

Review

# The Role of Citizen Science in Sustainable Agriculture

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**Abstract:** Farmers know much more than we think, and they are keen to improve their knowledge in order to improve their farms and increase their income. On the other hand, decision-makers, organizations, and researchers are increasing their use of citizen volunteers to strengthen their outcomes, enhance project implementation, and approach ecosystem sustainability. This paper assesses the role of citizen science relating to agricultural practices and covers citizen science literature on agriculture and farmers' participation during the period 2007–2019. The literature was examined for the role of citizen science in supporting sustainable agriculture activities, pointing to opportunities, challenges, and recommendations. The study identified the following gaps: insufficient attention to (1) long-term capacity building and dialogue between academics and farming communities; (2) developing countries in the global South and smallholders; (3) agriculture trading and marketing; (4) the rationales of selecting target groups; (5) contributing to accelerated sustainability transitions. The main aim of the research projects reviewed in this study tended to focus on the research outcomes from an academic perspective, not sustainable solutions in practice or sustainability in general. More research is needed to address these gaps and to widen the benefits of citizen science in sustainable agricultural practices.

**Keywords:** adaptation strategies; climate impacts; environmental impacts; community engagement; capacity building; rural development

## 1. Introduction

### 1.1. Citizen Science

As is the case for citizen science in general [1], citizen science in agriculture covers a very wide range of practices. These range from making scientific findings and expertise available to concerned groups in society through agricultural extension, to participatory projects where groups and communities collaborate closely with scientists in defining the aim, scope, and methods of scientific research. The focus of this paper will lie on practices where farmers, professionals, or members of the public mainly contribute to research through data collection and real-time monitoring [2]. Our focus thus corresponds to the first two of the Ten Principles of Citizen Science [3], namely 1. "Citizen science projects actively involve citizens in a scientific endeavor that generates new knowledge or understanding," and 2. "Citizen science projects have a genuine science outcome" (p. 29).

Citizen participants and academic scientists involved in citizen science projects are likely to have diverging motivations and constraints. Thus, a frequently expressed concern from academic

scientists has been how scientific stringency in data collection or monitoring can be ensured [4]. The terminological overview of Eitzel et al. [1] highlights some of the conflicting expectations and goals of citizen science, but also the wider potentials, such as building the “knowledge-producing capacity of society and a path to evidence-based decision-making” (p. 9), linking citizen science not only to improvement of local practices, but also to policy. In the context of agriculture, Ryan et al. [5] further stress the potential of citizen science as a form of extension in mobilizing farmers in action for sustainability.

In general, citizen science can contribute to the integration of public outreach and scientific data collection locally, regionally, and across large geographic scales [6]. Importantly, it can operate at different temporal and spatial scales to address conservation and restoration research, which help in creating lasting, culturally transmitted changes in land-use practices and long-term improvements in environmental quality [6].

Today, many citizen science approaches are digitally mediated [7]. For instance, Virtual Citizen Science uses web-based interaction between people and scientists to conduct scientific research [8]. To support interaction between people and science, several countries have set up portals. In Denmark, ScienceNordic launched a project named ‘Citizen Science: How you can help scientists’ in 2017, by which any interested person can sign up to help science and to make scientists smarter [9]. In Sweden, a national web portal for people interested in citizen science was developed in 2018. The main aim of this project is to help the academic sector (universities and research centers) to use citizen science and to interact with society in a reasonable and sustainable way [10]. Another portal was launched by the government of Canada aiming at improving society and discovering new things about the world through the positive interaction between people and science [11]. Scotland’s Environment has launched a citizen science portal to allow for sharing data and views regarding the same environmental issues [12]. Digital technologies also offer potentials for “gamifying”, and the use of simple scenarios for decision-making in farming communities.

Citizen science has been used in a wide range of areas of relevance to sustainability and sustainable agriculture, including climate change adaptation [13], marine problems [14–17], monitoring programs [18–21], disease-carrying vector management [22–24], sustainable education [25], agricultural practices [26], and land-use river pollution [27]. It has also been used to extend ecological observation and to improve the general public’s engagement with science [28].

