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Article

Soil Security in Sustainable Development

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Abstract: The United Nations (UN) Sustainable Development Goals (SDGs) provide an excellent channel to demonstrate the significance of soils when considering e.g., food production, water availability, climate mitigation and biodiversity preservation. For environmental sciences, including soil science, the SDGs provide "a point at the horizon" for future research. Progress to achieve the SDGs by 2030 will bureaucratically be monitored by targets and indicators but questions as to how effective research should be organized remain unanswered so far. The soil security concept, based on the five Cs (capability, condition, capital, connectivity and codification) can provide a clear guideline for soil science research, defining soil functions contributing to interdisciplinary ecosystem services that, in turn, can define measures to reach SDGs. A "storyline" is proposed linking the five Cs, emphasizing connectivity that becomes increasingly important in our modern "fact-free" world. The traditional linear research model does not apply when characterizing SDGs because of many conflicting interests that don't allow definition of specific "solutions". But different action-perspectives can be defined as a basis for decision making, creating much needed transparency in the decision process. Soil contributions are most effective when framed in the context of soil-water-atmosphere-plant models. Proper codification, including clear and candid communication with stakeholders, is essential to link science with society, a link that needs improvement.

Keywords: interdisciplinarity; transdisciplinarity; simulation modeling; soil classification; genoforms; phenoforms

1. Introduction

The concept of sustainable development was introduced by the Brundtland report of 1988 and has become a key document when discussing economic, social and environmental developments in the world ever since. Even though innovative at the time, inspiring and attractive, the concept did not include operational guidelines or performance criteria. The Millennium Goals of 2000 did so but they applied only to the developing world. The 17 Sustainable Development Goals (SDGs), approved in 2015 by 193 countries at a session of the General Assembly of the United Nations, extend the concept of sustainable development to the entire world and contain sets of binding targets and indicators to be met by 2030. This presents a real challenge to the science community and certainly to soil science [1].

But how to reach these targets and indicators is still subject to ad hoc initiatives by national or local governments and their agencies, as well as by citizen action groups, all of them needing advice from the research community. The 17 goals are very broadly articulated and every scientific discipline can and should play a role in devising scenarios that can lead to realizing the goals. This leads to a question as to the role of soil science, considering that soil science all by itself cannot and should not develop such scenarios. One objective of this paper is, therefore, to define the role of soil science in interdisciplinary research focused on the SDGs. Next, this paper will argue that the soil security concept, with the 5 Cs—capability, condition, capital, connectivity and codification [2,3]—can provide a systematic and operational approach for soil science that can result in effective contributions to interdisciplinary studies focused on realizing the SDGs. Just defining targets and indicators is not adequate when aiming for realization of the SDGs and runs the risk of leading to bureaucratic checking of boxes on evaluation sheets! However, currently the 5 Cs are often presented and discussed as seperate entities which is less effective than considering a storyline to be suggested in this paper, logically connecting the 5 Cs.

This paper also emphasizes the importance of the "connectivity" aspects when communicating with stakeholders and the policy arena. The introduction of social media during the last decade has drastically changed the relation between science and society as "post-truth" and "fact-free' attitudes become more prominent. The "connectivity" aspect of soil security will, therefore, receive particular attention in this paper.

The overall objective of this paper is to show that the soil security concept can significantly contribute to improving contributions by the soil science discipline to inter- and transdisciplinary studies focused on realizing the SDGs.

2. The Role of Soil Science in Interdisciplinary Sustainable Development Goal (SDG) Projects

Before discussing possible contributions of soil science to interdisciplinary studies focused on the SDGs, the question is warranted whether a focus on SDGs is desirable. Some may feel that such a focus presents a restriction to what should be complete intellectual freedom. However, this does not apply because the formulation of the SDGs is so broad that all research will fit in one way or the other. A major advantage of a focus on SDGs is the framing aspect because the relevance of soil research to the outside world will be more obvious when links with the SDGs are shown. Also, a common focus, however broad it may be, is useful for the soil science profession that is still divided into many rather independent subdisciplines. Think of pedology, soil physics, chemistry, biology and management. The SDGs provide a valuable "point at the horizon" for the soil science profession.

Of the 17 SDGs, al least five have a direct relation with soils, while others have a more indirect relation (Table 1). Even though each one can be summarized in terms of food, health, water, climate and ecosystems, the descriptions cover a wide variety of subtopics that require input by many different disciplines. For example, SDG 2 requires "ending hunger and food security" which has not only agronomic but also social, economic and, last but not least, political dimensions. The same can be stated for "Improvement of nutrition" where not only availability of healthy foods is required but also culturally determined habits of consumers that are difficult to manipulate. Finally, "sustainable agriculture", balancing economic, social and environmental aspects has been studied for decades by, among others, agronomists, economists and social scientists. At least 20 other disciplines could be involved with studying SDG2. Similar analyses can be made for the other SDGs showing their complexity.

Table 1. Five Sustainable Development Goals (SDGs) in which soils play a key role. Soils are also important for several other SDGs.

2. End hunger, achieve food security and improve nutrition and promote sustainable agriculture (FOOD).
3. Ensure healthy lives and promote well being for all at all ages. (HEALTH).
6. Ensure availability and sustainable management of water and sanitation for all (WATER).
13.Take urgent action to combat climate change and its impacts (CLIMATE).
15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably managed forests, combat desertification and halt and reverse land degradation and halt biodiversity loss (ECOSYSTEMS).

