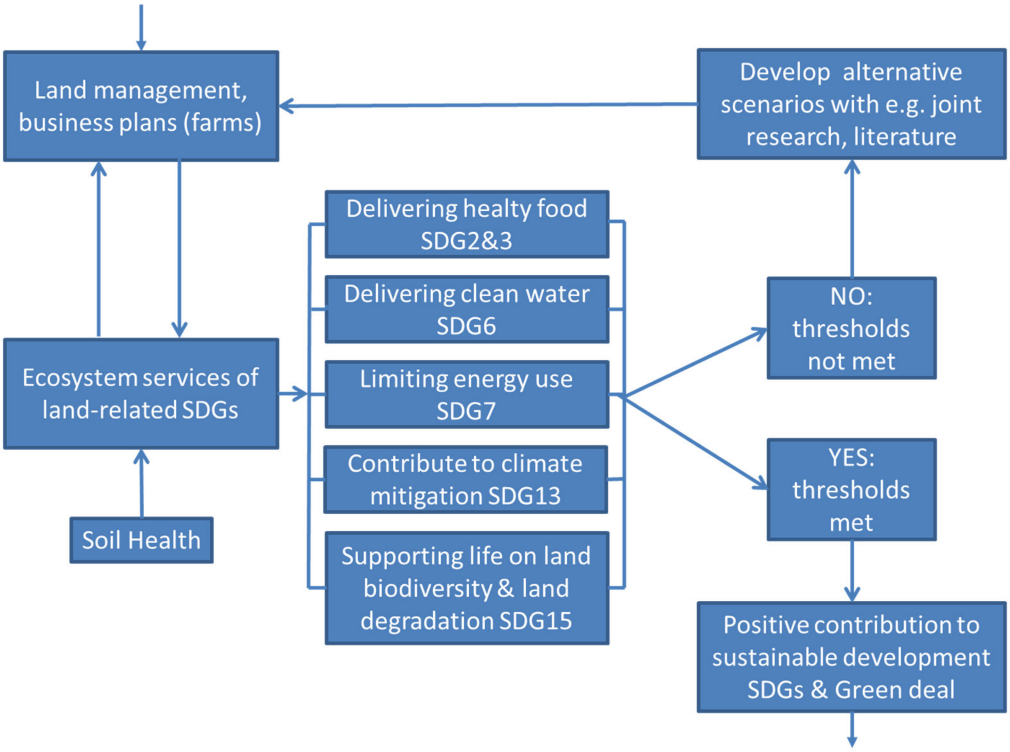

Figure 1. Flow chart demonstrating the procedure to test whether ecosystem services, contributing to achieving SDGs and the goals of the Green Deal, meet regional thresholds.

The following indicators are available for the ecosystem services contributing to the SDGs:

Crop production levels are important to provide sufficient food to avoid famine **(SDG2, zero hunger)** and can be derived from economic statistics, where attention is needed for differences between years reflecting weather conditions. Translated to the Netherlands, where hunger is not an issue, this SDG is about producing reasonable amounts of food, feed and fiber to supply mankind. In the Netherlands, reliable statistics on crop yields are available, allowing a judgement as to whether yields at a given farm are satisfactory (https://opendata.cbs.nl/, assessed on 20 February 2022) [12]. More and more farm management systems monitor crop yields at the farm level, eventually supported by remote and proximal sensing tools. A theoretical general yield gap approach is therefore more appropriate to define production levels where a water-limited yield (Yw) can be simulated, assuming there are no pests and diseases while nutrient levels are optimal [13]. A level of 80% is considered satisfactory and can function as a threshold. Simulations provided by the WaterWorks program in the Netherlands can be used to estimate Yw (http://waterwijzerlandbouw.wur.nl/, assessed on 20 February 2022) [14].

Producing healthy crops **(SDG3, good health and well-being)** implies the application of existing crop quality standards. Thresholds for chemical pollutants in crops are defined by regulations in the EU General Food Law, national regulations and in the “from Farm to Fork” EU program for a series of chemical compounds.

Clean surface and groundwater **(SDG6, clean water and sanitation)** is determined by sampling and laboratory analysis of N and P contents in water and is being judged by ecological thresholds for aquatic biodiversity, as specified by the EU Water Framework Directive [15]. Additionally, critical thresholds for biocides and such other pollutants as heavy metals are regulated within the WFD. The assessment of soil management on groundwater quality is relatively straightforward, with direct relations and generic thresholds.

The assessment of soil management on surface water quality is more difficult to define, as relations are often indirect and thresholds for surface waters vary depending on the desired ecological quality [15]. Because of expensive N and P measurements, proxies are defined in the Netherlands for N and P emissions to ground and surface water in terms of the mineral nitrogen content in soils before the start of the leaching season and of the overall nutrient surpluses at the farm level.

Agriculture has only a small share in total energy use **(SDG7, affordable and clean energy)**, as only 6% of total energy use in the Netherlands is assigned to agriculture (www.compendiumleefomgeving.nl, assessed on 20 February 2022). Thresholds for energy use in crop production are lacking at the farm level. However, 45% of farmers are already involved in renewable energy production, mainly by solar panels and wind turbines.

