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REVIEW ARTICLE

Citizen science breathes new life into participatory agricultural research. A review

Jeske van de Gevel[1,2] · Jacob van Etten[2] · Sebastian Deterding[1]

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Abstract

Participatory research can improve the efficiency, effectiveness, and scope of research processes, and foster social inclusion, empowerment, and sustainability. Yet despite four decades of agricultural research institutions exploring and developing methods for participatory research, it has never become mainstream in the agricultural technology development cycle. Citizen science promises an innovative approach to participation in research, using the unique facilities of new digital technologies, but its potential in agricultural research participation has not been systematically probed. To this end, we conducted a critical literature review. We found that citizen science opens up four opportunities for creatively reshaping research: (i) new possibilities for interdisciplinary collaboration, (ii) rethinking configurations of socio-computational systems, (iii) research on democratization of science more broadly, and (iv) new accountabilities. Citizen science also brings a fresh perspective on the barriers to institutionalizing participation in the agricultural sciences. Specifically, we show how citizen science can reconfigure cost-motivation-accountability combinations using digital tools, open up a larger conceptual space of experimentation, and stimulate new collaborations. With appropriate and persistent institutional support and investment, citizen science can therefore have a lasting impact on how agricultural science engages with farming communities and wider society, and more fully realize the promises of participation.

Keywords Citizen science · Participatory agricultural research · User-centered design

Contents

✉ Jacob van Etten
j.vanetten@cgiar.org

[1] Digital Creativity Labs, University of York, YO10 5GE York, United Kingdom

[2] Bioversity International, Montpellier, France

1 Introduction

Participatory research describes research that is done not only *for* or *on* but also *with* people. What sets it apart from conventional research is a deliberate, focused interaction between researchers and participants leading to changes in research design, technology development, and/or research evaluation (Ashby 1996; Lilja and Bellon 2008). While farmers have historically participated in all manner of agricultural research, farmer-participatory research became a specific focus in the agricultural sciences in the early 1980s. This stemmed from the recognition that farmers in marginal areas generally did not benefit from technological advances and thus that more effort should be invested into more inclusive approaches (Chambers 1994; Sumberg and Okali 1997; Johnson et al.

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2003; Biggs 2008; Scoones et al. 2008). In farmer-participatory research, farmers would be involved directly in setting research goals, selecting seeds, observing pests and crop diseases, or evaluating research products. The expectation was that such participation would help to tailor research to the needs and criteria of participants, which would lead to new insights, products, and services that were more useful for their prospective target audience and would empower participants in the process (see Section 2 below).

Farmer participation offers legitimacy to agricultural research and has shifted its paradigm from a linear transfer of technology approach toward more people-centered approaches revolving around innovation and learning. However, in reality, participatory research in agriculture did not live up to its promise, due to institutional and epistemic difficulties in its implementation. For example, in plant breeding, participatory styles of research are still evolving but have never become mainstream (Ceccarelli 2015). Even in institutional contexts in which participatory exercises have gained legitimacy, their findings are not fully used (Sumberg et al. 2013). While participatory research attracts attention, it is not fully integrated into biophysical or experimental agricultural research focused on technology development (Figure 1).

Despite this general disappointment with participatory research, it is currently receiving renewed interest with approaches that make more intensive use of new digital technologies, generally denominated as "citizen science." Citizen science has in common with "traditional" participatory research that it aims to produce new scientific knowledge while increasing public understanding of science and democratizing the scientific process (Cooper et al. 2015). Several initiatives have engaged in "crowdsourced" citizen science, engaging farmers and other actors involved with food systems in scientific experimentation and observation at scale, making use of digital media (for an overview of citizen science initiatives in agriculture; see Minet et al. 2017 and Ryan et al. 2018). In the context of citizen science in agriculture, the term "citizen" refers to farmers and members of the general public involved with agriculture "who actively contribute to science with their intellectual effort or surrounding knowledge or with their tools and resources. Participants provide experimental data and facilities for researchers, raise new questions and co-create a new scientific culture" (Green paper on Citizen Science 2013).

An obvious question is if citizen science can address the challenges that prevented participatory research in agriculture from becoming mainstream. Current enthusiasm over new digital technologies and research formats can easily overshadow concerns well-founded in decades of trial-and-error experience. In the worst case, ignoring the past can lead us to repeat its mistakes and failures. Only if citizen science can overcome existing barriers of participatory research will it meaningfully contribute to agricultural sustainability. Figure 1

To address the question if citizen science can realize the promises of participatory research in agriculture, we take a step-by-step approach. First, we review the relevant research literature to chart the promises of participatory research, and the different expectations on what participation in research should contribute (Section 2). The possible contribution of citizen science needs to be measured against these expectations (or these expectations need to be adjusted). Then, we explore the question why participatory styles of research have not become mainstream in agriculture (Section 3). Citizen science will eventually have to face the same barriers as other participatory research, especially when the initial enthusiasm will have waned off and long-term sustainability becomes a main concern. Finally, we assess recent research that explores the fresh perspectives that citizen science brings to participatory research (Section 4). We conclude by discussing whether and how citizen science can fulfill the promises of participatory research and address the extant barriers that have prevented participatory research from becoming mainstream (Section 5).

2 The promises of participatory research in agriculture

The existing discourse on participatory research in agriculture highlights three major potential positive impacts: increased effectiveness and efficiency of the research process, empowering marginalized social groups, and improved environmental sustainability of developed solutions.

Fig. 1 Researcher Naaman Orodi explains how to install weather sensors in sorghum trial fields in Nyando, western Kenya (July 2014). Credit: Jeske van de Gevel

2.1 Increased effectiveness and efficiency

According to Johnson et al. (2004), participatory research can strengthen feedback links between researchers and participants, which lead to a better understanding of the problems, more appropriate solutions, and faster adoption. It takes into account farmers' constraints and contextual factors from the outset, rather than designing optimal technologies on research stations and then undertaking a process of adaptive research (Collinson 2000). More generally, combining formal research and informal farmer knowledge practices can increase *effectiveness* by offering more appropriate solutions at local level (Sumberg et al. 2003; Hoffmann et al. 2007). More *efficiency* can be achieved by outsourcing certain tasks to participants, and by avoiding separate research and adaptation phases.

