

Chemical Innovation and Agrifood Systems in Switzerland: A Short Perspective of the Sustainable Development Goals

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Dedicated to Marco Quadranti



Abstract: Chemical innovation plays a key role to support the agrifood system with the final goal to deliver secure, healthy food for a growing population. The underlying link between chemical innovation, agrifood system and the 2030 sustainable agenda may have received less attention than it deserves. Here we provide an overview of the agrifood system and the Sustainable Development Goals (SDGs), alongside distinct aspects of the innovation with a focus on the Swiss reality are presented. Finally, the critical and unspoken role of soil for a wide range of SDGs is underlined. Some major axes on how chemical research and technologies can set new pathway to innovate through soil are discussed.

Keywords: Chemical innovation · Responsible innovation · Soil



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1. Introduction

In 2015, the member states of the United Nation adopted the agenda 2030 for sustainable development, which encompasses 17 Sustainable Development Goals (SDGs) and 169 associated targets. This initiative follows the Millennium Goals and the main purpose was to promote peace and prosperity for the present and future generations and preserve the planets resources. Although the SDGs were not legally binding, they were intended to secure commitments from both developed and developing countries. According to the United Nation website, since the inception of the SDGs, there have been more than 3880 events and more than 1300 publications.^[1] This article aims to analyze the SDGs from the soil and agrifood system perspectives with a strong focus on the

chemistry related disciplines and their potential role as innovation levers.

2. SDGs and Agrifood Systems: Where Do We Stand Today?

The FAO has recently published ‘Tracking progress on food and agriculture-related SDG indicators 2023’.^[2] This new report comes timely and describes the half-way progresses in the implementation of the Sustainable Development Goals (SDG) relevant for agriculture (*i.e.* SDGs 1, 2, 5, 6, 10, 12, 14 and 15) and in view of the 2030 agenda. The emerging picture is far from satisfying and raises concerns for the future.^[2] Furthermore, the unfolding global events in the last years, including the COVID pandemic, geopolitical instability, and armed conflicts, reminded us of the high vulnerability of the global food system, in terms of production and accessibility of food.^[3] Although a detailed analysis of the status of the SDGs is beyond the scope of this publication, it is worth highlighting some of the major trends both at the global and national level of the agriculture-related SDGs. According to the FAO statistics, the number of undernourished people increased in the last few years, and the level of global food insecurity reached 29.6% in 2022. In terms of preservation^[3b] of soil resources, which is the foundation of food and fibre production, the latest figures indicate that about 100 million hectares of productive land have been lost worldwide every year between 2015 and 2019.^[4] In terms of stable food supply, the increase in frequency and intensity of natural disasters led to high direct agriculture losses with an estimated cost of USD 20.7 billion in 2020 based on 42 countries.^[2] According to the OECD report,^[5] the situation in Switzerland is better and many of the SDG targets are close to being met or on track with the 2030 Agenda. In order to implement the 2030 Agenda, the Swiss Federal Council identified three main priorities: *sustainable consumption and sustainable production; climate, energy and biodiversity; equal opportunity and social cohesion*.^[6] The country relies on a solid economy and has high living standards. Yet, this does not translate into a general environmental quality deterioration. For instance, the greenhouse

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gas intensities are among the lowest among the OECD countries. By looking closer at some of the SDGs relevant in this paper, like **SDG 6** (particularly the *water quality*), it emerges that the country already achieved, or it is close to achieving this target. For the **SDG 12** (*i.e. ensure sustainable consumption and production pattern*) and **SDG 13** (*i.e. take urgent action to combat the climate change and its impacts*) progresses have been made, but further efforts will be needed.^[5] Despite this general positive trend, there are some points of concern. Switzerland is actively importing about half of the food and feedstuff. This makes the country vulnerable to and dependent on the changes of the global food supply, as the recent pandemic and conflict events have demonstrated. Moreover, such dependency transfers the footprint of the national activities to other geographies. Other important aspects make the food security a potential challenge for the country. Those are the decline in agricultural land area *per capita*, the higher incidence of natural disasters and the increase of pest pressure.^[7] Switzerland is one of the countries among the most affected by natural calamities. In 2020, the direct agriculture losses attributed to natural disasters amounted to more than USD 32 million.^[8] While the total agricultural land area remained constant in the last twenty years, the total agriculture land area *per capita* shrank by 20%.^[9] Finally, the changes in annual rainfall distribution over the seasons, the steady increase of the temperature and the atmospheric CO₂ concentration can lead to significant changes in pest pressure on many crops.^[10,11]