Greenhouse gas (GHG) emissions **(SDG13, climate action)** are widely studied and an excellent recent review [16] shows that many methods and models are now being used and applied. So far, there is, however, no agreement on a general methodology that can be applied in practice. Greenhouse gas emissions for a given farm are not only determined by the soil as there are many other sources as well. GHG emission values are currently estimated with modeling, through which rough estimates at the farm level can be generated [17]. So far, no thresholds have been defined.

SDG15, life on land, mentions a series of goals, of which "halt and reverse land degradation and biodiversity loss" is the most relevant to agriculture. Land degradation has a strong soil component and can be characterized by indicators for soil health that also allow an estimate of soil biodiversity (Section 2.2). Another component is above-ground biodiversity, which can only partly be assessed at the farm scale as there is a large regional component. In the Netherlands, 162 nature areas have been established in the EC NATURE 2000 program (https://www.natura2000.nl, assessed on 20 February 2022). If several of these occur in a given region, there could be more room for agriculture, but so far, policy decisions on future land-use scenarios have not been reached. Plans to define exclusive agricultural areas of prime agricultural soils have not been approved. Of course, avoiding the negative environmental effects of farming, such as pollution of soil, water and air, directly affect the quality of nature areas nearby in a positive way and can be seen as an indirect contribution to biodiversity. However, for above-ground biodiversity, indicators or proxies are still lacking.

2.2. Characterizing Soil Health as It Contributes to Ecosystem Services

In the introduction, the soil health concept is presented [8]. In simple terms: the healthier the soil, the better the contribution to the SDGs. To characterize soil health, a limited number of indicators are suggested to produce an operational, not too complex or expensive system that is essential to facilitate adoption in practice by 2030 [8]. The indicators are based on 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.

The procedures are summarized in Figure 2. Representative sampling patterns are part of the procedure, as well as documentation of the dominant type of soil, allowing the future extrapolation of obtained results to other locations with the same soil type. The soil pollution indicator first separates polluted from unpolluted soil. Remediation may lead to the possibility for further judgment later. Indicators must be measured and appropriate thresholds need to be selected. If thresholds are met, contributions to ecosystem services are satisfactory. If not, the procedure is repeated. The "one-out, all-out" principle can apply: when one indicator is negative, the soil is unhealthy.

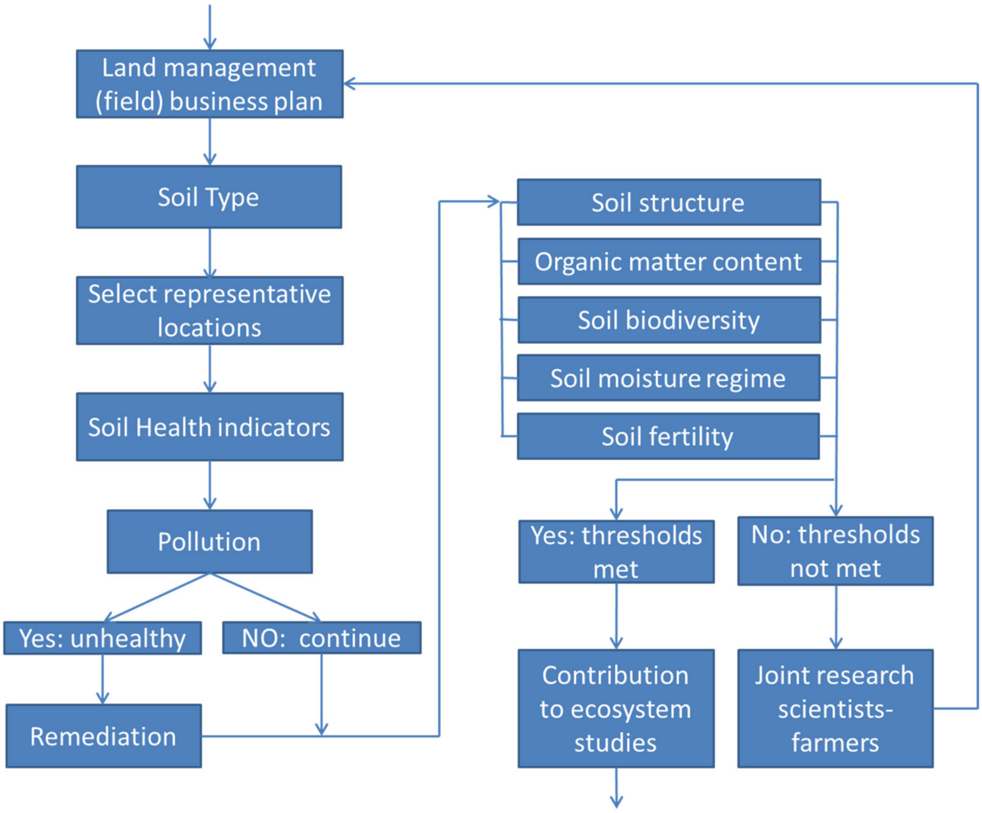

Figure 2. Flow chart demonstrating the procedure to test whether soils are healthy with the objective of maximizing soil contributions to ecosystem services (see text).