A concrete example is the plant breeding work of Ceccarelli (2015) and others, who pioneered participatory approaches in the early 1990s by bringing formal breeding techniques to local communities. Conventional plant breeding tended to favor resourceful farmers who are able to modify their environments to accommodate the requirements of new crop varieties. Poor farmers operating in marginal areas often do not have the resources to apply fertilizers and other inputs and are risk-averse when it comes to testing out new and unknown varieties (Ceccarelli and Grando 2007). By decentralizing plant breeding to on-farm selection, farmers can select and help to breed varieties that suit their specific environmental and social conditions. Experience has proved that involving farmers at the design stage leads to a faster and less expensive breeding process and higher adoption of new varieties (Ceccarelli 2015). Conventional breeding processes involve several years of breeding varieties, followed by on-farm testing of these varieties. Participatory plant breeding moves selection to farms in earlier stages of the process, significantly reducing its duration (Johnson et al. 2004; Ceccarelli 2015).

Johnson et al. (2003) state that the initial costs for participatory research might be higher as they require to establish links with local communities and community meetings, but these additional costs are not significant. Thus, Neef (2008) looked at the costs of adding participatory approaches to conventional research processes, and found that the costs for hiring local staff and compensating farmers' time and travel costs made up only a fraction of the total. Additionally, the costs for compensating farmers can be offset by a decrease in costs for research when certain tasks are taken up by farmers. Working in remote locations increases logistics, mobilization, and communication costs (Chambers and Jiggins 1987; Bentley 1994). But scaling conventional research to multi-location trials and research efforts would incur similar increases without the benefits of participatory approaches (Morris and Bellon 2004).

More farmer participation moves costs from researchers to involved farmers, requiring farmers' time, intellectual capacity, and sometimes also inputs such as land, labor, or assets (Morris and Bellon 2004). Some participatory approaches require considerable amounts of time away from the farm, for example, participatory rural appraisal exercises where entire villages are required to participate in meetings over multiple days (Hoffmann et al. 2007) or participatory plant breeding processes that require farmers' commitment at peak harvest times and usually cover multiple seasons (Collinson 2000). However, there are only few studies offering cost analyses from the farmer side. Farmers often calculate their opportunity costs to determine what they could earn if they used their time doing something else or continued participation at busy times in the farming cycle. Hence, their participation in participatory research can be read as an indicator that to them, participatory research is an effective and efficient use of their time.

One more general problem with cost-benefit analyses is that the gains of research are measured through a narrow focus on outputs, for example, the number of varieties released (Spielman and Kennedy 2016). Impacts like increased farm income, technology adoption, or improved livelihoods are less often measured in cost-effectiveness studies. As Lilja and Bellon (2008) point out, the benefits of participatory research for farmers extend to even more distal, indirect forms, for example, increased knowledge, changes in agricultural practices, or obtaining enhanced skills, as well as facilitating mutual learning between researchers, farmers, and other actors. These benefits are not easy to measure using standard impact assessments, and their value is often not considered. Emerging approaches attempt to document this wider range of benefits, using a mix of different methods, including participatory ones (Faure et al. 2020).

2.2 Empowerment

A main motivation to engage participants in agricultural research is empowerment (Sumberg et al. 2003). Some authors state that participatory research can enable marginalized groups in society to make their own decisions by equipping them with basic research skills or by giving them a voice in decision-making processes (Bunch 1982; Chambers 1994; Cornwall and Jewkes 1995). Several authors frame empowerment in terms of redressing some existing inequality, be it between different social groups, between researcher and farmer, or between different groups among farmer participants. For Bunch (1982), any intervention needs to consider the different socio-political rights of different groups within society; otherwise, interventions might reinforce existing inequalities and increase the power of the elite. For Chambers (1994), empowerment requires a change of role for the researchers to equip farmers with the tools to do their own appraisals and needs assessments. He states that researchers should develop methods that allow farmers to participate in a non-extractive way. Another theme that is often mentioned is cognitive justice. Cornwall and Jewkes (1995) state that "ultimately, participatory research is about respecting and understanding the people with and for whom researchers work. It is about developing a realization that local people are knowledgeable and that they, together with researchers, can work towards analyses and solutions" (p. 1674). While participation can empower farmers and other participants, it can empower researchers as well. Farmers' voluntary participation and their sense of ownership in research processes can be a form of legitimization for research and its institutions (Ashby 1996; Lilja and Bellon 2008; Johnson et al. 2004).

Empowerment depends on the ability of participatory activities to be inclusive in terms of recruitment and creating space for people to express themselves. Inclusion spanned across socioeconomic status, location, gender, cultural norms, or poverty (Johnson et al. 2003; Cornwall 2008; Waddington et al. 2014). Participation of women in agricultural research tends to be lower than that of men (Cornwall 2008; Pope 2013). This can be related to male-dominated mixed meetings in which women's voices remain limited (Joseph and Andrew 2008), explicit targeting of organized or literate farmers (Phillips et al. 2014), or cultural sensitivity, for instance targeting married women only (Najjar et al. 2013). Larger-scale or more innovative farmers are more likely to enter participatory research due to selection criteria of extension agents or farmers' self-selection (Anderson and Feder 2004), as well as confidence levels from previous experience in participatory research (Johnson et al. 2003). The design of the intervention or the composition of the research team can influence social inclusion through the quality of communication or social distance between researchers and farmers (Sumberg et al. 2013, p. 253; Trimble et al. 2014) or the timing and duration of activities, which can disproportionately affect participants who are time-poor (Hoffmann et al. 2007; Chambers 1994). Exclusion effects may be partially overcome by carefully deciding selection criteria and recruitment strategies beforehand (Friis-Hansen 2008). Also, carefully selecting formats of participation can activate mechanisms of social inclusion. Deliberate participation ("talking") through group discussions, for example, can exclude marginal voices due to leadership effects, while performative participation ("doing") can generate alternative spaces for expression (Richards 2007). Even though participation in agricultural research does not automatically empower farmers, there is broad agreement that appropriate participation is necessary if agricultural research is to contribute to empowerment.

