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Participatory approaches for soil research and management: A literature-based synthesis

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ABSTRACT

Participatory approaches to data gathering and research which involve farmers, laypeople, amateur soil scientists, concerned community members or school students have attracted much attention recently, not only to enable scientific progress but also to achieve social and educational outcomes. Non-expert participation in soil research and management is diverse and applied variously, ranging from data collection to inform large-scale monitoring schemes in citizen science projects to projects in which the participants define the object of study and the questions to be answered. The growth of participatory projects to tackle complex environmental and soil-related issues has generated literature that describes both the way the projects are initiated, implemented and the outcomes they achieve. We review the existing literature on participatory soil research and management. Existing studies are classified into three categories based on the degree of participation in the different phases of research. The quality of participation is further evaluated systematically through the five elements that participatory projects usually include: inputs, activities, outputs, outcomes and impacts. We found that the majority of existing participatory projects were contributory in nature, where participants contribute to generating data. Co-created projects which involve a greater level of participation are less frequent. We also found large disparities in the context in which these types of participation occurred: contributory projects were mostly documented in more economically developed countries, whereas projects that suggest greater involvement of participants were mostly formulated in developing countries in relation to soil management and conservation issues. The long-term sustained outcomes of participatory projects on human well-being and socio-ecological systems are seldom reported. We conclude that participatory approaches are opportunities for education, communication and scientific progress and that participation is being facilitated by digital convergence. Participatory projects should, however, also be evaluated in terms of their long-term impact on the participants, to be sure that the expectations of the various parties align with the outcomes. All in all, such participation adds to the quantum of soil connectivity and in this sense makes the soil more secure globally.

1. Introduction

Participatory approaches to scientific research have attracted much attention recently, not only for scientific and technical developments but also to achieve social and educational outcomes. There is indeed recognition that many environmental sustainability issues have a high level of complexity and cannot be treated in isolation from each other. These so-called “wicked” (Rittel and Webber, 1973) environmental issues have no single best solution (Bouma and McBratney, 2013), but instead a series of possible outcomes balancing the needs and interests of the different parties. As collaborative endeavours between experts, stakeholders and scientists, participatory approaches that balance interests, expectations and knowledge are increasingly used to resolve issues at the interface between science and society. Besides the benefit for large-scale scientific projects (e.g. in terms of data collection), participation is expected to build a shared vision among participants, reduce conflicts and in consequence increase the chances for success. Hereafter, the term participatory is based on the definition of Von Korff et al. (2012) and refers to the involvement of not only trained professionals (e.g. scientists, specialized stakeholders) but also of all other interested parties including, for example, lay people, amateur soil scientists, concerned community members or school students.

Participation of non-professional scientists in scientific development is not new (Florian Charvolin and André Micoud, 2007). There are many

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examples in the history of natural sciences of interactions between nonprofessionals and scientists (Bedessem, 2020), some examples of which are amateur ornithologists in the nineteenth century participating in bird spotting in France (Charvolin et al., 2007) or amateur societies or clubs describing and classifying natural objects in late Victorian Yorkshire (Alberti, 2001), and of course the contribution of the 19th century country vicars. Current renewed interest for participatory research has emerged from a variety of sub-disciplines at the interface between sustainability and society, ranging from water management (Von Korff et al., 2012) climate change adaptation (Hügel and Davies, 2020) socio-environmental decision-making and policy (Elsawah et al., 2020) or land sustainability (Bouma, 2022). Many studies are available documenting the increasing use of participatory approaches in the scientific process, showing at the same time an understanding of the utility of these approaches for public policy, notably as a tool for science communication.

There are in fact several, and sometimes used erroneously, definitions of participation. Often nonexpert participation in science is referred to as citizen science. Citizen science was coined by Irwin (1995) which broadly defined the term as a science performed "by" and "for" the people (Strasser et al., 2019), in other words, science should focus on the citizen's concerns and the scientific process should include their local contextual knowledge and experience that is unavailable in formal academic institutions. Another meaning of citizen science comes from Bonney et al. (2009) and is perhaps the most popular today. In Bonney et al. (2009), citizen science refers to non-scientists contributing to scientific data and as a tool for public education to science. The two concepts somehow point in opposite directions (Cooper and Lewenstein, 2016) and are sometimes referred to as contributory science or democratized citizen science (Bedessem, 2020). A variety of other concepts are commonly used, they partly overlap but differ in which aspect of participation they represent. Notably, existing typologies of participation rather describe participation as a spectrum composed of the quality of participation, the stage and degree of involvement, or the epistemic practices.

Take for example the three following studies from soil research and management: a) amateur scientists from 500 residential properties in Indianapolis contribute to soil data which are analysed in a central laboratory to map the soil metal concentration at the city level (Filippelli et al., 2018), b) scientists used a participatory survey approach to account for the local knowledge of farmers to map soil quality as well as to promote cooperation between local and external participants (Tesfahunegn et al., 2011), and c) local farmers in Indonesia initiate a co-experimentation with scientists and local stakeholders to establish an experimental field and test various soil amendment strategies for cultivating degraded soils. Each of these projects involved nonexperts to some aspects of the scientific process, but this was made with varying degrees of participation. The degree of participation in turn strongly impacts the outcomes in terms of education to individuals, science and also socio-ecological systems (Shirk et al., 2012).