The indicators and measurement methods for soil health and corresponding thresholds can be summarized as follows.

Thresholds for **pollutants in soil** are defined by current legislation. A form of what could be called "biological" pollution is formed by the (unintended) introduction of soil-pests and diseases in fields of the farm, such as nematodes with, e.g., seeds or attached ground to machines.

Soil structure is described in soil survey reports in terms of structure types and degrees of development, and standard methods to measure bulk density and mechanical resistance with penetrometers are available [18,19].

Standard laboratory measurement methods are also available to measure **soil organic matter** content, requiring field sampling and laboratory measurements that are costly and time consuming. Thresholds for organic matter contents of different soils are not yet defined in general protocols but can be derived for separate types of soil that have characteristically different ranges of organic matter content as a function of management [20,21]. Higher organic matter contents are not only relevant for carbon sequestration, as they will also improve nutrient dynamics and soil resilience, as well as increase the water holding capacity and water delivery to plant roots.

Soil biodiversity can be characterized more specifically than just measuring the organic matter content by determining the variety of soil organisms and by the Soil Protein Index, soil respiration and active carbon [22], as well as the microbial and fungal biomass, their ratios and the potential mineralizable N pool. So far, these detailed studies have not yet resulted in recommendations for routine application based on well-documented results focused on realizing ecosystem services. Until such data become available, organic matter content will have to function as a proxy value without clear threshold values.

The **soil moisture regime** is important for all land-related SDGs. Regimes have been defined in traditional soil surveys in terms of descriptive drainage classes (well drained, poorly drained, etc.). Rooting requires a well-drained soil profile that is neither too wet nor too dry, containing sufficient air during root growth. These descriptions are inadequate for modern demands and water regimes can now also be measured by modern monitoring equipment, such as tensiometers and probes measuring water content [18].

Soil fertility is characterized directly by applying well-established fertilizer application protocols, including field sampling and laboratory testing, in the Netherlands, available at www.handboekbodemenbemesting.nl, (accessed on 20 February 2022).

New methods will be discussed when analyzing future developments and the need for new methodologies in Section 4.2.

2.3. Arable Farming in Flevoland on Calcareous Light Clay Soils

This exploratory paper reflects results obtained from the BASIS long-term system experiment in the period of 2009–2018 on soil functions and soil quality at WUR Field Crops Experimental Farm, Lelystad [23,24]. BASIS is an example of a farming system experiment, designed and executed together with farmers and other stakeholders.

The experimental farm is representative for arable farms on marine, calcareous light clay soils, a prime agricultural soil in the Netherlands. The soils at BASIS consist of 55–65% sand, 20–24% silt and 15–20% clay (Mn15A in the Dutch soil classification), occupying 121 867 ha in the Netherlands, which is 23% of the total area of arable land. The BASIS conventional system consists of a 4-year crop rotation with crops including: seed onions (average crop yield 63 tonnes/ha), seed potato (33 tonnes/ha), sugar beet (100 tonnes/ha) and summer barley (8 tonnes/ha). These are average yields over the period of 2009–2018. Average yields are used since no trend over time was found. Soils are plowed in autumn. Average fertilization rates are 110 kg N/ha, 60 kg P/ha and 140 kg K/ha, applied with chemical fertilizers only, following standardized Dutch fertilization advice (www.handboekbodemenbemesting.nl, assessed on 10 January 2022). The input of crop protection agents is on average 8.5 kg active ingredients/ha. All these management data are used as they are needed for communication purposes when describing arable farming on marine calcareous light clay soils, using this soil type as a "carrier of information" for farmers operating on the same type of soil.

The experiments in BASIS are, in addition to monitoring the existing farming system, focused on two aspects that were considered to be potentially important for future management, as indicated by farmers, citizen groups and experts: (i) reduced tillage: replacing ploughing with non-inversion tillage; and (ii) conversion to organic farming, which so far is only practiced in 7% of the farms in Flevoland. These questions require experiments that were beyond the capability of individual farmers, if only because of financial requirements. Reduced tillage was applied for the same crop rotation and consisted of the replacement of ploughing in autumn by non-inversion tillage in spring. The organic system had a different crop rotation, with different crops consisting of ware potatoes, grass clover, white cabbage, spring wheat, carrot and a spring wheat–faba bean mixture and no use of chemical fertilizers and biocides. The results of the effects of reduced tillage and organic farming will be discussed in Section 3 in terms of possible future developments.

3. Results

The ecosystem services contributing to the various SDGs and the soil contributions to the ecosystem services will now be discussed as they apply to the BASIS arable farm, the "Living Lab". This will include an analysis of the available thresholds and of promising future forms of innovative management.