The Swiss Academies of Arts and Sciences published a relevant report highlighting the priorities for the Swiss sustainability research, with the goal to support the 2030 Agenda. The Swiss agrifood system was a theme included in the report. From their analysis it emerged that there is a lack of broad vision for a sustainable and resilient food production by involving the different players in the food value chain. Similarly, they highlighted a range of questions around the role of science and technology to support the agrifood system and how it can deal with the regional and global challenges, particularly around the increasing demand for healthy food produced without crossing the sustainable boundaries. Among the most important technologies, the authors underlined the role of novel breeding techniques and digitalization without neglecting other key aspects within the whole food value chain, from the local farmers knowledge to the consumers preferences. Although science and technologies are expected to play a key role, there is less awareness about the importance of innovation processes particularly with respect to the innovation from chemistry. Switzerland has a long-standing history in terms of chemical innovation starting in the 19th century with synthetic dyes.^[12] The next section aims to address one question which can be relevant for this scientific community, and we hope that this can spark innovative ideas and trigger further discussions. *How can innovation, particularly chemical innovation, support the endeavours in the agrifood systems?*

3. SDGs and Agrifood Systems: The Role of Innovation.

Science, technology, and innovation are often considered to be essential in order to address today's global challenges. Beside this general statement, it is worth noticing how these terms are often used interchangeably, even though their precise meanings differ. Whilst the distinction between science (*i.e. the acquisition of knowledge through observations leading to new discoveries*) and technology (*i.e. the application of scientific knowledge for practical applications resulting in new inventions*) is quite clear; the differences between them and innovation is still a matter of debate even amongst scholars. The OECD gives the following definition "An innovation is a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to poten-

tial users (product) or brought into use by the unit (process)".^[13] In other words the innovation is the last step enabling the diffusion and large adoption of new solutions in society to support human prosperity.^[14] Fig. 1 schematizes the link between science, technology and innovation and the key processes lying behind this.

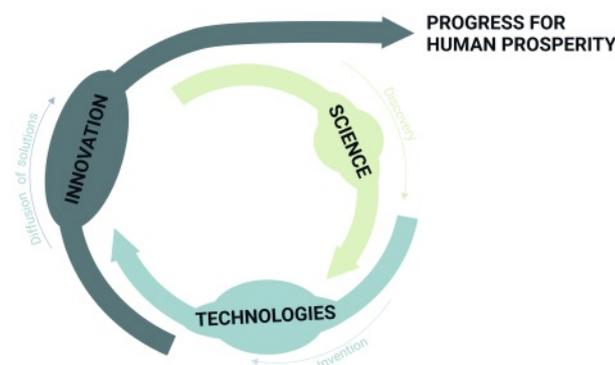


Fig. 1. Relation between science, technologies and innovation leading to progress.

Ultimately, science, technology and innovation will be critical to make progresses in many areas of the SDGs.^[15a,b] Wise development of the three key processes is expected to trigger a transformation of the agrifood system which can be effective to address **SDG 2** (*ending of hunger and malnutrition and promoting sustainable agriculture*), **SDG 6** (*ensuring availability of and sustainable water management*), **SDG 13** (*reducing climate change*) and **SDG 15** (*protect, promote sustainable use of terrestrial ecosystems*).^[16] It will continue to require the efforts of different players from academia and public research institutions who will be active and largely leading the science and technology side; while private R&D organizations will most likely be better placed to shape the innovation and particularly the breakthrough innovations leading to new solutions.^[17]

The remaining part of this section will focus particularly on the role of the public and private R&D organizations, with the intention to provide an overview of the most popular innovation models as reported in the specialized literature but possibly less known in the Chemistry and the Life Sciences domains.^[14,17,18]

In recent years new concepts of innovation received traction leading to alternative and more open models. Among them it is worth highlighting the responsible innovation, which spread particularly across Europe and the US.^[19] The definition proposed by Schomber is largely accepted: "a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view on the (ethical) acceptability, sustainability, and societal desirability of the innovation process and its marketable products".^[19]

