Healthy Soils

Subjects: Sociology | Geography

Contributor: Josephine Head, Zahra Didarali

Healthy soils are vital for sustainable development, yet consistent soil monitoring is scarce, and soils are poorly represented in United Nations Sustainable Development Goals targets and indicators. There is a clear need for specific ambitions on soil health, accompanying metrics, and cost-effective monitoring methodologies.

Keywords: Citizen Science,Soil Health ; SDG

1. Introduction

Soil is vital to life on earth, and provides a vast range of ecosystem services. Soils provide the nutrients and physical structures that sustain plant growth and biodiversity; act as a buffer against pollution and soil erosion; absorb, release, and purify the water we drink; and regulate flooding [1][2][3][4][5]. Moreover, soils and the vast carbon sink they represent are critical in tackling climate change [6][7]. Although there is uncertainty around global soil organic carbon (SOC) estimates, soils and surface litter contain at least two to three times as much carbon as is stored in vegetation and the atmosphere [8].

The state of a soil is generally referred to in terms of its “quality” or “health” [9]. Many authors consider that there is no difference between the two and that the terms can be used interchangeably (e.g., [10]), while others argue that soil “health” tends to focus more on biotic components (i.e., soil fauna and microbes) and that the two concepts are quite distinct (e.g., [11]). However, other researchers argue that any quantitative assessment of soil quality or health should focus on the function that soils are expected to fulfil (e.g., [12]). Irrespective of terminology, soil health or quality is increasingly recognised as a strong underlying concept akin to other descriptors of soil biological, physical, and chemical properties. In this paper, we define “soil health” as “the continued capacity of soils to function as a vital living ecosystem that sustains plants, animals and humans”[13].

Poor management of soil health will contribute to reduced food security [14][15], greater flood risk [16], and increased greenhouse gas emissions [17]; representing a major risk to public health [18]. Yet, despite their vital importance and the range of ecosystem services they support, soils are under threat [5][19]. There is now clear evidence that human pressures on soil resources are reaching critical limits —approximately 33% of soils are degraded [4], and 24 billion tons of fertile soil are lost annually from agricultural systems worldwide [15].

Although soils are essential to sustainable development, to date they have never been the specific focus of a multilateral environmental agreement [18]. The UN conventions on Climate Change, Biodiversity and Desertification (United Nations Framework Convention on Climate Change (UNFCC); Convention on Biological Diversity (CBD); and United Nations Convention to Combat Desertification (UNCCD), respectively) embed soil health improvement as a cross-cutting theme, but do not explicitly discuss the crucial role of soils in the discourse and across different ecosystems. However, both the Land Use, Land Use Change and Forestry (LULUCF) inventory of the UNFCCC and the “4 per 1000” initiative explicitly recognise the role of soil as a significant carbon sink [20]. Similarly, soil is poorly represented in the targets and indicators for the United Nations Sustainable Development Goals (UNSDGs) [21]. Not one of the 17 UNSDGs focus on soils specifically (although SDG 15 mentions land degradation and target 15.3 includes a specific soil indicator). While some argue that the critical importance of soil health in achieving the SDG objectives by 2030 has been exaggerated by soil scientists [10], others state that the absence of soil indicators reflects a lack of awareness of their importance in meeting SDG targets [22]. That notwithstanding, most agree that all SDGs have at least some type of dependence on soils and their functions [10][19]. Most notable for their relevance to soils are SDG 2 (Zero hunger), SDG 3 (Good health and well-being), SDG 6 (Clean water and sanitation), SDG 11 (Sustainable cities and communities), SDG 12 (Responsible consumption and production), SDG 13 (Climate action), SDG 14 (Life below water), and SDG 15 (Life on land) [18][22]. It has also been posited that soil may even have a role to play with respect to gender issues as in some countries soil preparation work is carried out almost exclusively by women, although cautions that many primary causes of issues highlighted by the UNSDGs are primarily political and economic in nature [10].