3.1. Ecosystem Services and Soil Contributions to SDG2 & 3 (No More Hunger and Health) Focusing on Priduction of Healthy Food

3.1.1. Actual Conditions and Thresholds

The current production levels in the BASIS experiment are reported in Section 2.3. Target levels of crop yields on clay soils in general are 40 t/ha for seed potatoes, 60 t/ha for seed onions, 95 t/ha for sugar beet and 6.4 t/ha for summer barley [12]. The actual yields reported in Section 2.3 indicate that only the yield of seed potatoes is 7 t/ha (=18%) lower than the threshold, suggesting the need for attention to possible causes, while the other yields are much higher. The conclusion is justified that the threshold for SDG2 is met. This conclusion is supported by the simulation analysis that produced, for example a value of 7.3 t/ha for summer wheat, which is above the 80% Yw value [13,14]. The Yw value is important to assess the general production level to be applied when comparing soils in an SDG context. Regular monitoring by regulatory bodies indicates that there are no problems with remnants of pesticides or too-high concentrations of pollutants in crops [25].

This issue is, however, highly dynamic as new chemicals are (unintentionally) introduced in the ecosystem (e.g., PFAS, microplastics, drug remnants), requiring increased attention from the research community.

In summary: the thresholds for ecosystems in line with SDGs 2 and 3 are satisfied.

3.1.2. Soil Health Contributions

Pollutants are absent in the soils being discussed. Rooting depth is directly affected by **soil structure**, as expressed by visual observations, supported by measured bulk densities and penetration resistances (Table 1). Bulk density is measured with soil sampling rings and penetration resistance with a penetrologger.

Table 1. Latest measured values for soil health indicators for systems' conventional ploughing, conventional non-inversion tillage and ploughing in organic farming including standard deviations (between brackets). The latest measured values are used, since soil properties have changed over time. Measurements from 2015 and 2016.

Indicator	Conventional Ploughing	Conventional Non-Inversion Tillage	Organic Ploughing
Bulk density g/cm^3 (2–7 cm)	1.35 (0.08)	1.35 (0.06)	1.30 (0.09)
Bulk density g/cm^3 (14–19 cm)	1.43 (0.07)	1.47 (0.06)	1.40 (0.09)
Penetration resistance MPa (15–30 cm)	0.67 (0.31)	1.90 (0.61)	1.38 (0.58)
Organic matter % (0–30 cm)	3.0 (0.3)	3.1 (0.3)	3.3 (0.3)

Bulk densities for conventional ploughing were somewhat lower when compared with the data in the national soil database for light clay soils that do not, however, report penetration resistances [26]. Calculated (not measured) bulk densities in the national database had a median value of 1.47 g/cm^3 and a range of 1.45 g/cm^3 to 1.51 g/cm^3 for topsoils and 1.53 g/cm^3 for subsoils with a range of 1.41–1.61 g/cm^3. The indicative threshold for bulk density is 1.55 g/cm^3 (NEN-EN-ISO 11272:2017). The relatively low values for bulk density and penetration resistance, below the thresholds for root development, illustrate the young character of the soils in Flevoland, developed since the 1950s, as compared with other marine clay soils in the Netherlands. A penetration resistance of 1.5 MPa is assumed to hamper root growth, and above 3 MPa, root growth is not possible (www.handboekbodemenbemesting.nl, assessed on 20 February 2022).

The **organic matter** content of the soils in BASIS is determined with loss on ignition and is given in Table 1. The national soil database reports a range of values between 1.0% and 2.2% for surface soil with a median value of 2.0% for light clay soils. A formal threshold is lacking but 3.0% organic matter would seem to be adequate to qualify as meeting a tentative threshold value of 2.0% organic matter. Organic matter can also function as a proxy indicator for **soil biodiversity** until a more representative and operational parameter can be obtained (see Section 2.2.).

Well-designed and maintained drainage systems establish favorable water table levels in BASIS, which range from an average lowest water table level at 120 cm below the surface at the end of the growing season in late summer to 60 cm below the surface in early spring. Simulation results of **soil moisture regimes** for the type of soil being discussed, determined by the methods presented by [14], do not result in a significant reduction in production levels as observations indicate that soils are neither periodically saturated nor too dry, thus meeting the threshold.

BASIS management strictly follows the Dutch **fertilization recommendations**, which de facto provide thresholds based on extensive field research.

In summary, the soils of the BASIS experiment are healthy and this conclusion remains valid when considering all land-related SDGs.

3.1.3. Future Prospects

Questions raised by farmers, citizens and the policy arena have resulted in experiments on reduced tillage and organic farming in the last decade. Non-inversion tillage overall did not lead to changes in production levels (Table 2). A further reduction in tillage intensity, in terms of no-till practices, is not seen as an option because of the root crops in the rotation scheme. A shift to organic production leads generally to lower production levels, confirming the results of other studies [27].

Table 2. Crop yields in tons of fresh product/ha for conventional ploughing and non-inversion tillage and crop yields for conventional and organic farming both derived from BASIC experiments. Average yields over the period of 2009–2018. Conventional reference based on [12].