Fig. 2 visualizes the key aspects of this new way to conceive innovation, where co-creation is critical. The model emphasizes the importance of having different stakeholders involved, spanning from academic researchers to policy makers, governmental, and business representatives. The R&D organizations are nested in the overarching mechanisms. Furthermore, a more systematised way of thinking is evocated to tackle the complex challenges and find impactful solutions. The increase of the open innovation approaches in agriculture led also to the spread of more public-private partnerships with the major goal to support sustainable growth and productivity. Rankin *et al.*^[20] carried out a review of more than 70 case studies in 15 developing countries to identify the main benefits of partnership. The study confirmed the positive impact of combining the operational efficiency and economic focus of the private sector with the enabling role of public sector

to create the right environment and regulation to safeguard the broad social interests. The report also showed evidence of positive effects on net income for farmers – especially smallholder farmers, increased productivity and efficiency.^[20] We witnessed an increase in collaboration between NGOs and industry. For instance, ‘The Nature Conservancy’ is one of the NGOs that over the years established many impactful collaborations around the world with unlikely partners to support sustainable growth.^[21] Large Agrobusiness, R&D organization like Syngenta engaged with several partners and associations.^[22] Partnerships can range from initiatives to restore degraded land to more fundamental research projects. For instance, The Nature Conservancy and Syngenta launched a partnership with the goal to support Brazilian farmers to restore highly degraded land in the Cerrado region by targeting 1 million hectares, through an integrated solution including financial support as well as technical assistance to optimize key inputs.^[21] Atwood *et al.*^[23] offered a good example on how partnerships between NGO and R&D organizations can lead to the development of a new framework to shape the way crop protection industry can innovate and develop new solutions by simultaneously targeting agronomical, environmental and economic goals. Similarly other important research centres in Switzerland as the World Food Center of the ETH Zürich successfully established partnerships with Agrobusiness industries to support research and innovation in sustainable agriculture.^[24] At international level there are many new initiatives to foster more collaboration. An example is the Phytobiomes Alliance which gathered under the same umbrella a wide range of stakeholders from non-profit organizations, industrial partners, academic groups, and governmental partners. The main goal is to promote science and technology by investing in the complex microbial community associated with the plants for a sustainable production of food, feed and fibre.^[25] Another important aspect to sustain the innovation in agriculture is to ensure sufficient R&D investment. The evaluation of the impact of R&D investment in agriculture has been difficult. This is due to the lack of robust assessing methodologies and the long lag phase to reap the economic benefits from the original investments; indeed the elapsed time in agriculture tends to be longer than in other industries being between 15 and 25 years.^[26] However, some attempts to size the impact of R&D investments are available particularly for the African continent and demonstrated the benefits in terms of productivity and farmers conditions.^[27] A close look at the public and private R&D expenditures in recent years shows some interesting trends. Although the data is fragmented, the estimated public agricultural R&D expenditure in the world accounted for 55% of the US 69 billion total in 2011.^[28] Similar figures were reported for the global expenditure in 2014.^[16] China, EU and India are among the countries that steadily increased their public R&D expenditures.^[29] Fuglie offered a compelling analysis underlining the growing role of the private R&D investments in agriculture. Between 1990 and 2014, global private R&D investments tripled reaching about USD 15 billion in 2014.^[30] Without doubt the increase of public and private expenditure in agricultural R&D will bring new innovative solutions for the agricultural related SDGs, but a legitimate question arises: “*is this enough?*”. Researchers from the International Food Policy Research Institute addressed this question by using a biophysical and economic model and trying to estimate the gap in the global R&D investments to meet the **SDG 2** (*i.e. end hunger*).^[31] They found that an additional USD 4 billion per year could be effective to match the SDG 2 by 2030. Similar outcomes come from other studies aimed at identifying least-cost investment options with the highest potential for **SDG 2**.^[32]

There are many initiatives that attempt to rank the national economies in terms of innovation. One of the most long-awaited publications is ‘The Global Innovation Index Report’ issued every year by the World Intellectual Properties Organization

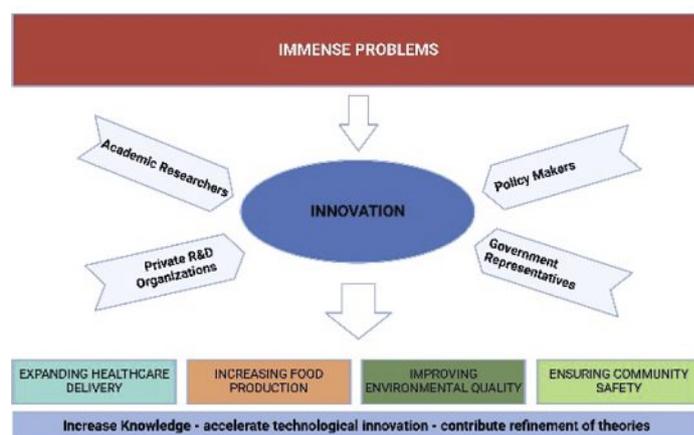


Fig. 2. Framework of the responsible innovation model. Modified from refs. [11,14,19]