This review focuses on participation in soil research and management and the topic is therefore broader than the recent overview of existing "citizen-science" projects made in Pino et al. (2022). In our review, we classify the research literature based on the quality of the nonexpert participation in scientific projects. The paper is structured as follows. In the first section, we describe the methodology for the literature search and the classification used to discriminate the corpus into three classes representing the three phases of a project in which participants are usually involved. The phases are called contributory, collaborative and co-created. For each phase of participation, we then describe the literature based on five elements characterizing the quality of participation: inputs, activities, outputs, outcomes and impacts. A final section discusses some key findings from which we draw general conclusions on the current state of participatory approaches to soil research and management.

2. Methodology

2.1. Literature search

The literature search was based on a two-step procedure combining a systematic literature search procedure and a grey literature search in a standard search engine. We describe these two steps in the next two paragraphs.

Step 1 - Systematic procedure We searched the Web of Science (Core Collection) database. The search was made on April 20th, 2022 using the strings "soil*" or "pedolog*" in the title, abstract or keyword and which contained at least one of the following words: "participative", "participatory", "participation", "citizen science", "citizen-science", "community involvement", "adaptive citizen science", "co-management research", "collaborative monitoring", "collaborative", "community-based", "participatory action research", "transformative", "public", "cooperative". These keywords were chosen to include a wide range of terminologies commonly used in participatory research. The search was refined for articles, written in English and falling within the broad categories of environmental sciences, environmental studies, agriculture, agronomy, soil science and geosciences. This search yielded 609 articles, which we refined using a screening procedure. First, with a title screening, we removed studies that had no direct link to soil science and soil management. Second, we screened the title to remove studies that were not linked to any participatory approach. Third, the remaining articles were removed if it was obvious from the full abstract that the study had no link to soil research and management or did not include any participatory approach. After applying these three exclusion criteria to the original list of 609 studies, there were 59 studies remaining which we used as a basis for defining broad categories of participatory approaches.

Step 2 - The grey literature Acknowledging that not all participatory projects are published as standard articles in academic journals, we complemented the systematic literature search with a grey literature search. After defining the broad categories in Step 1, we performed an open search using the Google search engine and keyword specific for each subsection (e.g. by searching "participatory rural appraisal" with "soil"). This step allowed us to find grey literature (e.g. reports, unpublished sources) that reported on a participatory approach for soil and project and organization websites. To limit the proportion of results found, we limited each search to at least 50 hits and continued until we noticed a sharp decrease in the relevance of the search results. Using this strategy, we found an additional 32 results which we included in this review.

In the two steps described above, we further excluded studies in which full-text screening subsequently revealed no focus on soil. In this review, we also deliberately excluded activities that aim to evaluate perceptions and adoption of measures by participants and lessons learned from past projects by means of participatory approaches. While these approaches rely on participation, the participants are not involved in any of the project phases. We also disregarded studies that involve public participation in science to influence or build policy. We did so because public engagement in policymaking is usually not considered part of participatory approaches to science.

2.2. Classification of the literature

The results from the literature search from Steps 1 and 2 were classified into broad categories based on the standard classification proposed in Bonney et al. (2009). The study of Bonney et al. (2009) proposed a tipology to classify public participatory approaches to science based on the degree of participation in the different phases of research. Hereafter the broad categories are based on this system (Fig. 1) and distinguish *contributory approaches* which are "designed by scientists and for which members of the public primarily contribute data", from *collaborative approaches* where the participants "contribute data" but

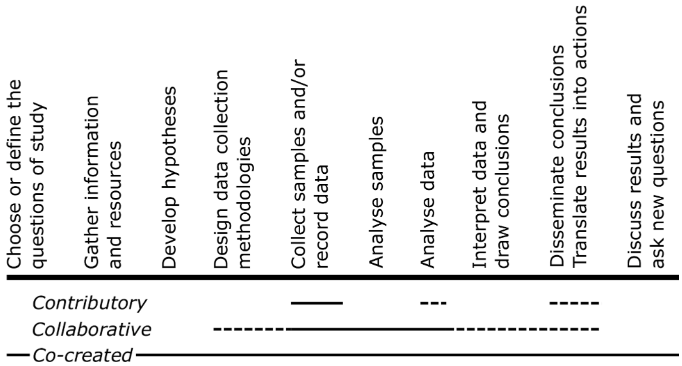

Fig. 1. The different phases of research in which public members might participate. The solid line indicates that the public participates and the dashed black line indicates that the public might participate in this phase, for each of the three broad categories. Adapted from Bonney et al. (2009).

also "help refine project design, analyze data and/or disseminate findings" and from *co-created approaches* where scientists and member of the public are "working together" and where at least some of the participants are "involved in most or all steps of the scientific process", that is, including for defining the question of study and for discussing results and ask new questions (Bonney et al., 2009, p. 17). Note that we do not imply a hierarchy of participatory approaches and higher levels of participation are not assumed to be superior. Instead, the different categories used in this study should be seen as a spectrum reflecting the different participatory practices.

We reviewed the literature for each category to further reflect on the quality of the participation using the framework elements proposed in Shirk et al. (2012). This framework is an outcome-oriented logic model that describes the outcome of participation as a balance between public and scientific interests. The five framework elements (i.e. *inputs, activities, outputs, outcomes* and *impacts*) are described in Table 1. In addition to the quality of participation, the framework allows one to distinguish the outcomes of participatory approaches for the participants (e.g. skills, acquired knowledge), the science (e.g. publications and new findings) and the socio-ecological systems (e.g. legislation, improved decision-making, conservation). A similar classification is made for participation in natural resource monitoring in Danielsen et al. (2009).