### *1.2. Sustainable Agriculture*

At the time of the 1992 Rio Earth Summit, the concepts of sustainability and sustainable development were framed so as to reconcile the need for economic development to address poverty, with the need to limit the environmentally destructive impacts of economic growth. The rationale behind the framing at that time was that the agenda of increasing global justice would avoid unfair distribution of the costs of necessary change, while including economic profitability in the framing would provide incentives and prevent large economic actors from blocking the sustainability agenda. In line with the objectives of the 1992 Earth Summit, the development of sustainable agriculture was consequently considered to be based on three pillars: a healthy environment, economic profitability, and socioeconomic equity. Over the past three decades, however, the framing suggested at Rio has proved insufficient to actually drive the necessary transformation of systems of production and consumption globally, including in the field of agriculture. Sustainability science has, in recent years, therefore increasingly focused on issues of pathways to sustainability (transition theory), lock-in effects, systems thinking, and planetary boundaries [29,30]. The current climate emergency and the shrinking likelihood that political commitment will be sufficient to keep global heating below 1.5 °C [31,32] have also led to increased attention to questions of adaptation, mitigation, resilience, and vulnerability, as well as the question of whether bottom-up transformation can be achieved in the face of strong lobbies striving to maintain the status quo.

Examples of research areas expressing this shift include understanding the cost of high-input agriculture for smallholders [33] or an interest in the potential of perennials to address the challenges of climate change for agriculture [34,35]. The destructive consequences of industrial agriculture on soil health [36–40], emissions, and biodiversity [40–43] have been highlighted in recent reports by international bodies, as well as the negative impacts on livelihoods and access to food [38,44,45]. A recent major concern has also been the collapse in pollinators [46]. In addition to calling for a move towards small-scale, diversified, environmentally friendly modes of agricultural production, attention has been given to economic implications for farmers [33,47], as well as the anticipated impacts of upscaling various approaches to carbon sequestration [32,39] and relatively new approaches such as enhanced rock weathering [48]. Among various available options, soil carbon sequestration and biochar were both found to have positive effects on all Sustainable Development Goals (SDGs) [32].

Every person involved in the food production system can play a role in achieving sustainable agriculture [49]. In broad terms, and for the purposes of this paper, sustainable agriculture can be understood as approaches and practices that aim at maintaining both economic productivity and the ecosystem services of the renewable natural resources that provide food, income, and livelihood for present and future generations [50]. In other words, food production and the basis for agricultural livelihoods must respect planetary boundaries to be sustainable [29,30].

Not only climate changes, but also world population growth in coming decades will increase the pressure on food production, which currently relies on use of chemicals, including business-as-usual pesticides and fertilizers. Shortages are anticipated in minerals currently used for fertilizers. Therefore, sustainable agriculture should be able to remediate soil and water quality to meet the growing demand for food [45] by using effective and environmentally safe techniques [39,42,44,51–53]. Examples include methods to control pests through the use of biological control through natural products, such as those derived from plants [54] or fungi [55], and smart, slow-nutrient-release bio-fertilizers, such as those based on bacteria or enzymes in their formulation [56].

### 1.3. Aims and Relevance

The nature of agricultural activities has always been tied to farmers' participation to promote awareness, acquire knowledge, and execute evidence-based implementations [5]. However, research projects using the term "citizen science" in connection with agriculture are still comparatively rare. Moreover, the potential role of citizen science in supporting sustainable land and water use, crop protection and yield, and, thereby, agricultural contributions to sustainable food production is still poorly developed. This paper reviews some of the recent literature on citizen science applications to agricultural practices with relevance to sustainability. A variety of exemplary applications are introduced, the underlying reasons for the lack of citizen science in some areas are analytically discussed, and suggestions for further studies are presented.