Continued soil degradation will slow or prevent the meeting of SDG targets that are underpinned by soil. This ongoing degradation is associated with a significant lack of specific ambitions and legislation around soil health at global and continental levels, alongside a lack of standardised metrics, challenges in assessing soils over large areas, and a disconnect between soil governance and the land policies upon which it depends [23][24][25][26][27]. A variety of monitoring frameworks and guidelines do exist, such as the IPCC Guidelines for Greenhouse Gas Inventories [28] which include methodologies for tracking the change in soil carbon, the Land Degradation Neutrality (LDN) target [29], the World Soil

Charter [30], the Voluntary Guidelines for Sustainable Soil Management [31], and the “4 per 1000” initiative [20]. However, to date, none of these provide the unified approach to data collection and interpretation that is required to calibrate soil health indicators in the round in a reliable manner across countries (but see [32] on LDN). Moreover, divergence in methodological approaches among the research community further hampers efforts to generate baseline data against which progress could be measured, and there remains ongoing disagreement around the most effective way to measure carbon in soils [33][34] and carbon emissions [8]. That being said, there is general agreement about changes that indicate a degradation in soil health over time if methods in a location are consistent. These include a decline in soil organic carbon and increased compaction, contaminant levels, and erosion, among others [23][25][27].

A similar lack of attention for soils is observed in statutory monitoring. While soil, water, and air are all essential to human life and society, soil is often the forgotten and neglected component compared to other environmental metrics in monitoring efforts (e.g., [35][36]). For example in Europe, while EU directives have been established for air [37], water [38], and biodiversity [39], the European Soil Framework Directive was withdrawn in 2007 and is yet to be re-tabled, although the EU Soil Thematic Strategy goes some way to addressing soil health and quality at the EU level [40], and will be updated in 2021 as part of the EU Biodiversity Strategy for 2030 [41]. Ronchi [36] highlights the lack of coherence in the legislative framework, policy instruments, coordination, and monitoring among member states which has resulted. Financial and human resource constraints also limit the collection of soil data at scale using traditional approaches, particularly in developing countries where the funding required creates a significant barrier [42], leading to infrequent sampling and patchy coverage. In industrialised nations, the issue is more about lack of funding for soil monitoring relative to that available for other natural assets (again driven by lack of political targets and strategies focussed on soil [36]) rather than because soils are intrinsically more diverse, stable, or dynamic than other assets and thus harder or more costly to measure compared to air, water, or biodiversity.

As of July 2019, 26% of the environment-related SDG indicators still have no established methodology (i.e., Tier III), while a further 32% have insufficient data available for global tracking [43][44]. The lack of specific measurable indicators and targets have been identified as a specific reason for the failure of meeting global biodiversity targets [45]. There is therefore a clear and important need for specific ambitions and accompanying metrics to fill existing knowledge gaps around soil if soil health is to be improved. Traditional data sources for soil health such as national monitoring programmes involving soil sampling and analysis are underfunded and to date insufficient in coverage, whilst new and non-traditional data techniques such as remote-sensing and citizen science sources can help accelerate measurement of global progress against the SDGs [46][47].

2. Citizen Science and Soil Health

Citizen science, defined here as “intentional collaborations in which members of the public engage in the process of research to generate new science-based knowledge” [48], is an example of an emerging non-traditional data source that could meet the shortfall in monitoring by providing the soil health data needed [49]. In order to provide useful data, citizen science approaches to soil monitoring and management relevant to the SDGs must be standardised and applicable on a wide scale and will require significant public engagement. Given that agricultural soils represent 50% of the globe’s habitable land surface [50], farmers and land managers are an essential group with which to engage at an early stage; as the gatekeepers of these soils, farmers have the opportunity and motivation to protect soils. To be effective, farmers require methods that are relevant (to farming operations as well as broader considerations of soil health), appropriate, reliable, and inexpensive, and to date little research has reviewed the extensiveness of existing citizen science soil monitoring methods or platforms that could be appropriate.

Where formal/traditional soil sampling is practiced by farmers (primarily in high-income sectors in high-income countries), some consider the requisite laboratory tests to be costly, complex, infrequently conducted, and lacking standardisation [51][52]. There can also be a significant delay in obtaining results, negating their utility in farmer decision-making with respect to, e.g., fertiliser requirements [53]. There is also evidence that analysis requested from commercial laboratories by farmers prioritise short-term requirements such as fertilizer needs over longer-term metrics such as soil organic carbon and soil biological activity (e.g., [54]). These findings can be challenged or explored further, for example, whether costs really are excessive considering their potential value in helping to conserve the most valuable capital asset of a farmer—their soil. Moreover, there is nothing intrinsically more expensive about soil analysis relative to water and air analysis, but farmers are currently not asked to undertake them to demonstrate they are not impacting environmental quality downstream. Furthermore, farmer focus on nutrient levels for fertiliser needs is influenced by the dominance of fertiliser companies in farm management advice and soil testing, which results in poor understanding as to standards and actions that can be taken to remedy other soil health issues identified (e.g., loss of soil organic carbon or compaction).