3. Contributory approaches

This category of participatory approach is research-driven where scientists define the object and the questions of study for which participants ("citizen scientists" and volunteers) are involved in data collection. Often, these projects require the collection of a large amount of data or data over large areas. In this category, the participants follow pre-determined protocols and are typically not involved in any other step of the research process. Most studies labelled "citizen-science" and "crowdsourcing of scientific data" fall into this category. On rare occasions, participants are also asked to document observations and perform basic analysis of the data they collected using visualization tools and charts, but they do not participate in the design, analysis and interpretation of the study results which is undertaken by professional researchers. Contributory projects to soil research are by far the most common approach to participation. In the following subsections, we characterize the existing soil science projects that fall within this category, many of which are reported in Pino et al. (2022).

Table 1
The five elements characterizing the quality of participation and their description (after Shirk et al., 2012).

Element	Describes...
Inputs	... the interests and expectations of the participants and professional scientists (e.g. knowledge, soil conservation, education).
Activities	... the bulk of the work to be carried out in the project, the tasks. This may include designing the sampling strategies and managing the project design and implementation, as well as the communication among participants and training.
Outputs	... the results of activities (e.g. new data collected). This usually is easy to quantify.
Outcomes	... the outcomes that result from the outputs. This may include skill sets and increased awareness for participants. Outcomes identified for science are better scientific understanding or innovative techniques. For socio-ecological systems, this includes improved relationships between environmental agencies and land users, or better policies for soil resource management.
Impacts	... the desired and measured long-term impacts that support better soil management, human well-being or development of scientific knowledge.

3.1. Input to the project

The review of the literature suggested that participants and soil scientists had different inputs and expectations in projects involving contributory approaches. Individual scientists are interested primarily in new data collection and achieving scientific results and practical outcomes. For example, in Bone et al. (2012) participatory soil survey was developed to gain new soil sample data in under-sampled areas from previous soil surveys. In Della Chiesa et al. (2019), the researchers expect to use the data for producing digital maps of soil properties and learn about the spatial interplay of alluvial fans and soil properties in their area of study. It is suggested that scientists interested in contributory projects are also effecting education and want to encourage raising awareness in participants. In Pino et al. (2021), although data collection on microbial decomposition is the main objective, the professional scientists involved in the project emphasize the educational aspects and their interest in increasing the connectivity of schools to soil and soil science. A central aspect of contributory approaches is the willingness and motivation of participants to monitor soils and collect data. Participants' interests in contributory projects are diverse, e.g., to get back in touch with nature (Bone et al., 2012), to have better insights into the area they live in or manage (e.g. gardeners and land managers, Rossiter et al., 2015) or to satisfy learning goals and interest in science. We found that local participants do not usually bring specific skills to contributory approaches and are asked to follow a pre-determined protocol. Other interests in contributory projects, such as those from other parties (environment agencies, regulators) are seldom reported in the literature.

3.2. Activities carried out by participants

Participants involved in contributory projects collect data using the support material or interface they are provided. The participants main activities are to collect topsoil samples following instructions (as in Taylor et al., 2021) or to perform a basic experiment following instruction videos and booklets (e.g. Sandén et al., 2020). The activities usually last for a few minutes to a few hours, although in some cases participants may decide to contribute to data collection over a long period. For example in Della Chiesa et al. (2019), farmers repeatedly contributed to data generation during the period 2006–2013. In Ferrando Jorge et al. (2021) data collection was made over two consecutive days. Activities of scientists involve designing all steps and managing nearly all aspects of the project, including communication between participants, project infrastructure and data-entry technologies. For example, Karamouz et al. (2021) established an infrastructure for data collection and data control through an online interface developed in a mobile phone and tablet software application. The application contains pre-filled forms and questionnaires and scientists defined classes to determine soil moisture. Also, in Thomas et al. (2016) the scientists devised the guide and protocols for sampling acid sulfate soils over a large area in South Australia and supported communication between participants. We found that activities of the scientist in contributory approaches always include task-related quality control of the data, either through i) training of participants (e.g. in Ferrando Jorge et al., 2021; Salley et al., 2018; Thomas et al., 2016; Ziss et al., 2021), ii) detailed guides and protocols (e.g. in Thomas et al., 2016) or by iii) *ex-post* data quality control (e.g. Bone et al., 2012). One such example of *ex-post* data quality control is using filters in data-entry forms (as in Karamouz et al., 2021; Pino et al., 2021).