## 2. Methods

This explorative review covers research published in English for the period 2007–2019. The review strategy consisted of three steps:

- (1) Searching: A search was made in April 2019 in the Lund University library database (LUBsearch) for peer-reviewed publications in English using the search terms "citizen science" AND "agriculture", combined with one of the additional search terms "fertilization", "irrigation", "land use", "crop yield", "pest control", "challenges", or "opportunities", respectively (see Table 1). LUBsearch gathers academic publications from a wide range of well-established databases, such as Web of Science, Scopus, and others. To also cover the gray literature and publications from journals not listed in these databases, an additional search was made in Google Scholar using the same search terms. In line with the explorative approach adopted, an additional search was made in Google to identify portals and projects where the interaction between citizens and scientists is mediated by websites. Additional items were found in research cited in reviewed publications.

The exploratory approach used was intended to capture both mainstream research and possible emerging trends. The collected data focused on the role of citizen science in agriculture to address global sustainability challenges [5], including empirical studies, research papers, and previous or ongoing projects. The search terms were chosen to keep an open explorative approach that could capture the breadth of the field and possible emerging trends, but, at the same time, could take a deeper look at some areas of particular interest for sustainable agriculture and practitioners in the field. Crop yield is significant for food security and farmer livelihoods [41,45]. Fertilizers and chemicals used in pest control disrupt ecosystems, while large areas of the planet used for agriculture are exposed to increasing water stress [39,45]. Finally, sustainable land use [57] is one of the critical factors to mitigate climate change and respect planetary boundaries [39,51]. The keywords “challenges” and “opportunities” were chosen to gain a wider picture of expected benefits and observed difficulties in the field.

**Table 1.** The outcomes of searching for the selected keywords for the period 2007–2019.

Used Keywords	Lund University Database	Google Scholar
Citizen science; agriculture	6	7
Citizen science; agriculture, crop yield	0	4
Citizen science; agriculture, fertilization	0	2
Citizen science; agriculture, pest control	0	5
Citizen science; agriculture, irrigation	0	7
Citizen science; agriculture, land use	1	9
Citizen science; agriculture, challenges	3	6
Citizen science; agriculture, opportunities	1	8

- (2) Screening: For each combination of search terms, abstracts of the first 40 publications yielded by the search in LUBsearch and Google Scholar were read, and relevant publications were selected (see Table 1). For the present study, the choice was made to select publications and projects that lie within issues traditionally addressed by agricultural science (e.g., irrigation, fertilization and crop patterns, control of pests and pathogens, land use, and yields) and with direct relevance to farming communities, and agronomists, horticulturalists, or agricultural engineers. Focus was also placed on environmental impacts as well as some alternatives to industrial chemical-intensive agriculture. Citizens involved in researching environmental impacts typically also include other groups than farmers, such as bird watchers, residents impacted by pollution, and activists concerned with the degradation of ecosystems. To enable an analysis based on the full text, not all publications meeting the criteria were selected for presentation in this review. Examples have instead been selected to give a broad overview of the variety of topics and methodologies used. In addition, some additional examples have been given of studies of relevance for interlinkages with forest management, health, water quality, policy, etc.
- (3) Analysis: In the final step, the extracted materials were summarized, organized, and analyzed in four categories (fertilization, pest control, land use and irrigation, and crops and yield). Examples of projects have been provided for the different categories of the analysis. Gaps highlighted in the literature or which appeared through the overview have been discussed to point to directions for future developments in this area.

### Limitations

To enable full text analysis and capture emerging trends as well as a wide range of issues, a selection was made here of publications presented to illustrate typical topics and different methodologies employed in the studies. Both qualitative and systematic bibliometric reviews of the entire body of published research would be needed to comprehensively identify topics, choices of methodologies, and geographical focuses. Our review aimed to explore the extent to which citizen science projects in agriculture address some current and emerging sustainability challenges. However, the findings have

been affected by the choice of keywords, since the search terms “citizen science” and “agriculture” limit the scope of this study to those publications and projects that specifically include these keywords. For instance, participatory or community-based approaches to the involvement of citizens in knowledge production generally do not appear in this overview and discussion because, in agriculture, such projects are rarely tagged with the keyword “citizen science”. Sustainability concerns all areas of human life and activity—including those disciplines and approaches that do not explicitly refer to sustainability and fields that contribute to deepening the global crises. Similarly, impacts of agriculture on climate, ecosystems, or human societies may be found in a very wide range of disciplines and research fields not included here, including food security, food and global trade systems, rural development, land-use conflicts, etc. The search was also limited to English-language publications and websites. Many additional or alternative search terms could therefore have been used.