In LEDC’s, laboratories are scarce and soil testing prohibitively expensive for most small-scale farmers [55]. Alongside soil sampling, farmers possess a deep understanding and local knowledge of soils and continuously take informal soil observations, but these are neither standardised nor typically recorded [56][57]. There is therefore a clear and important role for citizen science in complimenting statutory monitoring and traditional approaches, and empowering farmers to effectively monitor global soils [58][59]. The data created could ultimately feed into national and international databases to enable a picture of soil health to be established at relevant scales and establish if we are meeting SDG targets. Such an approach would also enable us to harness the existing experience and deep understanding of soils that farmers possess that does not translate to laboratory soil testing. Citizen science monitoring of soil health will also support farmers in minimising their environmental impacts and enable them to understand impacts of changes in management practises through ongoing, objective monitoring. Furthermore, citizen science approaches can engage farmers in the importance of soil health through putting them in control of understanding their own soils, supporting the critical move towards farmer-led, data-driven decision-making.

Several papers have explored the general role of citizen science in monitoring and implementation of the SDGs [42][47][60][61][62]. The most recent and comprehensive of these reported that citizen science is already contributing to five Tier I, II, and III indicators through SDG targets 9.1 (resilient infrastructure—OpenStreetMap; Tier II); 14.1 (marine pollution—UN environment method; Litter Intelligence; Tier III); 15.1.2 and 15.4.1 (terrestrial, freshwater, and mountain biodiversity in protected areas—>10 methods; Tier I); and 15.5.1 (Red List Index—>10 methods; Tier I) [63]. Furthermore, the review identified where existing citizen science methods could contribute to a further 76 targets (45%) across all 17 SDGs.

To date, no review has specifically explored the role of citizen science soil health monitoring in meeting relevant SDGs, although targets 15.1.2 and 15.4.1 are considered relevant to soil health since they cover protected areas [64]. Furthermore, only two citizen science projects with soil health relevance (GROW and LANDMARK) are included in the above review [63]. This is likely a reflection of there being no SDG explicitly or primarily focused on soil health—despite it being embedded within other SDGs, it seems to have slipped through the cracks to become the invisible component.

References

1. Bot, A.; Benites, J. The Importance of Soil Organic Matter; FAO Soils Bulletin, The Food and Agriculture Organization of the United Nations: Rome, Italy, 2005; pp. 1–3.
2. Butler, S.J.; Vickery, J.A.; Norris, K. Farmland Biodiversity and the Footprint of Agriculture. Science 2007, 315, 381–384.
3. García-Ruiz, J.M.; Begueria, S.; Nadal-Romero, E.; Gonzalez-Hildago, J.C.; Lana-Renault, N.; Sanjuan, J. A meta-analysis of soil erosion rates across the world. Geomorphology 2015, 239, 160–173.
4. Status of the World's Soil Resources (SWSR)—Main Report; Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils: Rome, Italy, 2015; pp. 4–24.
5. Shukla, P.R.; Skea, J.; Calvo Buendia, E.; Masson-Delmotte, V.; Pörtner, H.O.; Roberts, D.C.; Zhai, P.; Slade, R.; Connors, S.; Van Diemen, R.; et al. (Eds.) Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems; Intergovernmental Panel on Climate Change: Geneva, Switzerland, 2019.
6. Lal, R. Agricultural activities and the global carbon cycle. Nutr. Cycl. Agroecosys 2004, 70, 103–116.
7. Schwarzer, S. Putting Carbon back where it belongs—The potential of carbon sequestration in the soil. In Foresight Brief; United Nations Environment Programme Science Division: Geneva, Switzerland, 2019.
8. Scharlemann, J.P.W.; Tanner, E.V.J.; Hiederer, R.; Kapos, V. Global soil carbon: Understanding and managing the largest terrestrial carbon pool. Carbon Manag. 2014, 5, 81–91.
9. Baveye, P.C. Bypass and hyperbole in soil research: Worrisome practices critically reviewed through examples. Eur. J. Soil Sci. 2020, 1–20.
10. Haney, R.L.; Haney, E.B.; Smith, D.R.; Harmel, R.D.; White, M.J. The soil health tool—Theory and initial broad-scale application. Appl. Soil Ecol. 2018, 25, 162–168.
11. Laishram, J.; Saxena, K.G.; Maikhuri, R.K.; Rao, K.S. Soil quality and soil health: A review. Int. J. Ecol. Environ. Sci. 2012, 38, 19–37.
12. Bouma, J. Soil science contributions towards sustainable development goals and their implementation: Linking soil functions with ecosystem services. J. Plant Nutr. Soil Sci. 2014, 177, 111–120.
13. Bouma, J. The challenge of soil science meeting society's demands in a "post-truth", "fact free" world. Geoderma 2018, 310, 22–28.
14. Gomiero, T. Soil Degradation, Land Scarcity and Food Security: Reviewing a Complex Challenge. Sustainability 2016, 8, 281.
15. UNCCD (United Nations Convention to Combat Desertification). The Global Land Outlook, 1st ed.; UNCCD: Bonn, Germany, 2017; Available online: https://www.unccd.int/sites/default/files/documents/2017-09/GLO_Full_Report_low_res.pdf (accessed on 24 October 2020).
16. Alaoui, A.; Rogger, M.; Peth, S.; Bloschl, G. Does soil compaction increase floods? A review. J. Hydrol. 2018, 557, 631–642.
17. Schils, R.; Kuikman, P.; Liski, J.; Van Oijen, M.; Smith, P.; Webb, J.; Alm, J.; Somogyi, Z.; Van den Akker, J.; Billett, M.; et al. Review of Existing Information on the Interrelations between Soil and Climate Change; Final Report for the EU Commission by Alterra; Europa: Wageningen, The Netherlands, 2008; Contract number 070307/2007/486157/SER/B1.