3.3. Project outputs

In nearly all studies the main output resulting from the activities was new soil data to feed local or large-scale soil monitoring schemes. Karamouz et al. (2021) reported the collection of 42 and 8 new soil moisture observations in two campaigns that were used to calibrate MODIS land surface temperature satellite imagery. Taylor et al. (2021) reported 17, 256 soil samples from 3609 Australian homes as of May 2020. In Della Chiesa et al. (2019), the database comprises 16,139 samples collected over several years by farmers. The literature review suggests that the data output is large compared to the usual surveys in soil science, with some exceptions (e.g. Chaudhary et al., 2021; Ferrando Jorge et al., 2021; Karamouz et al., 2021). In Bone et al. (2012), the participatory survey output was 3332 records and more than 5000 earthworms identified, mostly from areas not included in previous field surveys. While project output mostly resulted in new data collection, during the field activities volunteers also obtained an active experience in collecting and/or documenting the data. In all studies, however, participants experienced interaction with soils and the local environment. The number of individuals reached is not always reported, and varies greatly between a few individuals (Karamouz et al., 2021) to a large number of school children. For example, the teatime 4 Schools initiative in Austria (Teatime 4 Science, 2019) has involved 150 schools over two years, whereas a similar project in Australia (Pino et al., 2021) has involved 23 schools, so approximately 500 individuals. In Sandén et al. (2020), about 4000 Swedish and 1500 Austrian individuals are involved. Bone et al. (2012) estimated that more than 14,000 public participants were reached through public events led by scientists.

3.4. Outcomes

Outcomes for individuals In studies such as in Ziss et al. (2021), participants experience low potential for new skills as they only collect soil samples in their garden and send them to a central laboratory. There is little to no local capacity building. The review suggested that many studies reported cases where participants generally increased content knowledge and technical soil sampling skills. Individuals have learned how to identify a soil type, test soil quality and discover the different species of earthworms (Bone et al., 2012) or they learned about soil sampling and site selection rational and GPS use (Thomas et al., 2016).

Outcomes for science We identified that the data collection resulted in a better scientific understanding of the spatial distribution of soil properties and earthworms in the UK (Bone et al., 2012), characterization of soil quality on a farm (Chaudhary et al., 2021), decomposition rates and stabilization factors (Pino et al., 2021; Sandén et al., 2020), large-scale urban trace metal contamination (Ziss et al., 2021), understanding the process of sulfidic acid sulfate soils forming for different lake bed sediment conditions (Thomas et al., 2016). The dataset collected by volunteers enabled local insights. The citizen-science project reported in Filippelli et al. (2018), for example, led to a better understanding of the origin and spatial distribution of metal distribution in the soils of the city of Indianapolis and found that soils near homes are more contaminated with Pb than soils on gardens. The development of contributory approaches also yielded innovative techniques for data collection. This is the case of the Tea Bag index, which was devised to facilitate crowdsourcing and requires minimal prior knowledge of soil biology (Keuskamp et al., 2013), but is currently used within contributory approaches and scientists alike.

Outcomes for socio-ecological systems Since the main outcome of contributory projects is data collection, the socio-ecological outcomes are seldom reported. Bone et al. (2012) reported improvements in the amount and quality of evidence that can be used to inform policy implementation. Thomas et al. (2016) acknowledged an improved social resilience in the local community to face environmentally stressful events and increased trust between communities and governments through coupling the interests of both parties. Although not explicitly reported, we inferred a use of the data to address environmental degradation in farming (e.g. in Della Chiesa et al., 2019), or an increased likelihood of participants' involvement in future policy to improve their surroundings, such as in residential areas with high trace element contamination (e.g. Sandén et al., 2020; Taylor et al., 2021).

Costs to individuals or communities Cost reported for individuals is usually low or it does not incur them costs. We found that costs relate either to the local volunteers who commit time to a program, for training for a set time (e.g. 1-day workshops in Thomas et al., 2016) and for the field surveys, or through the costs they incurred when sending the soil samples to the central laboratory for analysis (as in Taylor et al., 2021, for example). Thomas et al. (2016) estimated the cost of labour freely given by 100 volunteers to be 22,650 AUD, which they estimated was much lower than the costs of professional researchers performing the same soil survey. In Taylor et al. (2021), the authors reported a 100,000 AUD donation to the program over seven years.

Costs to researchers We inferred from the literature review that costs incurred by researchers and professionals is intermediate. In our review, however, there is hardly any information on the researcher's costs in salaries for the time spent in training the volunteers, assisting in the soil survey, maintaining the communication among participants and building the infrastructure. To our knowledge, these costs can be substantial. but we do not have sufficient information to know whether the additional costs of the researcher's time outweigh the decrease in costs obtained by volunteers freely giving their time.

Compromises Contributory projects increase data coverage but issues of data quality collected by volunteers were raised in nearly all studies. Soil observations collected by non-experts may not be as accurate as when collected by professionals. For example, Bone et al. (2012) reported on the uncertainty associated with identifying earthworm species. Rossiter et al. (2015) discussed the compromise between the necessary data quality control in contributory projects and the risk to discourage participants and to raise the required expertise level. In our literature review, only for studies for which participant involvement was very low (e.g. when participants only send topsoil samples to analyze in the laboratory), the issue of soil data quality was not questioned. In one study (that of Bone et al., 2012), the authors raised the problem of sustaining participant interest during long surveys. In a long contributory project, participants' interest may decline along with data quality and engagement. Finally, we inferred that since nearly all studies are externally driven they rely on funding to keep the project running and to guarantee a high level of expertise and training (e.g. to cover training, salaries of researcher, laboratory costs, etc.).

3.5. Impacts

Impacts are long-term changes that are seldom reported in the literature. Taylor et al. (2021) found that monitoring of trace metals in Australian gardens using crowdsourcing data enabled participants to better understand their environment and that the data collected advised them on how to protect their health. In Thomas et al. (2016), the impact of the contributory project is a better social resilience of the communities through the development of community leaders and local network for monitoring and, by a feedback loop, a better accounting of the local community knowledge. The authors inferred that through the links built during the project, the local communities are better prepared for a potential future drought event in their area.