### 3. Citizen Science and Sustainable Agriculture

The use of citizen science in the agriculture sector gives a good opportunity to achieve sustainable solutions when farmers and researchers work together [27]. However, the projects that deal with sustainable agriculture and citizen science depend on farmers who voluntarily give their time, efforts, and skills [58]. Beza et al. [58] found that motivations to participate in citizen science differed between smallholders and farmers with larger farms. The literature suggests that smallholders typically lack capacity to engage in and benefit from systematic citizen science projects, while academic researchers need large-scale studies under homogenous controlled circumstances to obtain easily calibrated data and statistically significant results. Citizen science that is connected to agricultural practice and that directly benefits farmers is therefore particularly relevant with respect to engaging farmers and agricultural communities in more sustainable practices. Such topics include fertilization, pest control, land use, irrigation, and crop yield.

#### 3.1. Fertilization

To increase food production, most farmers around the globe focused on the increasing use of fertilization, which has increased by over 500% (over 800% for nitrogen alone) over the past half-century [59]. The fast use of fertilizers has increased nitrogen and phosphorus pollution, while the increase in agricultural production has reduced the capacity of ecosystems to buffer and process nutrient inputs [60]. Developed countries were aware of these consequences. Therefore, phosphorus concentration and flux from large catchments have decreased in certain regions over the last two decades, although NO<sub>3</sub> has shown little change [61]. In France [62], the value of citizen science initiatives in quantifying long-term and seasonal consequences of changes in land management was demonstrated when high school students contributed to 18 years of research work about nutrients in agricultural catchments through the Ecoflux program. The students sampled weekly and found that nutrient concentrations decreased substantially over the period of recording.

In another example, in Welsh livestock farms as part of the PROSOIL project [63], an interesting citizen science study validated that the local knowledge of daffodils’ flowering dates across the country signifies the proper timing for the first nitrogen fertilizer application. The project set a peer-to-peer learning approach and involved 67 farmers’ participation for both cultivating a few bulbs of the same variety of daffodils and reporting the soil temperature upon flowering [63].

#### 3.2. Pest, Weed, and Pathogen Control

The excess and indiscriminate use of pesticides has developed pesticide resistance and led to the accumulation of toxic residues in food, soil, air, and water [64]. In order to better implement the regulation for pesticides in Europe, the coalition ‘Citizens for Science in Pesticide Regulation’ was launched in 2018. Although the European Union strongly regulates the use of pesticides, agricultural practice is not always consistent in this regard [65].

As an example, according to EuroBlight, effective control of the destructive late blight disease caused by the *Phytophthora infestans* pathogen in potato, the second most important crop in Europe, relies on frequent use of fungicide globally, although timely knowledge of the early attacks by the pathogen in local and regional scales will be helpful for meaningful reduction of fungicide usage. The BlightTracker smartphone app is a tool used to upload/observe early attack records of the late blight in Nordic countries [66], which will benefit from the participation of as many minimum-skilled farmers as possible.

The two-year citizen science program called Mosquito Stoppers [67] was a success story, where citizen scientists, with minimal education and training, were able to accurately collect data that reflected trends found in a comparable researcher-generated database. Other research used citizen science to identify host resistance in pest-invaded forests [68]. It was found that involving individuals (citizen scientists) in such programs provides a low-cost means of maximizing search efforts across regions and can provide an effective supplement to management approaches. Moreover, citizens helped in providing the first reports and monitoring forest pathogens [69,70]. Finally, with respect to weed management, farmers might not see the risks associated with overreliance on herbicides. Therefore, audience-specific outreach programs are needed to influence farmers' decisions regarding weed management [71].

### 3.3. Land Use and Irrigation

In October 2018, through its GLOBE Observer citizen science program, NASA included residents in their research. Citizens used their smartphones to photograph the landscape (land cover), and observations could then be compared with satellite data to provide essential information [72]. As part of the LandSense project, Olteanu-Raimond et al. [73] have started campaigns to develop an experimental framework for integrating citizen science into a land change detection process, which is aimed at developing policies on reducing soil sealing through increased urbanization as well as at meeting climate targets.