2.3 Sustainability

Ashby (1996) suggests that even though participation may make technology development more efficient, a more important positive impact is improving the environmental sustainability of developed innovations. To avoid further environmental degradation, researchers should always consider the long-term effects of the technologies they develop on future generations (Collinson 2000). Researchers and farmers operate in different realities; hence, adoption of technologies without adaptive research and/or stakeholder participation can lead to unsustainable solutions (van de Fliert and Braun 2002). Furthermore, participation can help to create a sense of ownership over the technologies or the research process, which means that people will be more inclined to look after them if it serves their interests (Hickey and Mohan 2004). Involving participants in research also increases sustainability because it avoids creating dependencies on outsiders to keep offering benefits (White 1996; Cornwall 2008).

New approaches have attempted to further decentralize innovation processes and decrease the dependency on a few central actors and create broader involvement of a range of stakeholders, including public and private organizations (Klerkx et al. 2012). Farmer-led research supported by civil society organizations attempts to make research unambiguously oriented to farmers' needs (Waters-Bayer et al. 2015). Innovation platforms have attempted to embed participatory research in broader processes of innovation to move away from technology-focused approaches to more system-focused approaches. Innovation platforms bring together individuals and public and private sector organizations and institutions for priority setting, networking, learning, negotiating, and experimenting, with the aim of building up long-term engagement between stakeholders to achieve more development impact (Schut et al. 2016). Even though these approaches have broadened the range of stakeholders beyond farmers, farmer-participatory approaches are seen as a crucial ingredient to support the sustainability of the change these approaches are expected to bring.

3 Why has participatory research not become mainstream?

Participatory research has successfully created "farmer-centric" approaches to developing agricultural technology, for example, through the development of farmer innovation networks (Waters-Bayer et al. 2007; Abrol and Gupta 2014), market-led development, participatory approaches to learning and impact assessment (Douthwaite and Hoffecker 2017; Heinemann et al. 2017), and farmer-to-farmer innovations (Van Mele 2006; Kiptot and Franzel 2014; Chowdhury et al. 2015). These approaches have responded to the changing role of farmer organizations (Hellin et al. 2009; Ton et al. 2014) and the development of more demand-driven extension services (Aker 2010; Humphries et al. 2015) and are embedded in more integrated approach toward agricultural research through multi-stakeholder innovation platforms (Schut et al. 2016; Douthwaite et al. 2017; Pigford et al. 2018). At the same time, co-design of farming system approaches has emerged (Meynard et al. 2012; Berthet et al. 2018) and participatory modeling and simulation approaches have made innovative contributions (Naivinit et al. 2010). In spite of this proliferation of approaches, we observe that they remain still unconnected to much biophysical research in agriculture in national and international research organizations.

This lack of mainstreaming needs to be explained. Two major issues emerge from the literature: the institutional and epistemic workings of agricultural research, and a lack of research and innovation around participation itself.

3.1 Entrenched scientific institutions and incentives

One well-evidenced barrier to mainstreaming participatory research has been the institutional workings of science itself. Waters-Bayer et al. (2015) describe how a lack of effective institutional learning and knowledge management processes keep formal research institutions, in particular the CGIAR, from learning from end users (see also Kristjanson and Harvey 2014). For international rice research, Sumberg et al. (2013) found that some participatory research formats, such as participatory variety selection, had found legitimacy but that there were no clear, established ways for their findings to inform research decision-making. Similarly, Becker (2000) describes a perpetuation of standard epistemological practice at strategy level where research priority setting tends to follow a natural sciences approach, "with a few ingredients of social sciences" (p. 5). The short-term nature of most participatory projects, the low number of scientists and managers that have experience in participatory research, a reward system which favors data production over impact, and the lack of exchange and learning opportunities on the topic of participatory research are further institutional barriers affecting international agricultural research centers and the national agricultural research systems in developing countries. The scientific value of participatory research is sometimes questioned because of its perceived lack of precision, control, replicability, and generalizability (van de Fliert and Braun 2002). Standard methods of collecting feedback, such as surveys, technology evaluation, and field visits, are insufficient to generate useful user feedback, and experiences, opinions, and knowledge from extension officers and farmers are rarely documented or used to validate results, underestimating their value. Further, it often takes more time to set up participatory forms of research and get participants involved, and therefore results also take longer.

These institutional and epistemological barriers are in turn perpetuated by several other systemic issues of agricultural research. First, competition between institutions and individuals for funding and academic merit prevents sharing data and learning experiences and generates a culture of knowledge hoarding (Hoffmann et al. 2007; Schot and Geels 2008; Abah et al. 2011; Pope 2013; Waters-Bayer et al. 2015). Second, high staff turnover inhibits the uptake and transfer of "new" participatory approaches (Johnson et al. 2003). Third, research incentives are not connected to accountability toward end users (Schut et al. 2016). Fourth, staff performance management lacks appropriate mechanisms to incentivize scientific workers to deliver end-user impact (Anderson and Feder 2004). Thus, as research systems move to higher accountability and client orientation, participatory research may become stronger (cf. Sumberg et al. 2013).