4. Collaborative approaches

This category of participatory approach is also research-driven where the scientists ask the questions of the study, for which non-experts contribute to the data collection (Bonney et al., 2009). In this category, however, participants are also involved in analyzing the samples and the data, and might also be actively involved in interpreting the data and disseminating the findings (Fig. 1). In general, participants assist scientists with shared research goals. On some occasions, the participants help the professional researchers to refine the data collection protocol and methodologies, for example by deciding the choice of the sampling sites or the methods for analyzing the samples. This category of participatory research demands greater engagement by participants than contributory approaches. Most studies labelled as "ethnopedology" (Barrera-Bassols and Zinck, 2003), i.e. including local (indigenous people and/or farmers, Richelle et al. (2018)) knowledge of soil and land evaluation fall into this category, many of which were developed using participatory rural appraisal (PRA) techniques and tools.

4.1. Input to the project

We found that professional scientists are interested in collaborative approaches to obtain scientific outcomes and increase the efficiency of the research process. For example, in Fujisaka (1989) the expectation of the scientist is to address problems of low agricultural productivity and to develop methods for on-farm adaptive research, whereas in Barrera-Bassols et al. (2009) the objective is to compare soil maps made by scientists and by local knowledge. In the study of De Groote et al. (2010), we infer that scientists are interested primarily in understanding the adoption of new technologies by farmers and in Panagea et al. (2016) the objective was to develop and test prevention, remediation, and restoration measures to mitigate soil salinization. It is suggested that scientists are not only interested in obtaining scientific outcomes from collaborative projects, but they may also want to test alternative methods of scientific research. Cools et al. (2015) described the objective to escape from the classical supply-oriented, top-down procedures for soil survey and land evaluation, and to promote interdisciplinarity and interactions. In Rushemuka et al. (2014), the objective is to stimulate interactions between farmers, scientists and the biophysical environment. In some instances, the expectations from scientists and nonexpert participants may be blurred. In Foale et al. (2004), besides the scientific objective of testing whether computer simulation models can assist practitioners to manage their farms, the participants and experts seemed to have similar expectations in understanding whether the current practices achieve the best management of soil resources and rainfall in farms of Central Queensland, Australia. The literature review suggests that most of the time. participants are interested in solving practical problems, for example, to mitigate accelerated soil erosion in their fields (Fujisaka, 1989). In Dalton et al. (2011) the aim of the participants (i.e. the farmers) is to improve their knowledge and their capacity for innovation. Participants may expect a return both in terms of education and technology (Dalton et al., 2011). In many studies, however, the participants' inputs or expectations were not reported. This comes inevitably from the method of participant involvement in collaborative projects that we reviewed, where participants are chosen at random in Barrera-Bassols et al. (2009) or in Gachimbi et al. (2002) which suggest that participant's expectation in the project are closely linked to the scientific expectations and learning goals of scientists. While methodological guides (e.g. for participatory determination of a soil quality indicator Barrios et al., 2012) include an assessment of participant expectations, this is seldom reported in the literature using this framework (e.g. Kuria et al., 2019). Overall, we found that participants' input was related to their assumed local knowledge of the soil in the area where they live (e.g. see Jemberu et al., 2018).

4.2. Activities carried out by participants

The cornerstone activities carried out by participants in collaborative projects involve workshops, groups and community meetings that bring together nonexperts of different experiences and perspectives. Workshops are held for different phases of the project and with various objectives, namely, to develop baseline ideas (Milgroom et al., 2007), to identify potential measures worthy of investigation (e.g. Zoumides et al., 2017), to define a set of indicators for soil erosion mapping (e.g. in Tenge et al., 2007), to create a working atmosphere and enable trust between participants (e.g. Zoumides et al., 2017), to select potential technologies for implementation (e.g. Zoumides et al., 2017), or at the end of the project to discuss the results (Tenge et al., 2007). Other reported activities to participants are rooted in the tools and techniques used in PRA, such as field transect walks (Rushemuka et al., 2014; Tesfahunegn et al., 2011), group discussions for consensus building and open-ended interviews (Tesfahunegn et al., 2011), questionnaires to evaluate the level of participants and the assessment of options identified. In ethno-pedological studies involving local communities, individual and group interviews are commonly conducted (e.g. in Barrera-Bassols and Zinck, 2003; Cools et al., 2015). We did not find information on the duration of activities, but it is speculated that they last at least one day (e.g. workshop in the morning and transect walk in the afternoon, such as in Tesfahunegn et al. (2011)), or several days. Activities by the scientists involve managing all aspects of the project design and infrastructure, as well as selecting the participants, selecting the study site (Panagea et al., 2016), developing a manual with instructions, contacting the local leaders or farmers (Tenge et al., 2007), preparing a shortlist questionnaire (Barrera-Bassols and Zinck, 2003; Rushemuka et al., 2014), guiding the debates during workshops and group meetings (Rushemuka et al., 2014), guiding field survey and household visits (Tesfahunegn et al., 2011), makeing a checklist of issues and observations (Tesfahunegn et al., 2011) or proposing techniques documented in the literature (Panagea et al., 2016). For example, in Zoumides et al. (2017) scientists developed what they called a stakeholder platform which is a broad term for defining the network of participants and the tools used to promote sharing and interaction between them (e.g. field visits, workshops, material, etc.). Admittedly, we found that collaborative approaches required a greater level of participant involvement than contributory projects and that activities are made to increase the local relevance of the solutions. However, project design and initiative are managed by a lead team which includes, in nearly all cases, only professional scientists.