Agricultural land use affects numerous aspects of ecosystems, microclimate, and environmental pollution. For instance, through their volunteer-based research on microplastic concentrations, Barrows et al. [27] found that citizen science was a valuable approach for quantifying microplastic abundance in a large, mixed-land-use watershed.

In Australia, 72 farmers/irrigators participated in research focusing on irrigation scheduling through the use of Short Messaging Service (SMS). In that project, irrigation scheduling advice was sent to all farmers, while irrigators sent back information about irrigation and rainfall, which was then used to update the water balance [74].

### 3.4. Crops and Yield

How to change crop patterns is seen as a complex issue, especially when farmers cultivate the same crop for decades due to the lack of alternatives that fit market needs and farmers' experience. Antonopoulou et al. proposed a Web-based Decision Support System to support the Greek farmers in selecting alternative crops between maize, soybean, sorghum, rapeseed, and cardoon [75]. Moreover, improving crop productivity has been one of the critical issues over the last two decades for approaching food security. To maximize crop productivity in India, Reddy and Ankaiah proposed a framework for a cost-effective agricultural information dissemination system (AgrIDS), which gave the farmers the needed expertise/advice about cultivating a crop and location based on the market's demand [76].

On the other hand, including the potential of productivity and the potential of resilience—'land potential'—is very important for sustainable agricultural production [77]. Herrick et al. developed a Land Potential Knowledge System (LandPKS) to provide individual users with point-based estimates of land potential based on the integration of simple, geo-tagged user inputs with cloud-based information and knowledge [77].

## 4. Challenges and Opportunities for Citizen Science in Agriculture

### 4.1. Challenges

Initial participation of citizens in volunteer research work depends on personal interests, self-promotion, self-efficacy, and social responsibility. However, long-term participation, especially in agriculture projects, is more complex and depends on motivation factors, such as trust, common goals, acknowledgement, mentorship, and external relationships [78,79]. Moreover, demotivating factors can limit the participation, such as the lack of time and technology, according to Rotman et al. [80], based on three case studies in the United States, India, and Costa Rica. All citizen science projects are based on forming and identifying the groups of citizens to be involved, which is challenging, but will allow a better implementation if the right people are selected [81]. On the other hand, most citizen science programs were based in developing countries and used apps and smartphones.

With some exceptions, such as work on groundwater quality in Lebanon [82], very few projects were conducted in the global South, which highlights the need to introduce these kinds of projects in developing countries and low-income regions, especially regions that are agriculture dependent, exposed to environmental degradation, climate and water stress, and socially or economically vulnerable.

The reviewed literature on challenges in citizen science in agriculture pointed to several areas that lack citizen science projects. Examples include projects dealing with nutrition. Other projects may need capacity building, especially those dealing with political and technical challenges to generate politically controversial data [83]. Further limitations that face agricultural projects that depend on citizen science include failing to attract community engagement [84], the lack of reflexive research works around participation itself [85], the fact that for large datasets, error and bias are poorly understood [76], the need for citizen science to be complemented by other forms of service delivery [86], and the need of some projects for trained volunteers [87].

### 4.2. Opportunities

Citizens can disseminate the information they gain, which enriches the studied issue [5,88], and can produce a multiplier effect. Through citizen science programs, engaged citizens can support their community and become science communicators, which gives a valuable opportunity to support the local decision-making process [5]. In other words, if the right people are selected, they will be able to participate in policy debates related to the studied issue [89], and it was seen that some citizen science efforts led to policy reforms [89]. Among the citizen science projects that have been innovative and successful, most of the data provided by citizens in the projects concerning detection and spread are based on photos, which can be validated by experts [5]. Moreover, involving farmers is cost effective compared to private subcontractors [90], and this provides a good opportunity to involve many communities for enhancing food security and producing healthy food/crops [89].