The obvious statement that soil science by itself cannot develop SDG scenarios, requiring participation in interdisciplinary projects, raises the next question as to how to select a limited number of research partners that can result in workable arrangements. I propose that working with soil-water-atmosphere-plant specialists is most effective as a first step, using a wide variety of validated models that are now available. Here, the Soil-Water-Atmosphere-Plant (SWAP) model will be used [4]. SWAP researchers and modelers will focus on soil functions that contribute to ecosystem services that, in turn, contribute to SDGs. The role of soil scientists is to define the soil functions that contribute to ecosystem services. To avoid confusing terminology use of the term "soil services" should be avoided [1]. Case studies, illustrating use of modeling to define SDGs will be presented later in this paper.

3. Linking the Five Cs of Soil Security to the Soil Functions, Ecosystem Services and SDGs

Each of the SDGs has a set of targets and indicators that define progress being made in achieving them. But how to reach these performance indicators is not defined and procedures have to be developed by the scientific community that somehow will be effective in reaching the SDGs by 2030. The Soil Security concept can play an important role in guiding this type of SDG oriented research. There is, however, a risk that the 5 Cs are approached independantly [2,3,5]. A storyline that logically connects the 5 Cs not only results in a link between them but is also useful for communication purposes to the outside world [6]. The following storyline is proposed:

> *Considering a given type of soil, how and by whom is the soil being used and managed? What are their questions and goals? Who passes judgements? ("connectivity"). What is its "condition" in terms of its contribution towards ecosystem services and what contributions might be potentially possible? ("capability"). How does this soil compare with other soils in terms of its contributions ("capital") and are its condition and capability properly addressed in societal and policy legal frameworks ("codification").*

Note that the usual sequence of the 5 Cs, starting with capability, condition and capital is changed putting more emphasis on "connectivity" which is crucial when aiming at realization of the SDGs in the near future. Even though "codification" is mentioned as the last item, this C is increasingly important as the gap between science and society appears to be widening.

4. The Importance of 'Connectivity' in a 'Post-Truth' World

4.1. Limitations of the Linear Research Model When Investigating SDGs

We have a problem in soil science. Several publications (e.g., [7]) emphasize the need for soil research by indicating that at least 30% of the soils of the world are degraded in various ways. But in all candor we have to admit that many case studies have been published showing that many of these problems can be solved by currently available technical and operational measures (e.g., [8,9]). A realistic question at this point in time is: "Why are land users not applying available results of scientific studies to combat soil degradation?" There clearly is a gap between science and society that is comparable to the gap between society and the policy arena in many countries. This gap also applies to soil science.

A recent thorough analysis that summarizes much earlier research [10] indicates that many people have the feeling that they are not being treated seriously by researchers. Trust is lost and people feel lack of recognized identity. Feelings like this fuel "post-truth", "fact-free", "alternative facts" and "fake news" phenomena that seem increasingly to affect the societal discourse, strongly enhanced by social media that have become prominent in only the last decade.

A concluding comment by chairman Budiman Minasny at the end of the successful PEDOMETRICS soil conference in 2017 illustrates the gap between soil science and society: *"Pedometrics is still mostly supply driven, not demand driven. Are results of pedometrical applications really used by land users?"* This rhetorical question implies a correct negative answer.

One major reason why trust has been lost is due to the linear model of research [11,12]. A problem is identified, a hypothesis is formulated, and research is undertaken with appropriate methods, either existing or newly developed. Results are statistically analysed and should be reproducible. Results are communicated to users. Whether results are implemented remains unclear. Agricultural research has been highly effective in the past by employing government-financed extension workers but most of them have fallen victim to privitization. The key product of the linear model of research is a solution and the basic procedure implies that "they" have a problem that "we" solve. This procedure has been very successful in the past and it still is when clear-cut problems are identified. But the linear approach fails when investigating SDGs because there is no problem with a unique solution. Considering the long descriptions of the SDGs and the many stakeholders involved, all with conflicting interests and opinions, all that can be done is developing action perspectives (scenarios), one for each of the groups involved. It is important never to say that something cannot be done as this will not be a contribution to trying to establish trust. Anything is possible, in principle, but we, as researchers, can show what the economic, social and environmental consequences would be of any scenario judged in terms of their effect on relevant SDGs. The stakeholders or the policy arena will have to choose and this will always involve tradeoffs between different scenarios. The product of this scientific analysis is scenarios. But a second product is at least as important: transparency. No more hazy deal-making and politicians hiding in the fog but clarity about the goals and tradeoffs involved. This approach implies a need for continuous contact with stakeholders to be sure that all actors stay involved in the research process. Here, in contrast to the linear approach, "we" have a problem and exploring scenarios implies joint learning with a step-by-step approach in which tacit knowledge of the stakeholders is considered first followed by applying existing techniques and methods, and if this does not result in satisfactory results, new research may be initiated.

Two case studies will be discussed to illustrate the discussed approaches with emphasis on engaging stakeholders.