18. Keesstra, S.D.; Bouma, J.; Wallinga, J.; Tittonell, P.; Smith, P.; Cerdà, A.; Fresco, L.O. The significant of soils and soil science towards realization of the United Nations Sustainable Development Goals. Soil 2016, 2, 111–128.
19. Diaz, S.; Settele, J.; Brondizio, E. Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. 2019. Available online: http://jaei.org.za/wp-content/uploads/2019/05/Summary-for-Policymakers-IPBES-Global-Assessment.pdf (accessed on 24 October 2020).
20. Minasny, B.; 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. Carbon 4 per mille. Geoderma 2017, 292, 59–86.
21. Bouma, J. Contributing pedological expertise towards achieving the United Nations Sustainable Development Goals. Geoderma 2020, 375, 114508.
22. Lal, R.; Horn, R.; Kosaki, T. Soil and Sustainable Development Goals; Schweizerbart: Stuttgart, Germany, 2018.
23. Eggleston, H.S.; Buendia, L.; Miwa, K.; Ngara, T.; Tanabe, K. Generic methodologies applicable to multiple land use categories. In IPCC Guidelines for National Greenhouse Gas Inventories; The National Greenhouse Gas Inventories Programme, Intergovernmental Panel on Climate Change: Hayama, Japan, 2006; Volume IV, p. 2, Chapter 2.
24. Jandl, R.; Rodeghiero, M.; Martinez, C.; Cotrufo, M.F.; Bampa, F.; Van Wesemael, B.; Harrison, R.B.; Guerrini, I.A.; De Richter, D.B., Jr.; Rustad, L.; et al. Current status, uncertainty and future needs in soil organic carbon monitoring. Sci. Total Environ. 2014, 468, 376–383.
25. Morvan, X.; Saby, N.P.A.; Arrouays, D.; Le Bas, C.; Jones, R.J.A.; Verheijen, F.G.A.; Bellamy, P.H.; Stephens, M.; Kibblewhite, M.G. Soil monitoring in Europe: A review of existing systems and requirements for harmonisation. Sci. Total Environ. 2015, 391, 1–12.
26. De Schutter, O. Towards a Common Food Policy for the European Union. Report for the International Panel of Experts on Sustainable Food Systems. 2019. Available online: http://ipes-food.org/_img/upload/files/CFP_FullReport.pdf (accessed on 24 October 2020).
27. Jian, J.; Du, X.; Stewart, R.D. A database for global soil health assessment. Sci. Data 2020, 16, 1–8.
28. Eggelston, S.; Buendia, L.; Miwa, K.; Ngara, T.; Tanabe, K. (Eds.) IPCC Guidelines for National Greenhouse Gas Inventories; Institute for Global Environmental Strategies: Kanagawa, Japan, 2006.
29. UNCCD. Scientific Conceptual Framework for Land Degradation Neutrality; following decision 3/COP.12; The United Nations Convention to Combat Desertification Science Policy Interface (SPI): Geneva, Switzerland, 2015.
30. Revised World Soil Charter; Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils: Rome, Italy, 2015; pp. 1–7.
31. Voluntary Guidelines for Sustainable Soil Management; Food and Agriculture Organization of the United Nations: Rome, Italy, 2017; pp. 1–15.
32. Cowie, A. Guidelines for Land Degradation Neutrality: A Report Prepared for the Scientific and Technical Advisory Panel of the Global Environment Facility; Global Environment Facility: Washington, DC, USA, 2020; pp. 1–29.
33. Donovan, P. Measuring Soil Carbon Change. 2013. Available online: https://soilcarboncoalition.org/files/MeasuringSoilCarbonChange.pdf (accessed on 24 October 2020).
34. Senesi, G.S.; Senesi, N. Laser-induced breakdown spectroscopy (LIBS) to measure quantitatively soil carbon with emphasis on soil organic carbon. A review. Anal. Chim. Acta 2016, 938, 7–17.
35. Environment Agency National Requests Team Response: Air and Water Monitoring. 2019. FOI no: NR115635. Available online: https://static1.squarespace.com/static/58cff61c414fb598d9e947ca/t/5e665d0b1b893d099a39798d/1583766795461/EA+response+NR115 (accessed on 24 October 2020).
36. Ronchi, S.; Salata, S.; Arcidiacono, A.; Montanarella, L. Policy instruments for soil protection among the EU member states: A comparative analysis. Land Use Policy 2019, 82, 763–780.
37. Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on Ambient Air Quality and Cleaner Air for Europe OJ L 152, 11.6.2008, pp. 1–44. Available online: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:152:0001:0044:EN:PDF (accessed on 24 October 2020).
38. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy. OJ L 327, 22.12.2000, pp. 1–73. Available online: http://data.europa.eu/eli/dir/2000/60/oj (accessed on 24 October 2020).
39. Council Directive 92/43/EEC of 21 May 1992 on the Conservation of Natural Habitats and of Wild Fauna and Flora. OJ L 206, 22.7.1992, pp. 7–50. Available online: https://eur-lex.europa.eu/eli/dir/1992/43/oj (accessed on 24 October 2020).
40. Report on the Implementation of the Soil Thematic Strategy and Ongoing Activities (COM/2012/046). 2012. Available online: https://eur-lex.europa.eu/legal-content/GA/TXT/?uri=CELEX:52012DC0046 (accessed on 24 October 2020).
41. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions EU Biodiversity Strategy for 2030 Bringing Nature Back into Our LIVES