3.2 Lacking research and innovation around participation itself

A second barrier to mainstreaming is lacking reflexive research around participation itself. In areas of agricultural research in which participatory methods were first applied, one finds a limited and relatively static repertoire of participatory methods in use (Sumberg et al. 2013). This extends to the way participation itself is conceptualized. Many authors stay close to Arnstein's (1969) "Ladder of Citizen Participation" (Biggs 1989; Pretty 1995; Lilja and Ashby 1999). Arnstein classified citizen participation according to the degree of power of citizens in decision-making processes, from nonparticipation through tokenism to true citizen participation. Biggs (1989) similarly describes four modes of participation in agricultural research as *contractual* (farmers are hired to participate in experiments or provide land), *consultative* (farmers' opinions are sought to plan interventions), *collaborative* (researchers and farmers work together in researcher-designed projects), and *collegiate* (researchers and farmers work together as a team to strengthen the informal research system). Lilja and Ashby (1999) later added a fifth mode of farmer experimentation: farmers experiment *independently* without interference or instruction of researchers. In these categorizations, variation in participation is generally plotted along a single axis of relative power or influence of researchers versus farmers. Arnstein's Ladder and derived categorizations imply a normative stance—more and more "genuine" participation is always better (Neef and Neubert 2011). It is telling that few have tried to develop more sophisticated perspectives on farmer participation or engage more directly in designing new participatory methods (Neef and Neubert 2011). The noncanonical status of participation and its highly normative conceptualizations seem to have led agricultural researchers to take participatory formats "as a given," focusing on their legitimation and adoption, rather than their selective and dynamic adaptation to different contexts.

This contrasts with digital technology design, which will be discussed in relation to citizen science below. In this field, researchers critically examine participation and deliberately and playfully explore and evaluate new methods for participation. McCarthy and Wright (2017) point out that Arnstein's Ladder is of limited value in participatory design contexts (in which participatory technology development in agriculture can be included), as it originated in public participation in a type of policy decision-making where relatively well-defined questions need to be answered. In design processes, in contrast, participation can and should take place in multi-dimensional, dynamically changing constellations of agency, control, self-determination and power, addressing, and often reframing ill-defined, significant problems. This has led them and many others to explore alternative formats for configuring participation suited to the particular needs and contexts of different projects.

In some areas of agricultural research, innovative experiments with alternative forms of participation have taken place, especially around farming systems' research and design. Interactive models of leadership sharing between farmer researchers and scientists have become more common (Drinkwater et al. 2016). Participatory modeling techniques have been developed to include different types of knowledge and values into decision-making processes (Berthet et al. 2016). These methods involve different forms of participation, such as the co-design of simulations using role play and gamified formats to explore possible scenarios in agriculture and natural resource management (Barreteau et al. 2003; Martin et al. 2011). These new approaches have also led to more reflective ways of thinking about participation. Reflecting on a companion modeling exercise, Barnaud and van Paassen (2013) show how effective empowerment involves dealing with important dilemmas between empowering stakeholders to lead the process and strategic interventions to ensure that less influential stakeholders also have a voice. They contend that a neutral posture is impossible in this context and indicate the need for a "critical companion" posture that involves deliberate design choices in shaping participatory processes, whose objectives and assumptions are made explicit to participants. While this approach does not steer free of new dilemmas and questions, these types of reflections and approaches clearly go beyond the type of simplistic normative stance described above. In the same vein, Neef and Neubert (2011) created a framework that structures reflection and decision-making around the design of participatory processes within agricultural research in a way that is not prescriptive but that invites consideration from multiple dimensions.

This renewed innovation and reflection around participatory research have influenced some areas within agricultural sciences much more than others. The static situation observed by Sumberg et al. (2013) seems to be applicable especially to those areas that generate data through field experiments and observational studies. The explanation advanced above is that a conceptual deficit around participation persists across the agricultural sciences and has impeded a more versatile design of participatory approaches. One innovative impulse may come from participatory approaches around systems modeling. In the following, we address the question if citizen science provides another impulse to rethinking participation in agricultural research.

4 New impulses of citizen science

To assess the potential of citizen science to bring a fresh perspective to participatory agricultural research, we discuss four novel aspects around participation that have emerged as part of the new experiences with citizen science. After introducing the concept of citizen science, we firstly discuss the new attention it has brought to the study of participants' motivations. Secondly, we explore role differentiation in citizen science. The complexity of citizen science projects has led to fresh thinking on how participants can take up different roles in projects. Thirdly, citizen science's emphasis on education has led to different ways to design and evaluate projects. We discuss how these experiences can provide opportunities to rethink participation in agricultural research and shed new light on its "empowerment agenda." Lastly, citizen science has made use of digital tools to support the experience of participants. We discuss how this relates to the challenge of participatory agricultural research to address social inclusion issues.

4.1 Citizen science and participatory research

The term "citizen science" has emerged in the past 15 years to describe new forms of participatory research across a wide range of disciplines, commonly enabled by new digital technologies. There is no universally agreed-upon definition. In fact, several researchers stress that the plurality of understandings is critical to the creativity and innovation found in the field (Schäfer and Kieslinger 2016; Eitzel et al. 2017; ECSA 2020). For instance, while Cooper et al. (2007) define citizen science as "a dispersed network of volunteers to assist in professional research using methodologies that have been developed by or in collaboration with professional researchers", other authors indicate that any scientific work undertaken by members of the general public should be considered citizen science, as long as it aims to follow protocols which align with standard practices within the discipline in which the research is framed (ECSA 2020). These broad definitions do not allow us to distinguish citizen science in any clear-cut way from participatory action research and participatory monitoring which have a longer history in the agricultural sciences. Nevertheless, the efforts that are labeled "citizen science" are distinct in their genesis and form.

Rick Bonney is credited as the first to publicly use the term citizen science, and then to describe the involvement of the public in large-scale data collection initiatives (Bonney et al. 2014; Woolley et al. 2016). He uses it to describe an alternative form of public outreach or science education to both build scientific literacy and harness large publics for data collection. Thus, citizen science allows researchers to benefit from scientific work generated by the public, and members of the public to be involved in authentic scientific activities, for example, modeling, collecting research data, and experimentation. For Bonney, this sets it apart from other forms of the public engaging with science, including informal or volunteer learning (Jordan et al. 2012; Bonney et al. 2016), public engagement with science (PES) (McCallie et al. 2009), or public understanding of science (PUS) (Bonney et al. 2016).

Others, most notably Alan Irwin (1995), use the term citizen science to emphasize the social responsibility of science and a fitting democratization of science: to serve and be accountable to the public good; common people should be included in research processes or enabled and organized to conduct their own research (see also Riesch and Potter 2014; Dickel and Franzen 2016; Woolley et al. 2016). This corresponds to already-mentioned notions of empowerment in participatory research, not only through participation but also through an emancipation of science from its institutional context and as the sole responsibility of scientists (Woolley et al. 2016).