4.2. Various Ways of Engaging Stakeholders in Six Case Studies on Land Use

One way to earn trust of stakeholders is to engage them right from the start of a given project, showing genuine interest in their opinion. Six published case studies on land use were analysed [13] emphasizing relevant SDGs and interaction processes with stakeholders. Study 1 discussed agricultural development versus nature conservation in Dutch heavy clay soils. Development required drainage and irrigation practices that could not be predicted with standard simulation models simulating soil moisture regimes because the "sand" model did not apply [14]. Tacit knowledge played a role by indicating practical problems encountered. Existing flow theory did not work and a series of new techniques had to be developed [13] (Figure 1). SDGs 2, 4 and 15 were addressed. Study 2 covered a problem arising from a conflict between nature conservation and a planned development scheme. Would breaking up of a hard podzol-B horizon result in lack of lateral water flow feeding surface ponds? Existing methods for measuring permeability could not be applied. Right away a new method had to be developed to measure Ksat of the B horizon [15]. (Figure 1). SDG 15 was addressed. Study 3 covered development of dairy farming protecting biodiversity (see also Section 6.1). Farmers proposed a circular dairy system with less external inputs and this was compared, applying a life cycle analysis, with traditional farming systems. The proposed system scored better than the traditional ones [16] (see also Table 2). Tacit farmer knowledge was important followed by applying existing models and available data. SDGs 2, 4, 13 and 15 were addressed. Study 4 covered agricultural development being hampered by environmental quality rules and regulations. Precision agriculture was developed to fine-tune fertilization practices, avoiding groundwater pollution by chemical fertilizer and biocides [17]. Tacit farmer knowledge was important here, followed by applying existing simulation models and data gathering techniques. However, new techniques had to be developed to define spatial patterns. SDGs 2, 12 and 15 were addressed. Study 5 studied the irrigation needs of maize hybrids with increased drought resistance. The study was made in the Destre Sele area in Italy of 20,000 ha (Figure 2) with four distinct landscapes and five soil series. Here and elsewhere in the Mediterranean area periodic drought is a severe problem that will worsen following projected climate change [18,19]. Farmers were approached by crop breeders offering new drought-resistant maize hybrids and by irrigation engineers offering smart irrigation systems. What to do? Simulation was used to define options (see also Section 4.3). Aside from tacit farmer knowledge, existing models and available data were adequate to complete the work. Note that other disciplines involved in this interdisciplinary project did need new plant-breeding research to establish the water demands of 11 maize hybrids. SDGs 2, 6, 13 were addressed. Study 6, finally, covered a regional project in The Netherlands intended to locally increase water storage as well as allow purification of urban wastewater (www.richwaterworld.com). Selected subcatchments had to be identified and excavated and hydraulic soil characteristics had to be measured to run regional hydrological models with the objective to obtain optimal placement of the various subcatchments. Citizens were involved in planning and, again, available methods could do the job. Note that other involved disciplines had to do new research to couple different models into a unified package. SDGs 4 and 15 were addressed.

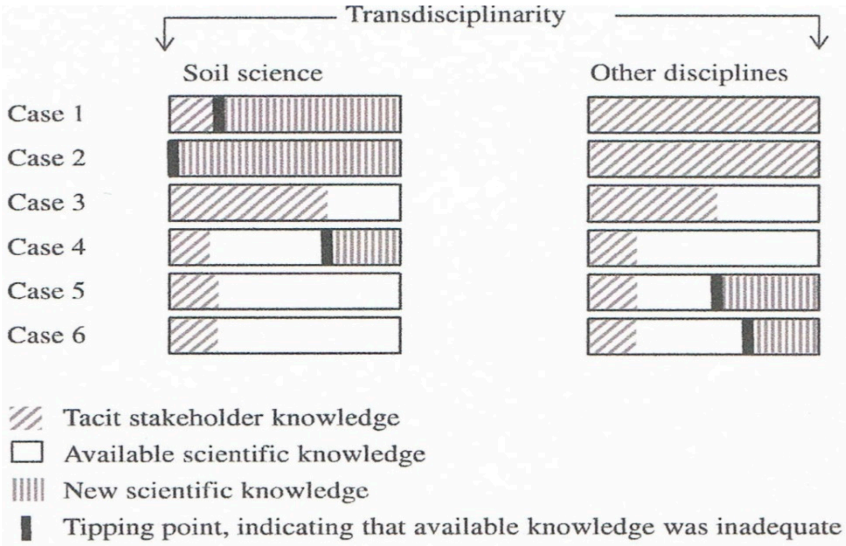

Figure 1. Application of tacit, available and new knowledge in six case studies. From [13].

Table 2. Results of the life cycle analysis for dairy farms in the Northern Frisian Woods comparing seven farms with circular management with seven traditional farms. Derived from [16].

non renewable energy use: 5.1 MJ/kg milk vs. 5.9	= −15%
input chem.fertilizer N: 128 kg/ha vs. 146 kg/ha	= −12%
nitrate leaching: 5.1 kgN/ha/yr vs. 7.0 kgN	= −30%
ammonia emission: 30 kgN/ha/yr vs. 35 kgN	= −15%
soil organic matter: 186 tonC/ha vs. 156 ton/ha	= +20%
av. farm income: 8.3 €/100 kg milk vs. 5.9 €/100 kg milk	= +40%