COM/2020/380 Final. 2020. Available online: https://ec.europa.eu/environment/nature/biodiversity/strategy/index_en.htm (accessed on 28 October 2020).

42. A World That Counts. In Mobilising the Data Revolution for Sustainable Development; The Independent Expert Advisory Group Secretary: Geneva, Switzerland, 2014; pp. 1–32.
43. IAEG SDGs Tier Classification for Global SDG Indicators; United Nations: Geneva, Switzerland, 2020; Available online: https://unstats.un.org/sdgs/iaeg-sdgs/tier-classification/ (accessed on 24 October 2020).
44. Measuring Progress: Towards Achieving the Environmental Dimension of the SDGs; UN Environment Programme: Geneva, Switzerland, 2019; Available online: https://wedocs.unep.org/handle/20.500.11822/27627 (accessed on 24 October 2020).
45. Green, E.J.; Buchanan, G.M.; Butchart, S.H.M.; Chandler, G.M.; Burgess, N.D.; Hill, S.L.; Gregory, R.D. Relating characteristics of global biodiversity targets to reported progress. Conserv. Biol. 2019, 33, 1360–1369.
46. Daguitan, F.; Mwangi, C.; Tan, M.G. Future Data and Knowledge Needs. In Global Environment Outlook—GEO-6: Healthy Planet, Healthy People; UN Environment, Ed.; Cambridge University Press: Cambridge, UK, 2019; Volume 6, pp. 599–617.
47. Fritz, S.; See, L.; Carlson, T.; Haklay, M.M.; Oliver, J.L.; Fraisl, D.; Mondardini, R.; Brocklehurst, M.; Shanley, L.A.; Schade, S.; et al. Citizen science and the United Nations Sustainable Development Goals. Nat. Sustain. 2019, 2, 922–930.
48. Shirk, J.L.; Ballard, H.L.; Wilderman, C.C.; Phillips, T.; Wiggins, A.; Jordan, R.; McCallie, E.; Minarchek, M.; Lewenstein, B.V.; Krasny, M.E.; et al. Public participation in scientific research: A framework for deliberate design. Ecol. Soc. 2012, 17, 29.
49. Rossiter, D.G.; Lui, J.; Carlisle, S.; Xing Zhu, A. Can citizen science assist digital soil mapping? Geoderma 2015, 259, 71–80.
50. Ritchie, H.; Roser, M. Yields in Land Use and Agriculture. 2019. Available online: https://ourworldindata.org/crop-yields#breakdown-of-global-land-area-today (accessed on 25 October 2020).
51. Friedman, D.; Hubbs, M.; Tugel, A.; Seybold, C.; Sucik, M. Guidelines for Soil Quality Assessment in Conservation Planning; USDA NRCS: Washington, DC, USA, 2001.
52. Thomsen, E.O.; Reeve, J.R.; Culumber, C.M.; Alston, D.G.; Newhall, R.; Cardon, G. Simple Soil Tests for On-Site Evaluation of Soil Health in Orchards. Sustainability 2019, 11, 6009.