Recently, the use of software has offered the benefit of generating data and linking the results. The use of the internet and social media provides an opportunity to mobilize communities to address new environmental problems [2]. The use of smartphone technologies gives farmers access to the needed knowledge of the technology, which widens participation in agricultural research projects [2,91]. Smartphones and SMS were, for instance, used for irrigation and updating water balance in Australia [74]. In their study about India, Ethiopia, and Honduras, Beza et al. [58] found that the majority of farmers had mobile phones, which they used to access extension advice and market information. There are many farm management apps that can be used by farmers, which include, among others: Bayer Weed Spotter, which helps in assessing nutrient deficiency in the field; mySoil, which increases farmers' understanding about the soil on their farms; iLevel, which acts as a "management tool for keeping control on stocks of all liquids on farms"; BASF Cereal Disease ID App, which gives "easy access to information on 36 key cereal diseases to aid identification"; Stockmove Express, which allows "livestock farmers in the UK to update their sheep and cattle

holding”; farmGRAZE, which can “improve the efficiency of fertilizer and feed use, boosting grazing efficiency and minimizing waste for dairy cows, beef cattle, and sheep”; and WeatherPro, which gives the latest satellite images of rainfall [92]. In June 2018, the researchers of the International Institute for Applied Systems Analysis (IIASA) developed a citizen science tool called FotoQuest Go app, which “allows users in the EU to collect pictures and information on land use and land cover” [93].

A number of research works focused on how to gamify citizen science [94,95]. Although gamification is mostly used to increase motivation among participants, it has potential applications for sustainable agriculture and citizen science by raising awareness and providing the education needed for active, informed, and skilled involvement of citizens (including farmers) in citizen science research. The simplified models in gamification could allow farmers to make choices individually or as communities on land use and technologies by clarifying the consequences under different scenarios. This, in turn, might contribute to the capacity building required for farmers and farming communities to play more proactive and leading roles in defining relevant research questions and methodologies. A limitation with most gamification approaches is that the underlying models may be excessively simplified, and users may not be able to tailor the focus to their own needs and local conditions.

Citizen science projects have addressed many challenges facing the environment, agriculture, and food production sectors, which illustrates the power of collection-based citizen science projects to inform agricultural research and management. Notably, some citizen science efforts led to policy reforms [89]. More opportunities exist that can link education and teaching about agriculture to citizen science, farming, and gardening [96].

Within all the areas investigated in this study, high-income countries are more represented, although lower-income countries in the global South will be more strongly affected by the immediate impacts of climate change, as well as by demographic pressures on land use and access to food. However, there are encouraging examples of agricultural citizen science in the global South, including a study on farmers’ participation in agricultural development in Iran [97], which showed that farmers were involved in the implementation phase, although not in the planning or evaluating phases of the agricultural programs. The study on citizen science in Iran highlighted the need for education and awareness programs to increase the participation of rural farmers in agriculture planning and policy. Moreover, Ahmadvand et al. [98] evaluated the social impact assessment (SIA) in the agricultural projects in Iran. Their study showed that there were legal and institutional constraints that hindered the effectiveness of the SIA, which highlighted the need to improve the professionalism of the practice of SIA. Moreover, the study recommended involving local communities in SIA and in the monitoring of project implementation.

## 5. Conclusions

This research paper aimed at reviewing the role of citizen science in agricultural practices with respect to sustainability. More than 60 research papers published in the period 2007–2019 were analyzed. By reviewing the literature about the role of citizen science in agricultural practices and how it can help to approach sustainable agriculture, we found that some areas need more analysis and involvement of local people and actors, including critical threats to the environment that have only been recently identified. To identify critical areas and enable necessary research, increased collaboration is needed between research centers with long experience of citizen science with farming communities on the one hand, and research centers working at the forefront of sustainability challenges, such as climate, biodiversity, collapse in pollinator populations, impacts of persistent chemical contaminants, or land degradation, on the other.

While the post-war years witnessed the belief that the mechanization of agriculture meant that rural development and food production were issues of the past, both climate change and perverse effects of industrial food systems on the environment, vulnerabilities, hydrocarbon dependence, and global distribution of income have shifted attention back to rural development and types of more

diversified or labor-intensive agriculture [33,35,42–45,99]. The urgency of the current situation has also led to greater interest in direct engagement with farming communities and organizations working with environmental activism, as well as increased focus on the immediate relevance of scientific knowledge production for action on the ground and accelerating sustainability transitions. Although much of the work in citizen science relating to sustainable agriculture still lies within a one-way paradigm of citizens providing data for scientists, potentials for development in this area are considerable.