Reduced Tillage			**Organic Farming**		
Crop	**Yield**		**Crop**	**Yield**	
	Ploughing	**Non-Inversion**		**Conventional Reference**	**Organic System**
Seed potato	43	44	Ware potatoes	52	39
Sugar beet	99	99	Grass clover	n.a.	74
Spring barley	7.6	7.8	Cabbage	84	59
Onion	74	71	Spring wheat	7.3	5.0
			Carrot	85	68
			Wheat-faba bean	n.a.	5.0

Even though the thresholds for SDGs 2 and 3 are met for the farm being discussed, there is still interest in other options to affect the production conditions of healthy crops in future as compared with the traditional approach discussed so far. This includes a reduction in biocide application, crop breeding and precision fertilization and irrigation. A reduction in biocide application can also be achieved in other ways than just omission: (i) rather than having very large fields with single crops in which pests and diseases can rapidly develop and spread, successful experiments have been conducted in Flevoland with strip cropping: growing different crops on adjacent small strips of land. This strongly enhances biological pest control [28]. The increased labor demand can be solved in future by using robots. (ii) Robots are available now as well to recognize infected plants and restrict the application of biocides to such plants only, realizing savings of up to 80%. This is part of precision technology, also extending to fertilization and irrigation, which is to be discussed in Section 4.2.

Crop breeding can result in new varieties that are more drought-, pest- and disease-resistant, while nutrient uptake efficiency may be enhanced. Current crop breeding is mainly focused on crop yield and pest and disease control, while it is known that large differences exist between varieties in water and nutrient efficiency and root development. Moreover, improving the energy uptake efficiency by chlorophyl in plant leaves (which is now low at appr. 4%) can have a major effect on yields.

3.2. Ecosystem Services Contributing to SDG6 (Clean Water and Sanitation) Focusing on Clean Surface and Groundwater

3.2.1. Actual Conditions and Thresholds

For groundwater, the following N and P thresholds apply for the region Flevoland: 50 mg/L nitrate and 3 mg/L phosphate in groundwater (https://www.rivm.nl, assessed on 20 February 2022)). Surface and groundwater quality have not been measured in BASIS directly. However, it is known that nitrate levels in groundwater on clay soils in Flevoland are generally below the threshold of 50 mg/L of the EU Nitrate directive (EU 2000, https://www.rivm.nl, accessed on 20 February 2022). Because soils are calcareous, phosphate adsorption is relatively high and phosphate contents in groundwater will most likely be low. In the area of the BASIS experiment, nitrogen and phosphate levels in some of the surface waters are inadequate and some biocides are found above threshold levels due to rapid runoff and drainage losses during the growing season (www.zuiderzeeland.nl, assessed on 20 February 2022). The proxy indicators show that: (i) the nitrogen level in the soil before the leaching season in winter is 58 kg/ha, which is lower than the threshold for clay soils of 70 kg N/ha; (ii) the yearly nitrogen and phosphate surpluses for the farm are 8 kg N/ha and 11 kg P2O5/ha, which is below and above the thresholds of 88 kg N/ha and 0 kg P2O5/ha, respectively [29].

In summary: the thresholds for ecosystem services in line with SDG6 are not satisfied as the proxy for P is negative and the situation for surface waters is unknown.

3.2.2. Future Prospects

In BASIS, reduced tillage and organic farming did not result in lower risks of nitrogen leaching looking at the residual N in the soil at the start of the leaching season. Other measures to improve water quality are: (i) a sound crop rotation design where residual nutrients are used by following crops or catch crops; (ii) crop breeding to improve nutrient use efficiency; and (iii) various hydrological measures and the removal of nutrients in drains and agricultural ditches that can improve water quality [30,31]. As phosphate thresholds may not be met in the soil being considered, high-tech precision procedures, to be discussed in Section 4.2, are now available to fine-tune fertilizer applications to the needs of the plant, which vary during the growing season.

3.3. Ecosystem Services Contributing to SDG7 (Energy Use)

3.3.1. Actual Conditions and Thresholds

On a national level, contributions by agriculture to energy consumption are relatively low at 6% of the total energy use of 2939 pJ (www.cbs.nl, assessed on 20 February 2022). In a study on energy use in Dutch agriculture, the average energy use in conventional arable farming on clay soils was calculated in a model study to be only 41 GJ/ha/year [32]. There are as of yet no legislative thresholds of energy use for open field crop production, although a general reduction in the use of fossil fuels is a current policy objective. The lack of a threshold for energy use in individual farms does not allow a judgement as to whether a threshold is reached for a given Living Lab. Considering the low values involved, energy use should not affect the ultimate sustainability conclusions about the BASIS experiment.