53. Attanandana, T.; Yost, R.; Verapattananirund, P. Empowering Farmer Leaders to Acquire and Practice Site-Specific Nutrient Management Technology. J. Sustain. Agric. 2007, 30, 87–104.
54. Rawlins, B.G.; Marchant, B.; Stevenson, S.; Wilmer, W. Are data collected to support farm management suitable for monitoring soil indicators at the national scale? Eur. J. Soil Sci. 2017, 68, 235–248.
55. Crane, K.S.; Webb, B.L.; Allen, P.S.; Jolley, V.D.; Chicas, R.; Naimi, M. Simplified Soil Analysis Procedure for Use in Small-Scale Agriculture. Commun. Soil Sci. Plant Anal. 2006, 37, 7–8.
56. Winklerprins, A.M.G.A. Local soil knowledge: A tool for sustainable land management. Soc. Nat. Resour. 1999, 12, 151–161.
57. De Bruyn, L.A.L.; Abbey, J.A. Characterisation of farmers' soil sense and the implications for on-farm monitoring of soil health. Aust. J. Exp. Agric. 2003, 43, 285–305.
58. Ryan, S.F.; Adamson, N.L.; Aktipis, A.; Andersen, L.K.; Austin, R.; Barnes, L.; Beasley, M.R.; Bedell, K.D.; Briggs, S.; Chapman, B.; et al. The role of citizen science in addressing grand challenges in food and agriculture research. Proc. R. Soc. B 2018, 285, 20181977.
59. Stoate, C.; Jones, S.; Crotty, F.; Morris, C.; Seymour, S. Participatory research approaches to integrating scientific and farmer knowledge of soil to meet multiple objectives in the English East Midlands. Soil Use Manag. 2019, 35, 150–159.
60. Flückiger, Y.; Seth, N. SDG indicators need crowdsourcing. Nature 2016, 531, 448.
61. West, S.; Pateman, R. How Could Citizen Science Support the Sustainable Development Goals? Stockholm Environment Institute: Stockholm, Sweden, 2017.
62. Bio Innovation Service. Citizen Science for Environmental Policy: Development of an EU-Wide Inventory and Analysis of Selected Practices. Final Report for the European Commission, DG Environment under the Contract 070203/2017/768879/ETU/ENV.A.3, in Collaboration with Fundacion Ibercivis and The National History Museum. 2018. Available online: https://data.jrc.ec.europa.eu/dataset/jrc-citsci-10004 (accessed on 24 October 2020).
63. Fraisl, D.; Campbell, J.; See, L.; Wehn, U.; Wardlaw, J.; Gold, M.; Moorthy, I.; Arias, R.; Piera, J.; Oliver, J.L.; et al. Mapping citizen science contributions to the UN sustainable development goals. Sustain. Sci. 2020.
64. Veerman, C.; Pinto Correia, T.; Bastioli, C.; Biro, B.; Bouma, J.; Cienciala, E.; Emmett, B.; Frison, E.A.; Grand, A.; Hristov, L.; et al. Caring for Soil is Caring for Life; EU Soil Health and Food Mission Board: Brussels, Belgium, 2020.