(WIPO).^[33] Since 2007, WIPO evaluates the innovation performance of more than 130 national economies by using 80 indicators clustered around seven major pillars: *institutions, human capital and research, infrastructure, market sophistication, business sophistication, knowledge and technology outputs, and creativity outputs*. Switzerland has ranked as the uncontested and most innovative country for the last 13 years demonstrating the national excellence to innovate.^[34] Fig. 3 compares the global innovation index of Switzerland versus the ‘G8+5’ countries and provides insights about the country’s score against the 7 major pillars. Switzerland outperforms in the pillar of institution which encompasses institutional, regulatory, and business environment. Similarly, the country ranks very high in the human capital and research pillar which includes education and R&D investments. The pillar of infrastructure is conducive for innovation like the access and use of information and communication technologies. Switzerland performs well also in the market sophistication, particularly in the credit for private sector and financing start-ups. Finally, Switzerland is the leading country in terms of creativity outputs, translating to excellence the industrial design, and creative goods.^[34] The power of such national innovation is visible in many productive sectors, it will be very important to further extend this positive trend also in agrifood systems.

4. SDGs and Agrifood Systems: Starting From the Soil

The importance of soil for today and future humankind prosperity is highly underestimated.^[35] Soils is a non-renewable resource delivering vital ecosystem services like food and fibre production, nutrient supply, detoxification, water, and nutrient retention, maintaining biodiversity and carbon sequestration.^[2,36] Although soil is not explicitly mentioned in the Sustainable Agenda 2030, it is at the intersection of many of the **SDGs** (*i.e. 1, 2, 3, 6, 7, 12, 13 and 15*). Fig. 4 highlights the close connections and the cross-interactions between the aforementioned SDGs and the major soil functions as defined by the EU Commission.^[36c] The complex matrix in the figure reveals also how a wise management of soil resources can lead to important achievements in terms of land restoration, food security, human health, water availability, climate change mitigation and biodiversity preservation.

There are two landmark publications that advocate for the importance of soil science and the translational science for the 2030 Sustainable Agenda.^[36a,c] Both these forum papers underlined the need of interdisciplinary and transdisciplinary approaches for such complex challenges, yet very little emphasis has been devoted to the role of the ‘responsible innovation’ to accelerate the invention and the adoption of new solutions.^[19]