4.3. Project outputs

In two studies (Barrera-Bassols et al., 2009; Cools et al., 2015) the output resulting from the activities is a soil classification map or a local soil unit map (i.e. an "ethnopedological map") which is made by participants by eliciting soil names used by local farmers during plenary workshops, which are then compared to soil maps made with a classical pedological survey. In both studies, it is inferred that another output for participants is the experience of making a soil map. In nearly all the remaining studies, the main output is a list of indicators or measures obtained in workshops, community meetings or transect walks which is complemented by real-world data collected by experts or experiments. In Gachimbi et al. (2002), for example, the main output is a list of signs and causes for declining soil quality, and strategies to cope with this problem. Data collection was also performed and data analysis was carried out by the scientists and fed back to the participants. Similarly, workshops in Jemberu et al. (2018) output a list of indicators that assess soil erosion types, rates and causes as well as indicators to measure rill erosion to assess soil-water conservation measures and to estimate the stability of these measures. This was complemented by expert monitoring of erosion on sample plots. In Tesfahunegn et al. (2011), the output is a list of soil quality indicators obtained during a transect walk and then classified into degradation assessment categories during household interviews. In Gachimbi et al. (2002) the project output is the identification of promising technical innovations in partnership with farmers.

4.4. Outcomes

Outcomes for individuals Few studies suggested outcomes for individuals. Some reported an increased confidence and content knowledge of participants (e.g. Dalton et al., 2011; Foale et al., 2004) and experience and managerial capacities gained via participation (Dalton et al., 2011), although this was not explicitly evaluated. Milgroom et al. (2007) and Okoba et al. (2007) reported that the co-development of a tool on soil erosion with farmers increased their awareness of environmental issues or soil erosion indicators. Dalton et al. (2011) and Foale et al. (2004) also noted indications of change of behaviour in management practices, which suggest that beyond the increased knowledge another outcome for participants was increased expertise related to an improved sense of place. In an impact assessment survey at the end of the project, Poudel et al. (2000) reported that most farmers considered participation as a useful tool for technology transfer.

Outcomes for science Despite collaborative projects having a greater level of participant involvement than contributory projects, we found that the scientific outcomes are still the main interest. In nearly all the studies, it was acknowledged that local knowledge was necessary, either to access data or to obtain knowledge that would remain unavailable without local insights from local rural communities. For example, Barrera-Bassols and Zinck (2003) stressed that the local soil map (i.e. the map using local-indigenous knowledge) goes beyond biophysical and agricultural attributes, but also includes a number of cultural considerations. In Cools et al. (2015) it was argued that farmers draw to the attention of professional scientists issues that would have been overlooked otherwise. Projects have also yielded a better scientific understanding of erosion and crop yield loss (Okoba et al., 2007), soil degradation and livelihood insecurity (Malley et al., 2006) or factors affecting soil conservation and fertility (Dalton et al., 2011), or soil erosion (Poudel et al., 2000). An indirect scientific outcome is also the development of innovative techniques for gathering, combining and analysing datasets from non-experts. For example, in Barrera-Bassols and Zinck (2003) conventional soil survey is complemented by ethnographic and socio-economic methods for data gathering.

Outcomes for socio-ecological systems Several of the projects seemed to have a socio-ecological outcome in mind at the input stage. This resulted in nearly all the projects contributing to developing better resilience of the socio-ecological systems or an increase in the social capital of the participants, although this was often not explicitly described. Identified outcomes include the provision of a basis for a consensus land-use plan (Barrera-Bassols and Zinck, 2003), an enhanced solidarity and familiarity between neighbouring farmers experiencing a similar problem and a better community motivation (Okoba et al., 2007), and a better management of resources through the research findings (e.g. Tenge et al., 2007). For example, Poudel et al. (2000) noted that the farmer cooperation survey for soil conservation in the Philippines resulted in change in the farmer practices by means of contour hedgerows in vegetable fields.

Costs to individuals or communities We found that despite intensive involvement participants were not paid for their time and therefore bear a large part, if not all, of the costs of project implementation (regular visits, field tests, etc.). This was described as a limitation in two studies: in Dalton et al. (2011) it was noted that participation requires commitment time, financial capital, land and farm resources. When local people participate in such projects in developing countries this is a severe limitation, although some material may be supplied. This was also emphasized as a limitation of the participatory project in Poudel et al. (2000) where farmers involved noted that their main limitation was their input time and costs and capital requirement since in this project farmers are expected to do their research at their own expense.

Costs to researchers From the literature review, we infer that the cost to researchers is intermediate, but we did not find quantitative information, for example on the cost of researchers' salary or external costs. Overall, it was stated on several occasions that participation is a means to decrease costs. Jemberu et al. (2018) present participatory research on soil erosion and soil and water conservation measures as an alternative to the costly field experiments. A similar argument is made in Milgroom et al. (2007) for monitoring soil loss. Cools et al. (2015) argued that participation can make use of the experience-based perceptions of farmers to mitigate low data density, whereas Tesfahunegn et al. (2011) argued that assessment of soil quality using participatory survey is less costly than conventional approaches, but did not report an assessment of this claim.