3.3.2. Future Prospects

A reduction in energy use is also desirable in the future in agriculture, if only because it is associated with reducing costs. Reduced tillage requires less power and allows the use of lighter tractors. Organic farming reduces the energy needs to produce chemical fertilizers and biocides, but more energy is needed for the mechanical and thermal control of pests. Moreover, crop yields are lower, resulting in a higher energy use per unit of output. A fundamental change can occur by introducing new small-scale automated mechanization based on robots and solar energy (Section 4.2).

3.4. Ecosystem Services Contributing to SDG13 Focusing on Carbon Sequestration and GHG Emission Reduction

3.4.1. Actual Conditions and Thresholds

There are no measurements nor thresholds available for the GHG emissions of arable farms on marine calcareous light clay soils. Modeling results for the Netherlands have been reported based on IPCC criteria [17]. Agriculture in the Netherlands emits 15% of all greenhouse gases, of which half is CH4, which is mainly associated with dairy farming (www.emissieregistratie.nl, assessed on 20 February 2022). Carbon capture is seen as a soil contribution to ecosystem services focused on SDG13. As discussed in Section 3.1.2, soil organic matter contents are above a preliminary threshold value of 2.0 g/cm^3, thus providing a positive contribution to carbon capture.

In summary: thresholds for ecosystem services in line with SDG13 are satisfied for carbon capture, but the lack of data on greenhouse gas emissions does not allow an overall positive conclusion on the contribution of this ecosystem service.

3.4.2. Future Prospects

The contribution of reduced tillage to carbon sequestration is also under debate in the BASIS experiment. A significant increase was not observed in a ten-year period (Table 1) [33]. An increase in carbon sequestration is possible by incorporating more crops into the crop rotation with large amounts of crop residues, such as cereals, growing cover crops and applying (more) organic manure [33]. This was conducted in the organic system, leading to an almost significant increase in organic matter content (Table 1). Defining thresholds of carbon content for different soils could focus efforts to guide suitable management practices with the objective to increase the carbon content to locations with carbon contents well below the threshold and where effects would have the highest potential.

3.5. Ecosystem Services Contributing to SDG15 Focusing on Reduction in Land Degradation and Biodiversity Preservation

3.5.1. Actual Condition and Thresholds

Soils in the BASIS experiments were healthy (Section 3.1.2), so land degradation, characterized by poor soil health, appears not to be a problem here. Thresholds for farms when considering biodiversity in a landscape context have not yet been defined and are subject to political debate (Section 2.1).

In summary, ecosystem services in line with SDG15 are satisfied in terms of soil health, defining the lack of soil degradation. However, the lack of criteria to define biodiversity in a regional context does not allow a conclusion on biodiversity preservation and thus on the ecosystem service involved here.

3.5.2. Future Prospects

Soil degradation is not a problem in the healthy soils of the BASIS experiment, but this is an exception worldwide. The EU Joint Research Center reported that 60–70% of European soils are degraded in various ways [8]. This will have a strong negative effect on ecosystem services that increase when effects of climate change are considered. Studies on Italian soils confirm this alarming conclusion [34–37].

The biodiversity discussion at the farm level not only relates to soil biodiversity, for which in this analysis the organic matter content is considered as a rough proxy, but also to farms in a landscape context. As discussed, this is the subject of a heated political debate that will soon have to result in policies that provide clarity, allowing the formulation of future business plans, including long-term investments, by land users, of which farmers form the largest category.

In summary, assuming that the BASIS experiment is representative of well-managed commercial farms, ecosystem services in line with the SDGs 6, 13 and 15 do not meet the requirements either because of a lack of data or a lack of policies on biodiversity.

The experiment therefore does not yet qualify as a "Lighthouse", even though its soils are healthy!

4. Discussion

4.1. Implications for Environmental Rules and Regulations and Support Programs

The proposed system of evaluating ecosystem services in line with the SDGs can be the basis for an attractive and relatively simple regulatory system based on comparing indicator values, as discussed above, with thresholds that still need to be developed in most cases. Such a system should be based on measurements in system experiments on experimental farms and in "Living Labs", applying relatively simple field methods, which farmers will welcome, as they complain about the current complex systems. This requires the development of new measuring methods that can produce a lot of data in a short period of time, allowing a scientifically sound evaluation of spatial variability (Section 4.2). Soil health studies are important as soil health makes major contributions to achieving ecosystem services, as was shown with modeling studies for some Italian soils [34–37].

Of particular interest is a link with the future Common Agricultural Policy (2021–2027) where payments for ecosystem services are now one of the options being discussed. This could mean a substantial payment when all ecosystem services have a sufficiently high level. If one or more of the services are inadequate, a focused subsidy on the lacking services can be considered, as a case study in Switzerland has shown, where subsidies were based on introducing cover crops and on applying minimum tillage to enhance carbon sequestration. This program turned out to be highly successful [38].

The system presented in this paper is based on the selection of a limited set of relatively simple indicators directly coupled to an ecosystem service linked to SDGs or, separately, to soil health contributing to ecosystem services. Along these lines, the application of a soil indicator set is being explored in the Netherlands [39].