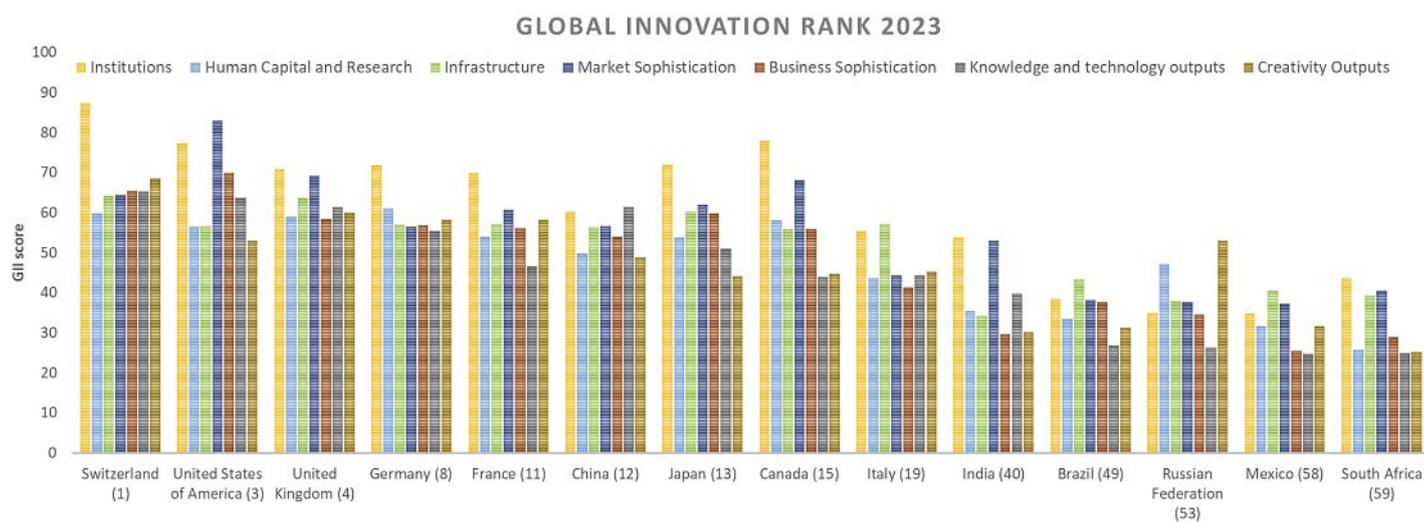


Fig. 3. Comparison of the global innovation index scores of the 'G8+5' national economies against the seven pillars: institutions, human capital and research, infrastructure, market sophistication, business sophistication, knowledge and technology outputs and creativity outputs. The number in brackets after the country indicates the global rank. Modified from 2023 GI Report.^[26]

In this section the role of chemistry to innovate in the soil space and support the SDGs will be presented. The subject can be quite broad encompassing many diverse applications and raising many technical-scientific considerations. For the purpose of this manuscript and to provide a broader view – hoping to stimulate further reflections - three major and different topics will be considered. All three topics share common features: addressing important global challenges, the need for more translational sci-

ence in each of these fields, opportunities for more public-private collaboration and ultimately their impact on the SDGs.

The first topic focuses on the global chemical and engineering aspects taking as an example the challenges associated with the nitrogen biogeochemical cycle, starting with the Haber-Bosch process. The second topic focuses on Green Chemistry as a major and emerging field with potential impacts on soil and SDGs. Finally, the third topic deals with new emerging and midlevel sensing and diagnostic technologies and their potential to monitor in a

SDGs	Main Soil Functions as defined by the European Commission					
	Biomass production	Preserving main Biogeochemical cycles (water, nutrients)	Biodiversity	Physical and Cultural Environment for Human	Source of raw material	Acting as carbon pool
1 End poverty in all its forms everywhere	✓				✓	
2 End hunger, achieve food security and improved nutrition and promote sustainable agriculture	✓	✓		✓		
3 Ensure healthy lives and promote well-being for all at all ages	✓	✓	✓	✓		✓
6 Ensure availability and sustainable management of water and sanitation for all		✓				
7 Ensure access to affordable, reliable, sustainable and modern energy for all	✓				✓	✓
12 Ensure sustainable consumption and production patterns	✓	✓				
13 Take urgent action to combat climate change and its impacts		✓				✓
15 Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forest, combat desertification, and halt and reverse land degradation and halt biodiversity loss	✓	✓	✓	✓	✓	✓

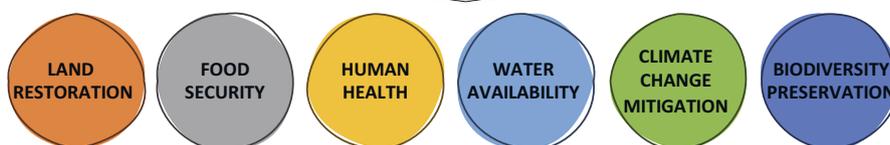


Fig. 4. Matrix underlining the connection between the vital soil functions and the SDGs and how they lead to positive impacts.

simple, cheap, and effective manner the progresses of intervention in soil and the SDGs.

Topic I - Harnessing the nitrogen cycle. Nitrogen is a major element supporting life. Its cycle on earth has been significantly altered in the last 100 years by agricultural and industrial activities. According to the latest evaluation of the Stockholm Resilience Center, the nitrogen biogeochemical cycle is one of the 9 planet boundaries which have been crossed, and urgently requires interventions.^[37] Similarly, Vaclav Smil, a highly acclaimed scholar active in many research fields from energy to environment, from food production to history of technical innovation is quite adamant about the role of nitrogen in our societies.^[38] In one of his most recent publications, he introduces the four pillars of the modern civilization: *ammonia, steel, concrete and plastics*.^[39] 70% of the annually produced ammonia *via* the Haber-Bosch process is used as fertilizer and consumes 2% of global energy.^[40] To put this into perspective, according to the latest International Energy Agency (IEA) analysis in 2021, the emission intensity of the ammonia production (*i.e.* tons CO₂/tons of product) is four and two times higher than the emission intensity of steel and cement, respectively.^[40]

The use of fertilizers is far from efficient, since only half of the nitrogen fertilizer deployed in the field is intercepted by the crops,^[41] the remaining is lost as nitrate in groundwater and/or surface waters, or lost as gases like N₂O which is a potent greenhouse gas, being 298 times more potent than CO₂.^[42] Thus, any interventions or new technologies able to harness the nitrogen cycle will have beneficial impacts on the **SDGs 1, 2, 3, 6, 13 and 15**.