Compromises In collaborative projects, we found that the expert often must choose between a study for science or a study for local farmers to improve overall soil condition. An example is found is in Milgroom et al. (2007), in which they recognized a trade-off between the quality of the information and the limited resources and time, especially in developing countries. The authors advocated a participatory farmer-oriented tool in situations where expert evaluation is not available, suggesting that erosion risk assessment is more accurately determined by technical experts than by a participatory approach. Another compromise was on willingness to participate, especially in developing countries. Jemberu et al. (2018) reported that farmers and local soil users are the daily users of the land but they are not always willing to participate as they are busy securing their food and basic necessities.

4.5. Impacts

Given that long-term impacts are seldom reported let alone quantified, we inferred only a few impacts from the literature review. Gachimbi et al. (2002) claimed that a long-term impact of the project is a more efficient use of the available water and possible greater food security. Another possible long-term impact is the maintenance of soil fertility in the area. In Dalton et al. (2011), the impacts are reported in terms of long-run strategies to preserve land productivity. Other impacts include improved scientific and civic literacy through community capacity building and empowerment and strengthen local knowledge systems (Jemberu et al., 2018), more knowledgeable farmers (Okoba et al., 2007), and agro-tourism, cultural or leisure activities and marketing of agricultural products (Zoumides et al., 2017). Milgroom et al. (2007) specifically argued that a long-term benefit of the participatory approach is to provide blocks of concepts to soil users so that they can solve new issues of soil erosion risks arising in the future.

5. Co-created approaches

This category of participatory approach is designed by scientists and nonexperts working together to solve a problem. In this case, however, the participants define the object of study and come up with the questions, for which scientists only provide guidance, technical and scientific expertise. The question of the study is usually an issue of concern for participants which hampers their economic activities or affects their well-being. In co-created approaches, at least some of the participants are actively involved in nearly all stages of the scientific process (Shirk et al., 2012). This category of participatory research, therefore, involves a significant level of engagement by participants. Most studies labelled as "participatory action research" or about community-based soil restoration fall into this category.

5.1. Input to the project

The literature reviewed showed that most co-created projects were carried out on farms and that there was an expectation of sharing and learning among participants and an exchange of knowledge between farmers and scientists. Individual scientists are not only interested in scientific outcomes but also in finding adapted local solutions for soil conservation and achieving results through the democratization of the scientific process. Dougill et al. (2002), for example, aimed to understand the applicability of international and national soil degradation assessment in evaluating the extent and cause of soil nutrient and fertility degradation in relation to local farmer livelihoods. In Hagmann et al. (1996), the scientists' expectations were to develop flexible options for soil conservation, options which can be adapted and refined by the farmers. Other expectations were to raise awareness for soil conservation and to encourage farmers' initiatives to promote technology transfer. In Kral et al. (2020) the hope of the scientists and the lead team is i) to work towards democratization of science, and (ii) to achieve better results, i.e. better application of the solution to the local context. The inputs of the participants were an overall interest in the scientific process to solve a local problem of concern. In Hagmann et al. (1996), the public expectation is experiential, i.e. to understand the process rather than being taught, and to build a favourable social environment for spreading process and innovations. In Kral et al. (2020) the input of participation is the hope to rehabilitate soil and soil heavy metal contamination areas and build a sustainable soil management practice that contributes to income generation. There is an overall expectation to restore soil functions in the former mining area after switching from mining to agriculture: to contribute to science or improve living conditions.

5.2. Activities carried out by participants

The bulk of the work is usually coordinated by a lead team but carried out by participants, for example through workshops and interviews at the different stages of the project (as in Mitter et al., 2014) in which non-experts are invited to define their problems and needs and to experiment with techniques from their own knowledge, in which case scientists are involved in facilitating the process to contribute to technical expertise and to help gather non-experts ideas for further research. This was the case in Hagmann et al. (1996) in which concepts from participatory technology development articulated around methods of learning through experimentation were applied. In Dougill et al. (2002) a lead team conducted various activities corresponding to the various project phases: i) livelihood analysis and environmental assessment using social surveys, ii) participatory nutrient budget evaluation using semi-structured interviews, field visits and the collection and analysis of soil samples, iii) feedback discussions on soil fertility and threats, and finally, iv) community workshops for dissemination and regional policy workshop for institutions. A similar approach is taken in Kral et al. (2020): in an experimental field close to that of the smallholder farmers, different amendments were tested. Monitoring is done jointly by scientists and farmers all year round and relies largely on observations from farmers while laboratory analyses of the samples is made by trained scientific staff. Scientists only provide consultation on crops to be cultivated and assist with feedback rounds on project progress and outlook. The main activities are different in Soto et al. (2020) where the scientists define a very large list of soil quality indicators which are then refined by farmers during a workshop. A visual soil assessment tool is developed and validated by and for farmers. In a further study, Soto et al. (2021) reported participants monitoring regenerative agriculture through workshops and field assessments.

5.3. Project outputs

In all studies, the output resulting from the activities was locally-relevant information to tackle a soil-related environmental issue of concern. Dougill et al. (2002) reported a solution to the problems of soil acidification through quantification of the nutrient fluxes and questionnaires to 15 farmers and identified potential improvements using local knowledge and practices. In Kral et al. (2020) the output was a list of soil amendments and crops for cultivating degraded soils and yielding higher harvests. In two studies the main output was a set of techniques or a protocol that suit the local context. In Hagmann et al. (1996) the 12 self-initiated trials resulted in a large number of innovative techniques. Similarly, in Soto et al. (2020) the main output was a farmer manual (i.e. a visual soil quality assessment tool).