Beyond its conceptual diversity, citizen science involves distinctive new elements or styles of research and participation that were absent or weak in previous participatory research, enabled by internet platforms, mobile phones, and other information and communication tools (ICTs) fostering computer-mediated communication, networking, and collaboration (Dickinson et al. 2012; Minet et al. 2017). Specifically, it makes use of so-called *social computing* formats and tools, for example, prediction markets, reputation systems, crowdsourcing, collaborative editing and filtering, and distributed sensing (Knol et al. 2008). Bonney et al. (2016) show that Internet technologies have made public engagement in scientific research more accessible and widespread in its ability to recruit large numbers participants and volunteers, including marginal groups. Large and complex datasets can be made available for piecemeal processing and analysis by many separate individuals online. As a result, digital tools have changed the scope of volunteer participation, enhanced the potential spatial and temporal coverage of data collection (McCormick 2012; Solli et al. 2013; Fuccillo et al. 2015), and improved data and image analysis (Crall et al. 2011; Cooper et al. 2015).

Citizen science in agriculture is a small but growing practice (Minet et al. 2017; Ryan et al. 2018). Agricultural research occupies a small percentage of the total effort dedicated to citizen science, with less than 2% of peer-reviewed articles reported to combine the term citizen science and agriculture (Ryan et al. 2018). Citizen science has proven efficient to collect observations from farmers and other nonprofessionals through digital "crowdsourcing" approaches (Minet et al. 2017). For example, PlantVillage uses digital tools to improve smallholder farming, involving different efforts to monitor pests and diseases in agricultural crops (https://plantvillage.psu.edu/). Similarly, large-scale on-farm experimentation is being done through citizen science format focused on crop variety evaluation (van Etten et al. 2019; https://climmob.net). Table 1 provides important examples of citizen science in different fields, including agriculture.

Citizen science is considered attractive because it can lead to a "double win," supporting more efficient and effective scientific knowledge generation for researchers while supporting learning for participants and their wider communities, accompanied by a greater social accountability of scientific research (Shirk et al. 2012; Bonney et al. 2016; Cooper et al. 2015).

As for the first win, more effective and efficient scientific knowledge generation, digital forms of data collection can yield higher-quality data (in terms of spatial and temporal coverage and immediacy) at reduced costs (Blaney et al. 2016). Data quality has been the subject of debate in much of the early literature around citizen science. Critics indicated that using data from non-scientists called for more extensive data verification. However, the possibility of generating high-quality data through citizen science is accepted in several fields (Cooper et al. 2015). Citizen data can come at a lower cost, leading to an efficiency gain. Besides the initial investments in program development, software development, advertisement, recruitment, and training, costs for citizen science projects tend to decrease over time. After a program is established, with relatively high initial costs, it is mostly the relatively low running costs for computing and networking that remain (Palmer et al. 2017). However, as for participatory agricultural research (Section 2.1), the benefits are difficult to capture in cost-benefit ratios (Bela et al. 2016; Blaney et al. 2016). Even so, cost-benefit ratios remain an important focus of attention in the discussion about citizen science

The second win emphasizes the educational value of citizen science. Learning takes different forms. Participants gain new skills or content knowledge (Brossard et al. 2005; Evans et al. 2005), improve scientific literacy or understanding (Trumbull et al. 2000; Jordan et al. 2011), connect deeper with their environment (Newman et al. 2017) or with other people (Bell et al. 2008), and enhance environmental stewardship (Evans et al. 2005; Ballard et al. 2017). Some authors emphasize learning as a more interactive process, taking on board the perspectives of participants. Citizen science engages participants in decision-making processes (Shirk et al. 2012) and addresses local community concerns (Middleton 2006; Ottinger 2010). These different benefits of citizen science

Table 1 Examples of citizen science efforts in different scientific disciplines

Discipline and topic	Case study	Locations	Participant tasks	Reference
Plant ecology				
Identification of invasive plants	Record presence of invasive and non-native species along hiking trails	New York and New Jersey, USA	Data collection	Jordan et al. 2011
Invasive plant species identification	Identify invasive plant species, map their distribution, and estimate abundance	Colorado and Wisconsin, USA	Data collection	Crall et al. 2011
Plant phenology monitoring	Monitor plant phenology of 19 plant species along a trail	Portland, USA	Data collection	Fuccillo et al. 2015
Bird ecology				
Nest monitoring	Observe birds occupying newly installed next boxes	Across USA	Constructing and installing nest boxes, data collection	Brossard et al. 2005
Nest monitoring	Observe and report nesting behavior and nesting success	Washington DC, USA	Data collection	Evans et al. 2005
Bird monitoring	Observe bird species presence contributing to a global database	Global	Data collection	Kelling et al. 2015
Environmental monitoring				
Monitoring coastal environmental disturbances	Monitor environmental disturbances, measure water and air quality	San Francisco Bay Area, USA	Data collection	Ballard et al. 2017
Community-driven stream restoration	Monitor and diagnose stream health	USA	Monitoring, diagnosis, planning, education, and action	Middleton 2006
Monitoring air quality	Air quality monitoring using inexpensive air sampling devices ("buckets")	Louisiana, USA	Data collection	Ottinger 2010
Risk assessment mapping	Mapping the long-term impact of the 2010 Deepwater Horizon oil spill	Gulf of Mexico, USA	Data collection	McCormick 2012
Agriculture				
Crop experimentation	Evaluate on-farm performance of different crop varieties	L America, South Asia, and Africa	Establishing and managing trial plots, data collection	van Etten et al. 2019
Plant disease identification	Contribute to a user-moderated Q&A forum on plant-related questions	Worldwide	Content generation and curation	Hughes and Salathe, 2015

closely match those of participatory agricultural research (Section 2 above)