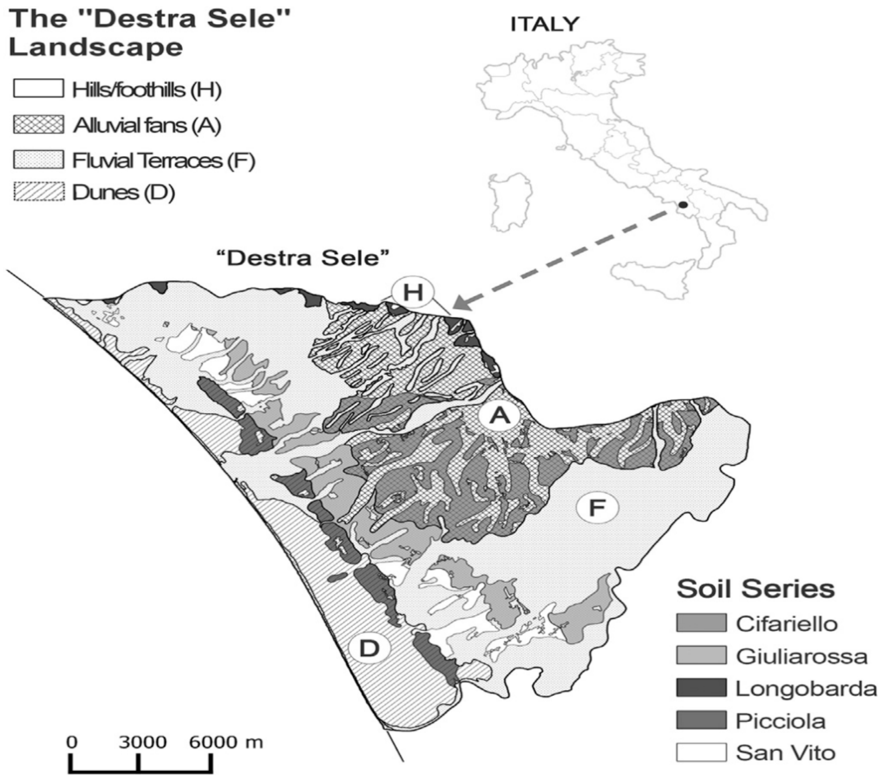

Figure 2. The Destre Sele area in Italy where the growth of 11 maize hybrids was studied as a function of water regimes and climate change (from [19]).

By involving stakeholders right from the start in all these studies, trust between researchers and stakeholders was established as a "joint-learning" trajectory was created. Involving stakeholders, however, takes a lot of time that is often not available as researchers have to reach demanding performance indicators. Also, note that in three cases available methods could do the job. No new research was needed. This message is important for the policy arena where questions are raised about continuing demands for research money, developing yet another model or database. Showing that existing methods cannot do the job is a better basis for documenting requests for new research funding.

4.3. Offering Options to Italian Farmers

As briefly discussed in Section 4.1., study 5 used the SWAP model to explore the effects of growing 11 maize hybrids, two of which obtained by genetic engineering [4]. Hybrids were subject to different moisture availabilities also considering projected climate change in the period until 2050 as defined by the Inter-governmental Panel on Climate Change (IPCC). Results in Figure 3 show effects of 80% and 60% water availability. Optimal development of the maize crop is indicated by dark bars. Not only do hybrids react quite differently to moisture stress, the effects of the five soils are quite different as well. As presented, results offer options to farmers. Considering the type of soils on their farm, they can either select a given hybrid or an irrigation regime as the model also defines the moisture deficit in mm for the 80% and 60% scenarios. Farmers receive options from which a choice can be made, representing a research approach that is suitable for studying SDGs. Note that soil types (here, soil series) are ideal "carriers of information" as each one delivers a particular "message", acting as a "class pedotransferfunction" [14].

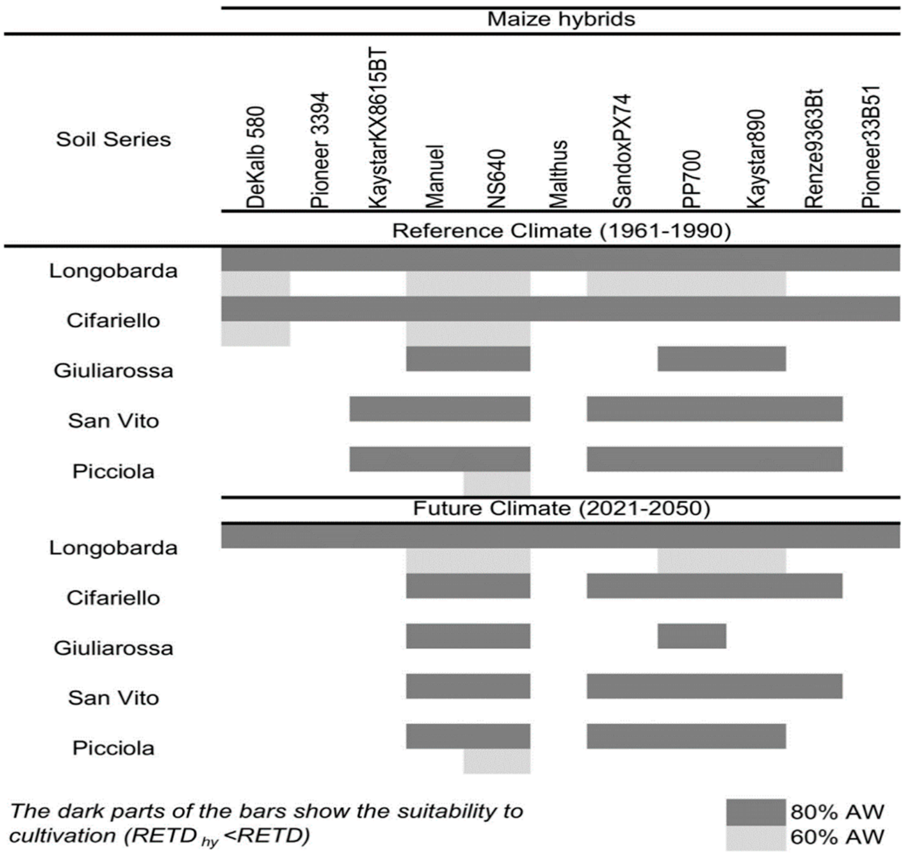

Figure 3. Development of eleven maize hybrids in the Destre Sele area in five soil series as a function of two water regimes supplying 80% and 60% of required water. Also, projected effects of climate change in the period 2021–2050 are indicated (from [19]).