Chemistry can play a critical role by addressing the cornerstone of ammonia production historically bound to the notorious Haber-Bosch process.^[38b]

There have been some advances and there is an urgent need to increase the efforts towards sustainable ammonia production.^[43] In 2020, 184 Mt of ammonia were produced. More than 70% of them are still based on oil and coal technologies. There are opportunities to explore other more sustainable technologies relying on CCU (Carbon Capture and Utilization for Urea production) as well as other more explorative approaches like the ones based on pyrolysis, biomass recycling and electrolysis.^[40] Future efforts in more fundamental and applied research fields can help to accelerate the development and implementation of more sustainable ways to produce ammonia.^[43] For instance, some specific efforts downstream of the ammonia production in the catalyst side reaped a success story for the Swiss company CASALE who in collaboration with Clariant developed a new ammonia synthesis catalyst. For this achievement they were awarded by the Swiss Chemical Society with the prestigious Sandmeyer prize in 2021.^[44]

Another area where chemical innovation can play a crucial role is in the optimization of the nitrogen cycle downstream using biological or synthetic nitrification inhibitors;^[45] the underlying principle is based on the use of a range of small molecules which can inhibit the key steps in the ammonia oxidation promoted by bacteria and archaea.^[46] Although there are some debates going on about the robustness of such technologies, there is broader evidence that these technologies can help to improve the use efficiency of nitrogen in major crops and reduce N losses.^[45,46b,47] The Intergovernmental Panel on Climate Change (IPCC) also recommended the adoption of a nitrification inhibitor to mitigate N₂O emissions.^[48] Further efforts in the fundamental understanding of the mode of action of nitrification inhibitors as well as new efficient ways to synthesize and efficiently produce natural or synthetic nitrification inhibitors can have a strong impact (*e.g.* brachialactone, benzoxazolones, and other terpenoids)

Topic II – Green chemistry. This is getting a lot of traction, and it is worth to mention that the Swiss Chemical Society has a dedicated working group.^[49] The goal of green chemistry is to reduce the generation of hazardous chemicals, the whole concept

hinges on 12 principles.^[50] Although many of these principles are tightly connected with the SDGs, for the purpose of this manuscript and for succinctness reason, we will focus on the **principle number 10** ‘*design chemicals and products to degrade after use*’.^[49,51] The underlying rationale is that fast degradability will minimize residues in different environmental compartments with consequently lower risk of bioaccumulation and chemical exposure. Advances in this field can have a major impact on the **SDGs 2 and 6**. Chemical innovation can contribute to a great extent in this challenge. More and new efforts are needed in the early phases of discovery and invention of new chemical products rather than later during the development and registration phases. In order to have a meaningful influence in the early stage and inform the chemical design, then new, fast, reliable and high-throughput methods combined with predictive *in silico* tools are urgently needed.^[51,52] Combined efforts between academia and private R&D organizations can help to develop a framework and suitable testing capabilities to address the challenges.^[51,52b] Having more accurate and sensitive tests alongside the continuous improvement of predictive sciences for biodegradability can pave the way to discover and develop the next generation of synthetic molecules to use in agriculture for crop protection and animal health.^[51,52] Fig. 5 offers a graphical representation of a possible framework of capabilities where public and private efforts can synergize.