The importance of citizen science involvement has been highlighted and acknowledged by all and can save some of the costs for observations on the ground, as well as pointing to blind spots in existing research. A considerable increase can be observed in projects aiming to address climate change impacts and to approach sustainability and food security. The use of the internet, social media, and apps has been one of the most important opportunities and has played a vital role in engaging farmers in both local and international research efforts. In line with the conclusions of the working group reported in Ryan et al. [5], we also believe that citizen science in agriculture can contribute to addressing major sustainability challenges both for agriculture and for human societies in general. Low-income communities in the global South are most exposed to impacts of environmental degradation and climate change, but also have the least adaptive capacity. It is therefore vital that greater focus be placed on the specific concerns and challenges of these areas.

The results indicate that involving citizens can help in addressing most agricultural issues. However, there are many issues to be addressed that have not been given sufficient attention, such as tillage, trading, long-term planning, and copying the lessons learned. Moreover, most of the research work was focused on a group of citizens/farmers in a specific area for a specific period of time, which limited the investigation of the long-term impacts and the expansion of these activities to a national or regional level. Cooperation with other local actors was found to be limited as well. Shifting the knowledge to a higher decision cycle level and focusing on environmental and socioeconomic issues, such as climate change, poverty, gender, or water scarcity [41,45,99–103], would help to maintain and secure funding.

The original definitions of citizen science included both making science accessible to citizens and contributions of citizens to science. Although our study has mainly focused on projects where citizens contribute with data and monitoring, in current approaches to addressing sustainability challenges, the relationship between citizens and academic environments is not seen as two separate lines of information flow, but as a more integrated and collaborative process. In addition, the need for urgent and radical changes in practice has blurred the distinctions between development projects and applied and foundational science, moving greater focus in the direction of so-called “mode II science”. Such close collaboration and dialogue require increased education, competencies, and capacities among farmers and other citizens, as well as development of relevant capacities in scientific communities and understanding of which methodologies can help make science relevant to citizens. The development of methodologies in citizen science can therefore not simply be focused on ensuring that the data collected are sufficiently standardized and calibrated to feed into big data modeling, or that they meet other criteria internal to the scientific systems of knowledge production.

Our review makes a contribution to the academic research on citizen science in agriculture by exploring the intersection between a selection of research areas that are relevant to farmers and agricultural professionals and that are simultaneously of concern with respect to major sustainability challenges. Ryan et al. [5] have pointed out there is great potential both to obtain important data and expertise from farmers and to mobilize farming communities in the transition toward sustainable practices. However, even when environmental impacts are substantial, farmers need to understand the relevance to their livelihoods and have access to sustainable alternatives. Continuity is essential for enabling local capacity building over time. The academic structures driving this type of citizen science research appear fragmented and not well connected to environments at the forefront of research on sustainability transitions or planetary challenges. Although the research methodologies in the projects display considerable ingenuity, the solutions found appear largely driven by constraints connected

to traditional methods for establishing validity and reliability, as well as by the dynamics of data collection for big data methods. Particular attention is required to enable citizen science in low-income contexts globally.

The findings from this study can contribute to debates on how to shape policy, research funding, and strategies of research institutions to better support citizen science in agriculture in areas that are significant for foundational sustainability research as well as areas where rapid changes in agricultural practices are needed. The study can also provide input for education and training in agricultural professions and for the education of researchers.

This review covered a small selection of search terms and a limited number of publications. Future research involving extended systematic bibliometric reviews would be needed, to identify the most critical issues that are currently under-researched with respect to challenges and vulnerabilities facing farming communities in different geographical areas. Further research would also be required to identify research institutions and projects that offer examples of best practices in citizen science that can be adapted to a variety of local conditions, including low-income communities, conflict zones, and areas exposed to natural disasters.

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