5. Soil-Water-Atmosphere-Plant Models Characterizing 'Capability, Condition and Capital'

Soil capability, condition and capital have already been characterized well by several authors [2,3]. Here, the emphasis will be on an option to link up with an agronomic study on the "Yield Gap" (www.yieldgap.com) [20]. In this program, Yp is defined as the potential production level of a selected representative crop, as determined by radiation and temperature assuming optimal water availability and soil fertility and lack of pests and diseases. Yp acts as an indicator of **capability**. Yw is the water-limited yield, which is identical to Yp except that the actual soil water regime is considered. Ya, finally, is the actual yield that can either be measured or estimated by simulation and represents the **condition.** The soils in the Desta Sele area (Figure 1) to which the Lazzaretto soil series was added, were characterized by simulating Yp and Yw values with the SWAP model [4]. Yw values were calculated for four climate periods, a reference climate and IPCC climate data for three consecutive periods up to the year 2100. Figure 4 shows values for each soil that are generally decreasing in the coming century. For a detailed analysis the reader is referred to [21]. Here we emphasize that the analysis can also be made for different forms of soil degradation of which the effects of compaction (Figure 5) and erosion (Figure 6) on Yw will be shown. Any of these represents a given **condition**. The degraded soils have the same soil classication as the non-degraded variant but thus different "Phenoforms" can be distinguished as a function of management that has resulted in compaction and erosion [22,23]. Again, as in Section 4.2, the soil series acts as a "carrier" of information. Certain soil series have consistently higher values than others in the different climate categories, often due to textural differences and rooting depths. Therefore, they represent higher **capital**, as compared with other soils.

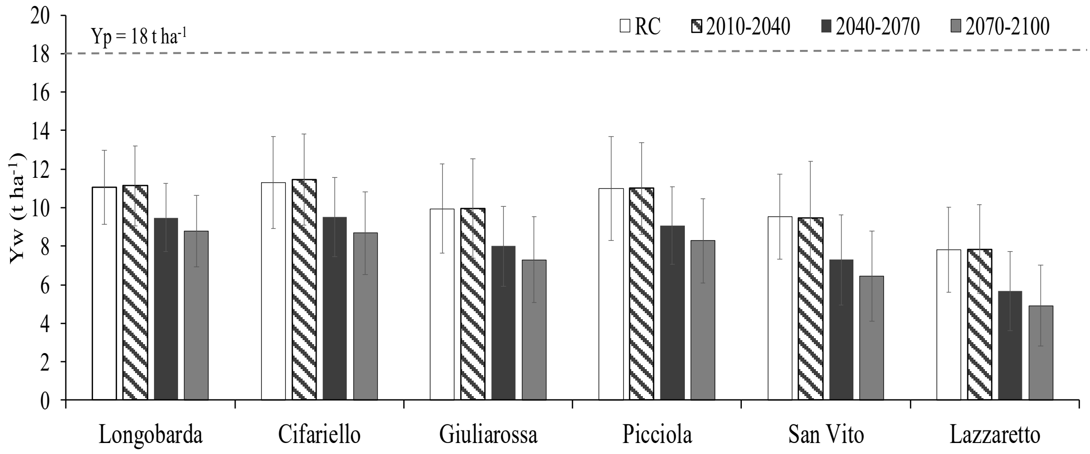

Figure 4. Yw values for six soil series in the Destre Sele area, indicating effects of the reference climate and three climate scenarios of the Inter-governmental Panel on Climate Change (IPCC) (from [21]).

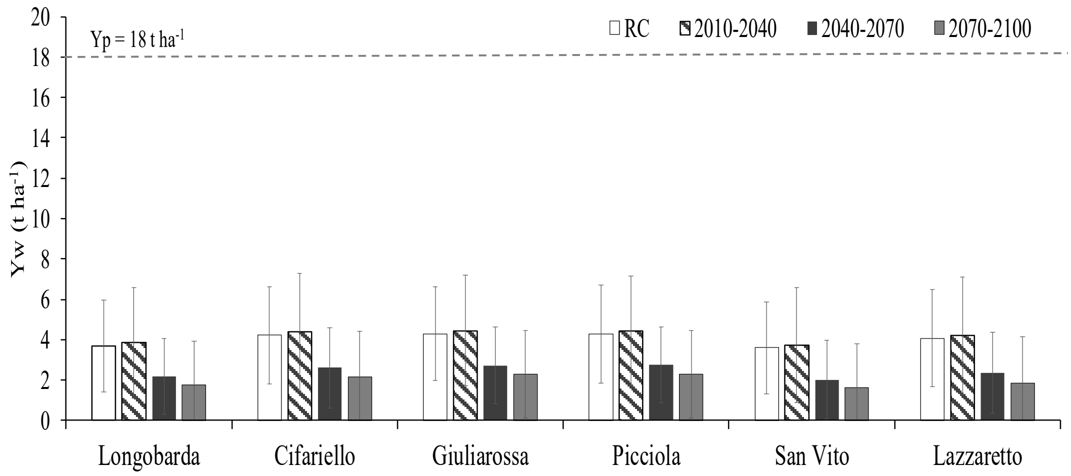

Figure 5. Effects of a plowpan on Yw in each of the six soil series, again expressed for four climate scenarios. Compacted soil series represent Phenoforms of the particular Genoforms (from [21]).