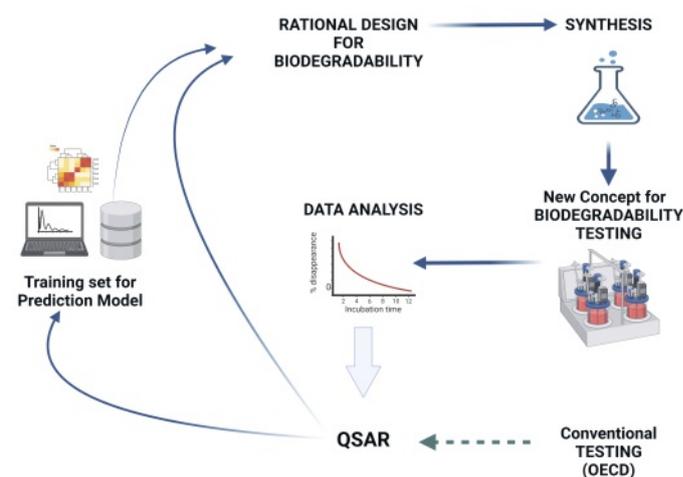


Fig. 5. A new capabilities framework for the rational design for biodegradability to be built through public-private collaborations. Modified from ref. [52]

Topic III – Sensor technologies and soil. The whole sensor industry grew exponentially in recent years. The global market for nonmilitary, open sensor technologies exceeded hundreds of billions of US dollars in 2011.^[53] About one-tenth of the global market concerns Life Science with 99% targeting biomedical applications and the remaining focusing on agrifood and environmental monitoring.^[53,54] The major interest in the agrifood sector is linked to the increasing concerns about food, soil, and water contaminations.^[53,54b,55] A related area with potential future development is around soil sensors for crop productivity by applying the precision agriculture principles.^[54b,55,56] The research efforts in this domain date back more than 20 years,^[55] but the progresses in the field were much slower than in other Life Science disciplines.

Many of the sensors used for soil analysis are chemical or biosensors.^[55,56c] Originally, they were developed as an alternative to the conventional lab-based ‘wet-chemistry’ methods which require that samples ought to be collected in the field and then shipped to specialized labs for analysis making the whole operations expensive and long.

The major desirable features of the soil sensors are fast measurements, ideally on-the-go,^[56a] suitable to be combined, sufficiently sensitive and cheap.

Due to its nature, soil is complex and many of its properties can vary in time and space. Therefore, soil analysis is fundamental to better manage such complexity, by tracking the key biogeochemical processes (e.g. mineralization of organic matter, nitrogen oxidation/reduction processes, etc.). The goal is to improve crop productivity. Fig. 6 highlights the major types of sensor technologies and their applications.

Although there have been many efforts in the area of science and technology there are still major limitations in the adoptions of these technologies at scale and to fulfil the major users' needs, in first instance farmers, but also local government agencies, agricultural advisors and others.

Further efforts in this area focusing on gaining major applicability of the sensors particularly in developing countries will have a profound impact on agriculture and surely have an impact on the SDGs 2, 13 and 15.

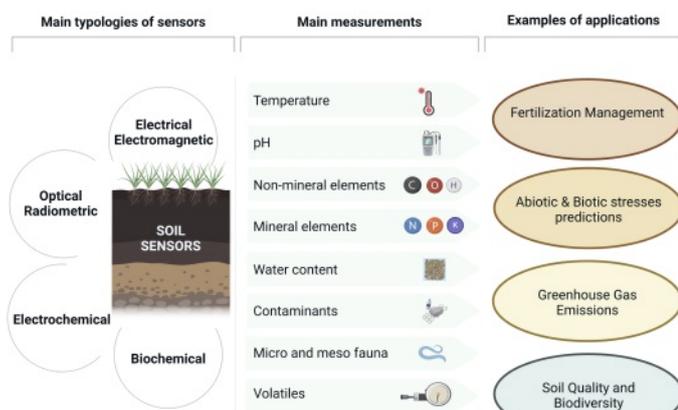


Fig. 6. Soil sensors and their applications.

5. Conclusions

The 2030 Agenda is approaching and there are major concerns about whether the SDGs can be fully reached by then. Agriculture and the agrifood system are tightly connected with the SDGs and reflect a different way of how we need to look and operate on our planet in a responsible manner. There is an urgency to increase the awareness and the value of nutritious and safe food, produced in a responsible way without jeopardizing several of the planet's resources. To this end a system thinking approach is essential and innovation can play a key role. The concept of innovation evolved over the years and a new concept emerged around responsible innovation and the needs to tackle the coming challenges in a more collaborative way. Switzerland is well positioned in this endeavour, being already recognized as a leading innovative country. We hope this overview can spark further reflections in our community and particularly in the generation of young scientists. The previous sections underscored the importance to have more translational science and innovation efforts in the agrifood system and the hope that public and private sectors continue to have SDGs as a key part of their agendas.

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