4.2. Need for Operational Measuring and Monitoring Methods

4.2.1. Ecosystem Services for Farming Systems

Ecosystem services for farming systems were only partly adequate, as demonstrated in Section 3. As discussed, production levels were well-documented and can be supported by modeling the soil–water–atmosphere–plant system. Several well-tested models are available [40–42]. Basic soil data, such as texture, bulk density and organic matter content, are used in so-called pedotransfer functions to predict hydraulic soil characteristics needed for modeling such as hydraulic conductivity and moisture retention [43,44]. However, aside from modeling, measurements of real yields are still also necessary to validate the models. We advocate for attention to climate change, which will have major effects on food production. Obviously, only modelling can handle future climate scenarios **(SDG2)**. Healthy food, based on healthy crops, can be assessed by existing health regulations' defining thresholds. This is, however, a highly dynamic field of study as new pollutants arrive **(SDG3)**. The quality of ground and surface waters **(SDG6)** could only be derived from national monitoring systems and are not yet part of monitoring systems at the farm level. This would be required when assessing "Living Labs" in future. Modern automated monitoring systems are available to obtain hard data that do not depend on debatable interpolations from current, often far-away, measurement locations. Energy use (**SDG7)** is less relevant from a national point of view but is important for individual farmers as a cost item to be reduced. The emission of greenhouse gases **(SDG13)** is important and is now being estimated by modeling, even though the particular soil being considered here was not yet covered. However, modeling is only justified when the models are properly validated with measured data. This validation process is still rather undefined, and direct measurements are therefore needed. The available measurement methods using small on-site chambers are cumbersome and costly while only providing point data at specific moments in time. Applying frequent satellite images would be highly attractive, as is being explored now by the European Space Agency (https://www.esa.int, assessed on

20 February 2022). This type of work needs a high priority and strong support. **(SDG15)** refers to land degradation, where the indicators for soil health are relevant to assess soil degradation. Biodiversity (as discussed in Sections 2.1 and 3.5) is, however, still undefined in terms of specific indicators for the entire farming system. Policy decisions on future land-use scenarios are therefore urgently needed. Innovative methods for measuring ecosystem services are summarized in Table 3.

Table 3. Summary of methods to be used for characterizing ecosystem services in line with the SDGs and the Green Deal and the contributions of soil health, as discussed in this paper.

	Methods for Measuring Ecosystem Services	**Methods for Assessing Soil Contributions to Ecosystem Services**
SDG 2/3	• governmental statistics • remote sensing • modeling the soil–water–atmosphere–plant system, also considering climate change	• new methods to characterize soil structure: radiation methods for bulk density; proximal sensing for organic matter • modeling the soil–water–atmosphere–plant system
SDG 6	• automatic monitoring equipment	• modeling soil nutrient regimes to support precision techniques
SDG13	• satellite remote sensing for measurement of emissions • validated models estimating greenhouse gas emissions	• proximal sensing of organic matter content focused on carbon capture
SDG 15	• soil health • biodiversity on a landscape scale	• all of the above

4.2.2. Soil Contributions to Ecosystem Services

Soil contributions to ecosystem services can be framed in terms of soil health, for which several indicators have been defined as discussed in this paper. Soil as a favorable environment for root growth is key for all ecosystem services contributing to the five SDGs being considered. Soil structure, the organic matter content and soil moisture regimes are key indicators for soil health, assuming a lack of pollutants and adequate levels of nutrients by fertilization. The current standard methods assessing **soil structure**, as reviewed above for bulk density, use relatively small soil samples and are costly and laborious as they require laboratory analysis, not providing instant data. Standard deviations among replicate measurements are relatively high due to small sample volumes (see Table 1) and, considering 95% confidence intervals, hardly allow the distinction of differences among treatments, let alone among different soils. Measuring the penetration resistance is attractive, as many observations can be instantly made. An important factor causing variation among measurements is moisture content; so, measurements will have to be made at certain periods only, preferably only when the soil is at field capacity. Innovative techniques are available to allow rapid, multiple and cheap measurements for both **organic matter** content and bulk density once equipment has been obtained. The application of proximal sensing for organic matter [45–47] and further testing of radiation techniques for measuring bulk density (e.g., [17]) are highly recommended. Field research on the impact of present and past soil management on the organic matter content of a given type of soil can provide valuable insights on the effects of management that differ significantly among soils. Organic matter contents were sampled at fifty farms on two prominent Dutch soil types, and the study could relate actual organic matter content very well ($R^2 > 0.8$) with current and past management, providing valuable suggestions for future management practices [20,21]. There are thousands of experiments out there in the field waiting to be discovered! **Soil biodiversity** is being studied widely, but so far, standard techniques have not been suggested or approved. Doing so is a high priority as soil biodiversity plays a key role in soil functioning (Section 2.2). Applying proxies, such as the organic matter content, as in this study, needs improvement.