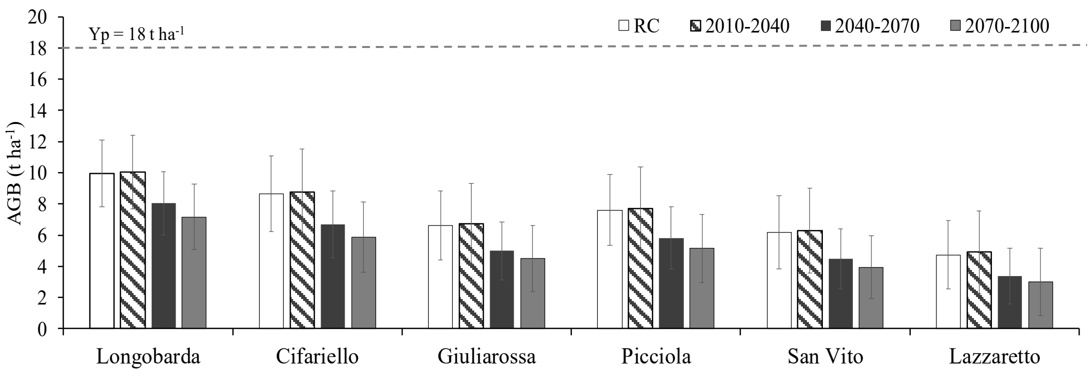

Figure 6. Effects of soil erosion on Yw in each of the six soil series. Eroded soil series represent Phenoforms of the particular Genoform, assuming that erosion has not resulted in a change of classification (from [21]).

6. Facing 'Codification' as a Major Challenge to Connect Science with the Policy Arena

6.1. A Circular Approach to Farming Can Be a Guide for New, Innovative Environmental Policies

Codification, expressed by environmental policies, forms a structural link between the science and policy arena. Stakeholders and citizens at large are only supportive of governmental rules and regulations when the reasoning behind the rules and benefits are clear. When unclear, problems arise. This clearly occurrred in The Netherlands as discussed elsewhere [24,25]. Rather than complain about existing laws, a group of Dutch dairy farmers initiated an effort to realize circular dairy farms with lower external inputs of feed and labor, lower chemical fertilizer rates and higher applications of organic manure. Lower protein content of feed led to lower ammonia emissons when manure was applied to the land (study 3 in Section 4.2) [16]. Comparing seven farms with a cyclic regime with seven more traditional farms clearly showed the advantages of the cyclic approach (Table 2). Net income was higher because of lower costs, not higher milk production. This example can be an illustration of what could become a future regulatory system. Currently, only threshold application rates of fertilizer are defined in legislation with the objective to protect ground- and surface water and air quality. But these goals of the legislation are not measured at farm level, while farmers are required to prepare detailed time-consuming accounts of nutrient inputs and outputs of their farm.The current system is hard to explain because the link with environmental quality is missing. To regain trust by farmers in future, water and air quality should be measured at the farm level, using modern sensors that are widely available, and nutrient fluxes should be determined using models as reported [16,26]. Once farmers satisfy environmental threshold values for water and air quality, they should receive a "good-practice" certificate and be left alone. Every farmer is different and that' is why "tailor made", rather than: "one-size-fits-all", approaches are needed. Periodic at random tests should be made to make sure that farmers continue their agreed upon practices. Such a procedure would be more effective than loosely defining "good" and "green" practices [27].

6.2. The Challenge of the '4per1000' Proposal of the Paris Conference of the Parties (COP21)

A major recent codification issue is the "4per1000" proposal of the Paris climate conference in 2015 (Conference of the Parties, COP21). This proposal is part of SDG 13 on climate change and, as governments have signed up to reach the SDGs by 2030, this does include the "4per1000" proposal. The basic principle is clear and simple: soils contain large amounts of carbon. Only a relatively small increase could significantly contribute to binding greenhouse gasses, like CO_2, from the atmosphere. Each year 4.3 billion tons of carbon (C) is added to the atmosphere by greenhouse gasses (CO_2, CH_4). All soils of the world contain 1500 billion tons of C. So if the soil-C content could increase by only 0.4% a year ("4per1000") then the increase of atmospheric greenhouse gasses could be neutralized. It is a clear proposal that everybody can understand and this is necessary to attract attention by the policy arena and the public at large. The reaction of the soil research community was immediate. A paper exploring the feasibility of the plan [28] was criticized [29–31]. But other authors showed that smaller increases than claimed would be possible [32–35]. Just a little more than a decade is left before 2030. Whatever change is feasible from a scientific point of view will have to be realized in the real world where actual land management is being practiced. Communication with and encouragement of land users is crucial. As C contents of arable land have most strongly been reduced, focusing on such pieces of land would be most efficient. This is illustrated by data for two major soils in The Netherlands (Table 3 with data from [36,37]). Arable land has significantly lower contents of organic matter than meadows. Overlaying a soil map with a land-use map, or using satellite images to distinguish arable land, allows identification of areas with arable land where efforts to increase the organic matter content are bound to be most successful. Subsidies could be used to simulate farmers to innovate their management. Note that the ranges of organic matter contents for Phenoforms of, in this case, a sand and a clay soil are quite different. When discussing organic matter contents of soils, distinction of soil types as "carriers of information" (or class-pedotransfferfunctions as defined by [14]) is important to stratify data. Soil types have a fascinating "story to tell". It is the difficult task of soil scientists to articulate that story in terms of human language that is bound to produce only a poor version of the original.

Table 3. Different contents of organic matter of topsoils as a function of management in two soil series in The Netherlands. Two genoforms are shown with each three Phenoforms. Regression equations presented show a highly significant relation between the actual %C and current and past land use of the two soil types (derived from [36,37]).