The goals and benefits of citizen science and its diversity may create the impression that citizen science is little more than a new label for participatory research. But even though there are important areas of convergence, citizen science shows some important differences. These not only reflect new methodological possibilities afforded by digital technologies but also the origin of citizen science, which emerged predominantly from rich economies and academic natural science research. Participatory agricultural research, in contrast, originated largely in and around applied agricultural research focusing on poor rural areas. In this sense, the differences between citizen science and participatory agricultural research are arguably not only scientific but also social. These differences in origins and trajectories make it interesting to explore possible ways to cross-fertilize between the two areas. The following sections explore different aspects of innovation within citizen science that address identified challenges of participatory agricultural research

4.2 Unpacking participant motivation and engagement

One of the distinguishing features of citizen science is the active involvement of citizens in scientific research with mutual benefits for both the scientists and the citizens (Robinson et al. 2018). This has sparked new research on the motivation and level of engagement of participants. Citizen science projects have often relied on the intrinsic motivation of participants (and rarely payment) and relatively open forms of (online) recruitment (Crowston and Fagnot 2008). The volunteer nature of citizen science participants and the shift away from monetary compensation makes a more reciprocal perspective obligatory, and sharpens the question how to attract, engage, and retain participants (Cooper and Lewenstein 2016). Hence, researchers have felt a strong need to understand why participants join and keep contributing to citizen science projects, leading to findings that are inspiring for participatory agricultural research as well. Major reasons to participate in online citizen science efforts are the motivation to contribute to scientific research (Raddick et al. 2013), gaining content understanding and skills, "helping" (referring to the positive, prosocial feelings of volunteering), as well as participants' understanding of the process as well as its usability (Reed et al. 2013). Geoghegan et al. (2016) and Frensley et al. (2017) found that a contribution to science, sharing knowledge, and an interest in conservation were the main motivational factors for environmental citizen science projects. Hobbs and White (2012) found that personal benefits such as learning, enjoyment, as well as health and well-being are driving motivations in wildlife monitoring. They report that bird tracking even alleviated symptoms of depression for some of the participants. Dehnen-Schmutz et al. (2016) asked British and French farmers about their willingness to contribute to agricultural research as citizen scientists. Relatively few farmers deemed financial compensation to be essential, but this differed between tasks related to observation and data collection (where 9–18% rated financial compensation as essential) and tasks that involve experimentation (37%). Beza et al. (2017) studied the motivations of farmers to contribute to agricultural citizen science experiments in India, Honduras, and Ethiopia. The ability to contribute to scientific research and an interest in sharing information were found to be the most important factors. When farmers were asked about what they expected in return for participation, they generally mentioned information and technical advice, and rarely mentioned monetary compensation. These findings imply that approaches that mobilize intrinsic motivations are also feasible when working with resource-poor farmers.

The literature on volunteering makes fine-grained distinctions between the different factors that influence participants' motivation in different phases and roles and how this relates to the characteristics of participants (Clary et al. 1998; Grube and Piliavin 2000; Penner 2002; Piliavin et al. 2002; Unell and Castle 2012; van Ingen and Wilson 2017). This literature has influenced research on motivation in citizen science. Crowston and Fagnot (2008) distinguish between initial, sustained, and meta-contributors. *Initial contributors* are driven by curiosity, in combination with having time available to contribute and feeling confident in their expertise and self-efficacy. *Sustained contributors* are motivated by feelings of fulfillment or obligation to the project, in addition to an intrinsic motivation in completing the tasks or by the feedback received from the activities or from other participants. *Meta-contributors* go beyond what is to be expected from volunteers and can help with building up the research. They are driven by a sense of group belonging as well as responsibility toward the group to participate fully as well as by intrinsic motivation from the activities. There is empirical support for the relevance of this classification of contributors. Jennett et al. (2016) find that initial motivation to participate is driven by curiosity and an interest in or wish to contribute to science. However, sustained participation depends on continued interest, a "feeling they had aptitude for the task", as well as establishing a "rhythm of working." Participants develop their skills by participating on a regular basis, which makes participation also more rewarding. It also increases the opportunities for social engagement. Motivations also tend to change over the lifetime of participants.

Some authors choose to group volunteers in terms of their consistency in volunteering: *constant volunteers* have volunteered consistently throughout their adult lives, *serial volunteers* have volunteered intermittently, and *trigger volunteers* have only started volunteering after retirement for example (Hogg 2010). Geoghegan et al. (2016) found that sustained volunteering depended on the ability to develop skills or gain knowledge and how much project feedback and communication were appreciated. This is echoed by Rotman et al. (2012), who see egoism as the main reason for engagement in citizen science in terms of personal curiosity, previous engagement, existing hobby and affiliation with the subject, or gaining experience. Secondary to this are motivations driven by recognition or attribution, feedback, community involvement, and advocacy. Differentiated motivation factors also correlated with socioeconomic factors. Frensley et al. (2017) found that prior experience in citizen science participation and a higher gross income are drivers for sustained participation. People tend to drop out due to time constraints and a perceived lack of ability to use online tools. Eveleigh et al. (2014) argue that "super volunteers" (who contribute much time) are important, but "dabblers" (casual volunteers) also need to be engaged. Generally, there are limited numbers of super volunteers, but large number of dabblers and drop-outs who give up after their initial participation yet remain interested. They argue that citizen science projects should make space for both types of volunteers yet approach them in different ways. They indicate the need to design for multiple points of entry without "forcing individuals into a sustained commitment" (p. 2992) by encouraging them to gradually increase their contribution, emphasizing the liberty of choice of participants, designing small tasks, using feedback loops to raise interest in the project, or making former participants reconsider joining again. Nov et al. (2014) show that tapping into extrinsic forms of motivation of volunteers might be useful too, as the quality of contributions is mostly affected by collective motives or social norms and reputation.

In summary, citizen science has generated substantial insights into the reasons why people participate and how this should affect the design of research projects. Participatory agricultural research has generally focused on farmer motivation from a narrow cost-benefit focus (Section 2.1) and often relied on monetary payments or free input provision to incentivize farmers rather than taking up the question of motivation as a wider design consideration. Citizen science stimulates thinking about motivation as an integrated part of research design and as a critical area of inquiry.