The simulation of **soil moisture regimes** combined with nutrient dynamics in the soil–water–atmosphere–plant system can provide important information for precision agriculture where nutrient inputs are fine-tuned to the needs of plants, optimizing the **soil fertility** regime. This can result in substantial savings of fertilizer input and costs of up to at least 10%, thereby also reducing leaching and groundwater pollution by excess nutrients. A study on precision fertilization consisted of the preparation of a functional soil map with four different soil units, derived from the interpolation of point data, with a distinct behavior in terms of water regimes and nitrogen dynamics. Modeling was applied to determine the critical moment when the available nitrogen reached a threshold. Then, fertilization was needed. This moment was different for the different soil units, providing a basis for applying precision techniques [48]. Again, robots can in future perform the task of fertilization, strongly reducing labor demand and reducing pressures on soil by traditional fertilization equipment.

Innovative methods for measuring ecosystem services and soil health indicators are summarized in Table 3.

4.3. Need for a Paradigm Shift in Research

To reach the targets of the SDGs, farmers have to adapt their soil management and farming system to meet the thresholds of at least five ecosystem services. This presents "wicked" problems that cannot be solved with linear research approaches, as discussed in Section 1.2.

A farmer will choose the option or elements of different options that correspond best with their particular farming style [49]. Researchers should therefore preferably act as honest brokers considering the various options fitting the targets of the SDGs and the farming style of the farmers [50]. Then, producing "storylines" for particular soil types is an effective procedure for communication purposes, linking particular soil types to successful management plans [51]. This approach is, by the way, also followed in business courses at Harvard University [52].

There are already many storylines on management systems in the Netherlands and elsewhere that are actively promoted on social media and the internet: organic, bio-dynamic, circular, nature-inclusive, regenerative [53], enriching, high-tech precision, etc. However, all these systems can be judged the same way by considering whether an adequate level of ecosystem services is provided, including the contributions by soil science. This will create much-needed clarity to the farming community and society at large, allowing a more effective focus on the SDGs to be achieved.

However, defining best practices when working in "Living Labs" has broader dimensions. A recent EC document specifying the Mission approach to the European Science and Innovation program: Horizon Europe 2021–2027 [2] included a statement for the "Soil Deal for Europe" Mission: "*people from all works of life and businesses can co-create knowledge and solutions in real life conditions and demonstrate their value*". In addition: "*Introducing Citizen Science and citizens becoming soil stewards are desirable innovative approaches*" that do, however, require "*clear and concrete objectives*". Working in "Living Labs" does, therefore, involve more than researchers and farmers working together. Frequent communication with society and the involvement of citizens is needed to establish agriculture as a major positive contributor to environmental health and sustainable development rather than as a persistent polluter, as seems to be a persistent message from some quarters.

However, broad and effective multi-stakeholder efforts in "Living Labs", ideally resulting in the establishment of "Lighthouses" where all ecosystem services meet their thresholds, will have little effect when not incorporated in governmental rules and regulations and subsidy schemes, as discussed above for the CAP 2021–2027. In this context, the recent Berlin communiqué by 68 ministers of agriculture, following the Global Forum for Food and Agriculture, is very important [54]. They discuss sustainable land use and conclude that "Food security starts with the soil". Not only the importance of soil health is emphasized, but also the role of soils in addressing 24 issues related to the SDGs. As in other publications [2,8], operational methods and criteria needed to achieve the goals are not discussed, justifying the focus of this paper on methodology.

Finally, ten challenges for future soil research have been defined, reflecting discussions within the IUSS-PEDOMETRICS working group [55]. Their Challenge 7 focuses on recognizing, quantifying and mapping soil functionality, and Challenge 10 focuses on how to generate quantitative soil contributions in realizing ecosystem services. The discussions in this paper can therefore be seen as a contribution to these important and crucial PEDOMETRICS discussions. Clearly, more research is needed to develop protocols of general validity.

5. Conclusions

1. The proposed joint establishment of "Living Labs" and system experiments at research farms to develop sustainable land use systems in line with the SDGs and the Green Deal requires an as-yet not existing methodology that allows the assessment of ecosystem services and thresholds to assess system functioning. "Lighthouses" can only be established when these thresholds are satisfied.
2. Soils can make crucial contributions to ecosystem services by assessing and improving soil health, to be demonstrated in interdisciplinary case studies.
3. The development of new innovative monitoring techniques is essential to assess the sustainable development of land-use systems, where farms constitute the largest group. The current laboratory tests are often too costly and time-consuming. Studies on new monitoring techniques, among them proximal and remote sensing, need strong support.
4. A focus on documenting indicators and thresholds for ecosystem services when working with farmers is particularly relevant, as the future Common Agricultural Policy (CAP) intends to focus its support partly on the provision of such services.
5. Adaptive management by farmers implies not only producing heathy food but also protecting ground and surface water quality, restricting greenhouse gas emissions, increasing carbon capture, combatting land degradation and protecting and improving biodiversity. This presents a "wicked" problem that cannot be approached by linear research, but needs more stakeholder-oriented holistic approaches and can be expressed by well documented "storylines" that are also effective for communication with the policy arena, farmers and citizens at large.

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