Genoform: coarse loamy, siliceous, mesic Plaggenthreptic Alorthod (Soil Taxonomy); Plaggic Entic Podzol (WRB)	
Phenoform 1: topsoil old grassland	OM = 8.1%
Phenoform 2: topsoil reseeded grassland	OM = 6.3%
Phenoform 3: topsoil conv. arable land	OM = 4.8%
% Org.matter = 3.40 − 1.54 × Maize +0.19 × Old + 0.55 × GWC.	(R^2 = 0.75) (50 farms)
Genoform: loamy, mixed, mesic Typic Fluvaquents (Soil Taxonomy); Haplic Fluvisol (WRB)	
Phenoform 1: topsoil old grassland	OM = 5.0%
Phenoform 2: topsoil organic arable land	OM = 3.3%
Phenoform 3: topsoil conv. arable land	OM = 1.7%
% Org. matter = 20.7 + 29.7C1 + 7.5 Cv +7.5 Miv	(40 farms) (r-square: 0.74)

So far, a systematic approach to increase the C content of soils at farm level is missing. Many process studies on C transformation are made but C dynamics in soil are highly complex and so are the corresponding simulation models. There also is a tendency for researchers to develop their own models.

Acknowledging the importance of process studies, a pragmatic procedure using soil survey data and measurement of organic matter contents for different Phenoforms in the field of a given Genoform could be a pragmatic approach to reaching practical results within a limited time frame.

7. Conclusions

1. The UN SDGs provide a useful frame to present scientific research to the outside world.
2. The 5 Cs of the soil security concept can provide a systematic roadmap to realize effective SDG-oriented research. Targets and indicators that are now part of the SDG proposal are inadequate as a guide for the research process.
3. Models of the soil-water-atmosphere-plant system are an effective vehicle for interdisciplinary soil studies that are needed, aimed at realization of the SDGs.
4. In the post-truth 21st century, connectivity is a key ingredient of SDG-oriented studies, linking stakeholders to problem identification, research execution and implementation and also allowing (hopefully) a meaningful connection with politicians.

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References

1. Keesstra, S.D.; Bouma, J.; Wallinga, J.; Tittonell, P.; Smith, P.; Cerdà, A.; Montanarella, L.; Quinton, J.N.; Pachepsky, Y.; van der Putten, W.H.; et al. The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals. *Soil* **2016**, *2*, 111–128. [CrossRef]
2. Field, D.J.; Morgan, C.L.S.; Mc Bratney, A.B. (Eds.) *Global Soil Security*; Springer: Cham, Switzerland, 2017.
3. Richer-de-Froges, A.C.; Carre, F.; Mc Bratney, A.B.; Bouma, J.; Arrouiays, D. *Global Soil Security. Towards More Science-Society Inferfaces*; CRC Press/Taylor and Francis Group: Boca Raton, FL, USA, 2019.
4. Kroes, J.G.; Van Dam, J.C.; Groenendijk, P.; Hendriks, R.F.A.; Jacobs, C.M.J. *SWAP Version 3.2. Theory Description and User Manual*; Alterra Rep.; Alterra: Denver, CO, USA, 2008; p. 1649.
5. Bouma, J.; van Ittersum, M.K.; Stoorvogel, J.J.; Batjes, N.H.; Droogers, P.; Pulleman, M.M. Soil Capability: Exploring the potenials of soils. In *Global Soil Security 2016*; Field, D.J., Morgen, C.L.S., Bratney, A.B.M., Eds.; Springer International: Cham, Switserland, 2016; pp. 27–44.