4.3 Rethinking participation

Another contribution of citizen science is that it has explicitly addressed questions of differentiated participation in more nuanced ways. Riesch and Potter (2014) write that it is not realistic to expect regular attendance or continued participation over prolonged periods of time, given the voluntary nature of participation in citizen science. Participation in all stages of a project is still widely held as an ideal, but differentiated conceptualizations of participation have become prevalent (cf. Section 3.2 above). An important impulse comes from the use of digital data collection techniques for citizen science. Internet-based forms of participation using crowdsourcing formats can be relatively small scale and passive on the part of an individual volunteer, but make substantial contributions to scientific research and benefit both the user and the researcher. Haklay (2013) indicates that in citizen science projects, different levels and roles of participation are regularly being combined. For example, contributors can start with a doing small crowdsourcing tasks and as they contribute more, move up in their level of participation and in consequence acquire more and different project roles. There is evidence that the level of participation does not correlate in a straightforward way with the impact of the work. Phillips (2017); Phillips et al. 2019) and colleagues studied levels of engagement in several citizen science projects. They found that even though participants of co-created projects—which would rank higher in a "Participation Ladder"—engaged in more activities than participants in (lower ranking) contributory or collaborative projects, this did not necessarily lead to increased motivation or deeper learning. Deep learning is possible in any project, as participants learn differently and engage with the project in unplanned ways (see also Edwards et al. 2019).

From the practical perspective of designing citizen science projects, Purcell et al. (2012) indicate that projects should cater for *multiple points of entry* by offering experiences for different comfort zones. This is linked to insights on how motivation can dynamically change over time but also to different levels of skill or cognitive ability of participants. For example, participants in citizen science projects are not necessarily non-scientists, but can be professional scientists who contribute voluntary in their free time (ECSA 2020). Differences in experience or familiarity with research processes can be found in any sample of citizen scientists requiring strategies to ensure that learning is supported by materials catering for different groups, as their abilities to participate in terms of time, labor, or learning needs are likely to differ. Not every actor needs to be involved in scientific research at the same level or needs to attain the same learning goals. Science, according to the authors, should be one of the many resources that individuals can draw upon to make informed decisions. If scientific literacy is a collective property, then participatory projects should set learning outcomes that cater for different forms and levels of participation. This is also "more consistent with a democratic approach in which people make decisions about their own lives and interests" (ECSA 2020).

Citizen science efforts make deliberate use of role differentiation, making more differentiated normative claims about participation, moving beyond ideals of simple epistemic equivalence between scientists and participating non-scientists. Epistemic equivalence was already contested in the agricultural sciences (e.g., Bentley 1989). In participatory agricultural research, role differentiation was mainly associated with lead-farmers who had group leadership roles. Approaches did generally not assign differentiated roles and justify this differentiation in a positive way, with the exception of the work on participatory modeling and simulation with approaches designed to take diverging interests into account (Farrié et al. 2015; Berthet et al. 2018). Thinking about participation as a collective, distributed effort with differentiated roles, also in observational and experimental work, opens a new spectrum of possibilities for research design. This can be an impulse for innovation in participatory agricultural research. Here, agricultural research can again take a page from the book of fields like human-computer interaction, where Vines et al. (2012) developed and advocated a lightweight and flexible approach to participation with room for configuring multiple levels of contributing. Multiple forms of participation are likely to occur naturally within participatory processes. It is more a call for the researcher to acknowledge them and be flexible about the boundaries it sets for participation (Vines et al. 2013).

4.4 Changing accountabilities and challenging epistemologies

Citizen science can fulfill its democratizing function through mobilizing an extended peer community of stakeholders (Funtowicz et al. 1997). This can challenge but ultimately enrich mainstream science, as the success of modern science depends on epistemic pluralism (Leonelli 2007). Digital tools, such as cheap sensors and social media, can afford new ways of social mobilization around knowledge, which can then feed new epistemologies, most visible in citizen science driven by activist objectives. In a paradigmatic example, Ottinger (2010) found that citizen scientists using cheap air quality sensors successfully challenged scientific standards, measuring and establishing the scientific and practical relevance of aspects of air quality that were overlooked by scientists—thereby actively holding professional scientists accountable for their current practice and its consequences for human health. In another citizen science project around crop variety recommendations, the project results questioned current crop variety recommendations from agricultural science in overlooking important spatial aspects (van Etten et al. 2019). Frickel et al.

(2010) unpack how citizen science can address "undone science," which they define as "areas of research that are left unfunded, incomplete, or generally ignored but which social movements or civil society organizations often identify as worthy of more research". Citizen scientists can go beyond advocacy for a shift in scientific priorities and enact this shift themselves, which empowers them to question existing epistemic biases on the basis of new data. In the case described by Ottinger (2010), the citizen science effort did not only produce new data itself but also had an impact by spurring new professional science efforts with new methods to address the questions raised by the measurements of citizen scientists.

A crucial new element in this is that cheap sensors and digital connectivity have made "big data" participatory science possible. Big data does not only imply a quantitative shift (more data) but also an epistemic shift in data interpretation, adapting the methods to take advantage of "opportunistic" data that is collected without following standardized sampling procedures, but sampled following the possibilities and interests of volunteers (Kelling et al. 2015; Ojha et al. 2015). In agriculture, it was precisely the rise of modern statistics (focused on small sample experiments) in the first half of the twentieth century that moved farmer-participatory experimental research to the background, as randomization practices were unpractical for farmer experimentation (Parolini 2015). It could therefore be argued that the citizen science provides a truly new occasion for a rethinking of the epistemology of agricultural experimentation and accountability of the agricultural sciences.

4.5 Designing participation

A characteristic feature of most citizen science projects is that they use digital technologies to facilitate data transmission, communication, and collaborations, and to enable participation at a scale that was previously unattainable. Today, hundreds if not thousands of citizen science websites and applications exist and are used by people from different age groups or backgrounds, and with different skills and motivations. The design of these digital technologies powerfully shapes the experiences and action opportunities of participants (Sharma et al. 2019). Researchers are therefore collaborating with professional digital developers and human-computer interaction (HCI) specialists, and as a result, *design* issues around data quality, sustained participation, and adoption of tools and technologies are now better understood (Skarlatidou et al. 2019a).

HCI builds on a long tradition in ergonomics, the design of artifacts, and systems to fit human capabilities and needs. It evolved from improving the usability of early computing devices to a multidisciplinary field which includes participatory design and community interaction to understand and improve all aspects of humans interacting with and through an increasingly ubiquitously computer-mediated world (Vines et al. 2012; Preece 2016; Caroll 2017). User-centered design lies at the heart of HCI, involving methods and principles that put the needs, abilities, and constraints of a technology's "end user" front and center in design (Caroll 2017). Citizen science has connected with HCI from the outset, using HCI and user-centered design concepts and methods to enhance the experience of citizen scientists and configure complex constellations of participation between people and machines. Hence, there is a rich and growing literature on citizen science HCI (for reviews, see Newman et al. 2010; Kim et al. 2011; Wiggins and Crowston 2011). For example, Sturm and Tscholl (2019) indicated the importance of user feedback for participatory design approaches by distinguishing between general user feedback, contributory user feedback and co-creational user feedback to be able to cater for different types of volunteers. Spiers et al. (2019) explore user issues and volunteer behavior in 63 online citizen science projects and found that many subtle design choices influence how and how much interaction takes place and, ultimately, who participates or not. Skarlatidou et al. (2019b) present a series of highly specific design considerations based on a systematic review of the literature and conclude that user studies should be fully integrated in any citizen science project design. Sullivan et al. (2014) describe how to design citizen science projects for both data quantity and data quality. In addition, there has been substantial research on how to design effective platforms for citizen involvement in science as well as designing incentive systems aimed at motivating people to participate (cf. Cooke 2000; Kim et al. 2011; Shirk et al. 2012; West and Pateman 2016; Edelson, Kirn and Workshop Participants 2018).

While citizen science has placed participants' motivations front and center, and opened new, differentiated forms of conceptualizing and organizing participation, thanks to its intersection with HCI, it has also paid sustained attention to the detail design and design processes of volunteer participation, embracing user-centered and participatory design methods. Deeper engagement of agricultural citizen science with the wider citizen science community and HCI research would be beneficial. For participatory agricultural research, this could lead to an acceleration of learning through exchange of insights and more systematic digital design processes, potentially leading to innovations in areas such as interaction design of data collection tools or gamification of experiences (Beza et al. 2018).

5 Conclusions

We indicated several reasons why participatory research has not become mainstream in the agricultural technology development cycle. First, there has been a lack of strategic-level investment within agricultural research institutes in the structures needed to implement effective participatory processes. Even though farmer organizations and private sector research initiatives have been involved in multi-stakeholder innovation platforms over the recent years, this did not necessarily lead to an effective inclusion of participatory approaches in agricultural research. Second, most institutions are using incentive systems that favor data production over impact. The outcomes of participatory processes are often part of wider dynamic processes and more difficult to measure than concrete research outputs. Planning, resource allocation, and evaluation of participatory research do generally not ensure that its findings will affect decisions on the design of new products or future research priorities. This has resulted in a relatively low accountability toward the end user of research outputs. Third, competition between institutions and a resulting lack of institutional learning has hindered the progress of participatory research in terms of theory building and sharing its successes and its limitations. Finally, the discourse on participatory agricultural research has been dominated by a relatively one-dimensional view of participation and the notion that "more participation is better." All of these have affected the perceived success of participatory projects.

It could be argued that citizen science will break through many of these barriers simply because it can reduce costs per data point. But citizen science externalizes certain costs to citizen scientists and creates new ones, such as maintaining digital tools, data verification, managing online communities, and facilitating communication among large groups of stakeholders. Therefore, cost reduction per se should not be expected to be the only or even main reason for citizen science to break through previous barriers. In our view, the main difference with previous participatory research formats is that citizen science can involve more diverse ways of distributing work across stakeholders and aligning these kinds of work with different types of motivation to participate. Such alignment requires careful design of citizen science projects. Here, citizen science could make inroads by challenging some of the concepts of participation that have held sway in agricultural participatory research. Citizen science has brought attention to more diverse configurations of participation that can involve more differentiated roles of participants, both more active and more passive forms of participation, and a stronger emphasis on the design of the experience of participants. In this sense, citizen science can help participatory science to break out of a straitjacket that was highly normative, opening a wider space of experimentation to creatively conceive and test different configurations of participation. This opening up could and should go hand in hand with an opening to more scientific and epistemic accountability to stakeholders and more open forms of science. Only then are citizen science-inspired forms of participation likely to overcome the institutional and epistemological barriers that have revealed themselves over the last four decades.

Even then, extractive forms are still possible within a citizen science context. Citizen science will need to address new dimensions of social inclusion: potential citizen scientists are likely to have unequal access to digital means of communication and will have different levels of digital literacy. Citizen science, however, has renewed an interest in participant motivation and the use of digital tools to tailor and monitor participants' experiences building on human-computer interaction research, which can support new ways to monitor and evaluate social inclusion.

Lastly, we believe that citizen science stimulates innovation in participatory agricultural research because it connects different disciplines that can learn much from each other. Much creativity can be unleashed when agricultural scientists work with digital designers, human-computer interaction researchers, and get involved in the wider community of scientists that are engaged in citizen science, such as ecologists and environmental scientists. Also, citizen science involves data science challenges that transcend disciplines, such as dealing with "opportunistic" sampling and certain biases in citizen science data. This is another area where mutual exchange between disciplines can stimulate creativity.

In summary, citizen science has the potential to provide an impulse to participatory agricultural research by providing opportunities to reconfigure cost-motivation-accountability combinations using digital tools, by opening up a larger conceptual space of experimentation to do this, and by stimulating new collaborations between disciplines. With appropriate and persistent institutional support and investment, citizen science can therefore have a lasting impact on how agricultural science engages with farming communities and wider society, and a useful approach to deliver on the promises of participation.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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