6. Bouma, J. How the soil security concept can pave the way to realizing some soil-related SDG´s. In *Global Soil Security. Towards More Science-Society Interfaces. Proc. Global Soil Security Conference, Paris, France, 5–6 December 2016*; Richer-de-Forges, A.C., Carré, F., McBratney, A.B., Bouma, J., Arrouays, D., Eds.; CRC Press/Taylor and Francis Group: Boca Raton, FL, USA; Londen, UK; New York, NY, USA; Leiden, The Netherlands, 2018; pp. 3–11.
7. ITPS: Intergovernmental Technical Panel on Soil. *State of the World's Soil Resources Report*; FAO Publication: Rome, Italy, 2015.
8. Schwilch, G.; Hessel, R.; Verzandvoort, S. (Eds.) *Desire for Greener Land. Options for Sustainable Land Management in Drylands*; University of Bern (CDE): Bern, Switzerland, 2012.
9. Liniger, H.; Critchley, W. (Eds.) *WOCAT—Where the Land Is Greener. Case Studies and Analysis of Soil and Water Conservation Initaitives Worldwide*; CTA, FAO, UNEP, CDE: Wageniongen, The Netherlands, 2007.
10. Fukuyama, F. *Identity, Contemporary Identity Politics and the Struggle for Recognition*; Profile Books Ltd.: London, UK, 2018.
11. Bush, V. *Science—The Endless Frontier*; Government Printing Office: Washington, DC, USA, 1945; (Reprinted in 1960).
12. Pielke, R.A. *The Honest Broker. Making Sense of Science in Policy and Politics*; Cambridge University Press: Cambridge, UK, 2007.
13. Bouma, J.; Kwakernaak, C.; Bonfante, A.; Stoorvogel, J.J.; Dekker, L.W. Soil science input in Transdisciplinary projects in the Netherlands and Italy. *Geoderma Reg.* **2015**, *5*, 96–105. [CrossRef]
14. Bouma, J. Using soil survey data for quantitative land evaluation. In *Advances in Soil Science*; Stewart, B.A., Ed.; Springer Verlag: New York, NY, USA, 1989; Volume 9, pp. 177–213.
15. Dekker, L.W.; Wösten, J.H.M.; Bouma, J. Characterizing the soil moisture regime of a Typic Haplohumod. *Geoderma* **1984**, *34*, 37–42. [CrossRef]
16. Dolman, M.A.; Sonneveld, M.P.W.; Mollenhorst, H.; de Boer, I.J.M. Benchmarking the economic, environmental and societal performance of Dutch dairy farms aiming at internal cycling of nutrients. *J. Clean. Prod.* **2014**, *73*, 245–252. [CrossRef]
17. Stoorvogel, J.J.; Kooistra, L.; Bouma, J. Managing soil variability at different spatial scales as a basis for precision agriculture. In *Soil-Specific Farming: Precision Agriculture*; CRC Press/Taylor and Francis Group: Boca Raton, FL, USA, 2015; pp. 37–73.
18. Bonfante, A.; Monaco, E.; Alfieri, S.M.; de Lorenzi, F.; Manna, P.; Basile, A.; Bouma, J. Climate change effects on the suitability of an agricultural area to maize cultivation: Application of a new Hybrid Land Evaluation System. *Adv. Agron.* **2015**, *133*, 33–69.
19. Bonfante, A.; Bouma, J. The role of soil series in quantitative Land Evaluation when expressing effects of climate change and crop breeding on future land use. *Geoderma* **2015**, *259–260*, 187–195. [CrossRef]
20. Van Ittersum, M.K.; Cassman, K.G.; Grassini, P.; Wolf, J.; Tittonell, P.; Hochman, Z. Yield gap analysis with local to global relevance a review. *Field Crop. Res.* **2013**, *143*, 4–17. [CrossRef]
21. Bonfante, A.; Terribile, F.; Bouma, J. Refining physical aspects of soil quality and soil health when exploring the effects of soil degradation and climate change on biomass production: An Italian case study. *SOIL* **2018**, in press. [CrossRef]
22. Droogers, P.; Bouma, J. Soil survey input in exploratory modeling of sustainable soil management practices. *Soil Sci. Soc. Am. J.* **1997**, *61*, 1704–1710. [CrossRef]
23. Rossiter, D.G.; Bouma, J. A new look at soil phenoforms-definition, identification and mapping. *Geoderma* **2018**, *314*, 113–121. [CrossRef]
24. Bouma, J. Applying indicators, threshold values and proxies in environmental legislation: A case study for Dutch dairy farming. *Environ. Sci. Policy* **2011**, *14*, 231–238. [CrossRef]
25. Bouma, J. The importance of validated ecological indicators for manure regulations in the Netherlands. *Ecol. Indic.* **2016**, *66*, 301–305. [CrossRef]
26. Viscarra-Rossel, R.A.; Bouma, J. Soil sensing: A new paradigm for agriculture. *Agric. Syst.* **2016**, *148*, 71–74. [CrossRef]
27. Bouma, J.; Wösten, J.H.M. How to characterize: "Good" and "greening" in the EU Common Agricultural Policy (CAP): The case of clay soils in The Netherlands. *Soil Use Manag.* **2016**, *32*, 546–552. [CrossRef]
28. Minasny, D.; Malone, B.P.; McBratney, A.B.; Angers, D.A.; Arrouays, D.; Chambers, A.; Chaplot, V.; Chen, Z.-S.; Cheng, K.; Das, B.S.; et al. Soil carbon 4 per mille. *Geoderma* **2017**, *292*, 59–86. [CrossRef]

29. Van Groenigen, J.W.; van Kessel, C.; Hungate, B.A.; Oenema, O.; Powlson, D.S.; van Groeningen, K.J. Sequestering soil organic carbon: A nitrogen dilemma. *Environ. Sci. Technol.* **2017**, *51*, 4738–4739. [CrossRef]
30. White, R.E.; Davidsen, B.; Kee Lan, S.; Chen, D. A critique of the paperSoil carbon 4 per mille' by Minasny et al. (2017). *Geoderma* **2018**, *309*, 115–117. [CrossRef]
31. Baveye, P.; Berthelin, J.; Tessier, D.; Lemaire, G. The "4per 1000" initiative: A credibiklity nissue for the soil science community? *Geoderma* **2018**, *309*, 118–123. [CrossRef]
32. Smith, P. Soils and climate change. *Curr. Opin. Environ. Sustain.* **2012**, *4*, 539–544. [CrossRef]
33. Chenu, C.; Klumpp, K.; Bispo, A.; Angers, D.; Colnenne, C.; Metay, A. Stocker du carbone dans les sols agricoles: Évaluation de leviers d'action pour la France. *Innov. Agron.* **2014**, *37*, 23–37.
34. Arrouays, D.; Balesdent, J.; Germon, J.C.; Jayet, P.A.; Soussana, J.F.; Stengel, P. *Increasing Carbon Stocks in French Agricultural Soils? Synthesis of an Assessment Report by the French Institute for Agricultural Research on Request of the French Ministry for Ecology and Sustainable Development*; Sci. Assess. Unit for Expertise, INRA: Paris, France, 2002; 36p.
35. Smith, P. Soil carbon sequestration and biochar as negative emission technologies. *Glob. Chang. Biol.* **2016**, *22*, 1315–1324. [CrossRef]
36. Pulleman, M.M.; Bouma, J.; van Essen, E.A.; Meijles, E.W. Soil organic matter content as a function of different land use history. *Soil Sci. Soc. Am. J.* **2000**, *64*, 689–694. [CrossRef]
37. Sonneveld, M.P.W.; Bouma, J.; Veldkamp, A. Refining soil survey information for a Dutch Soil series using land use history. *Soil Use Manag.* **2002**, *18*, 157–163. [CrossRef]