5.4. Outcomes

Outcomes for individuals All studies reported a change of attitude and a feeling of ownership of the land by the participants. Dougill et al. (2002), for example, indicated that participants increased their self-confidence and were willing to change their actions, although they also noted that many soil users are not interested in improving their farming practices. Hagmann et al. (1996) argued that the participatory approach built farmers' confidence in their knowledge and a deeper understanding of the process of trials and experiments. It was also acknowledged in Kral et al. (2020) where a better understanding and knowledge of soil nutrients was reported, as well as a feeling of ownership of the land by farmers. It also resulted in a better sense of ownership of individual farmers and social learning through a sense of belonging to the land, which lead to implement regenerative agriculture practices (Soto et al., 2021), or to avoiding the land being re-mined by local exploitation on the rehabilitated land since agriculture is now more profitable.

Outcomes for science We identified that co-created projects resulted in high precision of results due to the inclusion of local knowledge (Dougill et al., 2002) and an increase of capacity for the researchers to understand the best options. An outcome reported in Hagmann et al. (1996) is a set of new techniques for mechanical, agronomic, biological conservation and water-saving methods. The methods are based on very localized knowledge and originate mainly from traditional farming practices. As a metric of success, Hagmann et al. (1996) reported an evaluation of the adoption of soil conservation measures over three seasons and found that 80% of the households implemented at least one conservation practice.

Outcomes for socio-ecological systems We found several well-documented outcomes for socio-ecological systems in co-created projects, many of which relate to better formal communication among participants and a better relationship between participants and local government and administration. Kral et al. (2020), for example, reported a better degree of organization between the administration and local farmers to prioritize farming over previously mined areas and to address land degradation. Similarly, Hagmann et al. (1996) reported the strengthening of local institutions and capacities and better relationships. It also improved the dialogues between farmers who now feel more welcome to bring change. Soto et al. (2021) reported some progress to achieve soil quality restoration. It was also argued that the co-created project generate social cohesion and support between participants sharing similar philosophies of agroecosystem restoration. Finally, Dougill et al. (2002) reported a number of socio-ecological outcomes: better direct decision-making on best management practices and mitigation of soil degradation, better structure of communities with regional policymakers and institutions, greater understanding of the impact of management practices and inorganic fertilizer on soil acidification, better formal communication among participants, and better recognition of the institutional frameworks needed to mitigate soil degradation. Finally, in Hagmann et al. (1996), the farmers questioned argued that the participatory co-created project brought development in the area.

Costs to individuals or communities The costs to individuals or communities were high in terms of commitment and project implementation, but usually low in formal costs. For example, Kral et al. (2020) reported a low cost to local communities or individuals beside time and involvement. It was for example shown that farmers organized a tractor from the local cooperative to speed up the manual work in levelling the field and that there was no need to buy any new technology or implement new techniques. One limitation was given in Soto et al. (2021) in which it was explained that some participants had to drive up to 2 hours to attend the workshops and that no compensation existed.

Costs to researchers None of the studies reported information on the potential costs for researchers. We infer, however, that the co-created project might have high costs to start because of the initial training of participants but then would incur low costs to maintain.

Compromises Some studies reported slower processes and unequal outcomes between areas. For example, Hagmann et al. (1996) noted that while the project was highly beneficial in many aspects to the local communities, the project required endurance and continuous stimulation and that the process was complicated and not equally successful in all areas. Kral et al. (2020) noted the difficulty in the alignment of scientific and farmers' objectives in the experiment - the challenge of aligning conflicting preferences. For example, the scientists wanted to test zeolites as amendments but it was abandoned because it was likely too expensive for farmers and so it would preclude applications, should it prove beneficial.

5.5. Impacts

Few long-term impacts were reported. A long-term impact given by Hagmann et al. (1996) includes the growth of the farmer club which helped drive the leadership of local institutions. In Kral et al. (2020), the positive long-term impact was the scaling of the local experimental field to neighbouring islands.

6. Discussion

6.1. Why are participatory projects on soil initiated?

Participatory approaches to soil research and management have the common goals that they address complex problems that cannot be solved by a single best solution. These approaches, therefore, consider various options balancing the interests of the different parties. We found, however, that nearly all projects were initiated from scientific interest rather than public interest. In most contributory projects, for example, the aim is to collect data that can produce a scientific outcome. Public interest is ensured to maintain data accuracy and good spatial coverage. We found similar situations in collaborative and co-created soil studies. One explanation might be that our literature review is mostly based on scientific literature, and we may have disregarded small projects that are initiated from public interest. While we found in our review that participatory projects were driven and initiated by scientists, the project initiation was, conversely, driven by the idea that the public and nonexperts could enhance the implementation. In some cases, participation was initiated, notably, to ensure that local knowledge is accounted for, and to enhance the relevance of the local solutions.

6.2. Are there differences in participation in relation to the degree of economic development?

The classification approach taken in this review revealed that contributory approaches (”citizen science” or “crowdsourcing of scientific data”) were mostly applied and documented in the context of economically developed countries, whereas projects that suggest greater involvement of participants (i.e. collaborative and co-created approaches) were mostly formulated and applied in developing countries. The review revealed in fact two distinct bodies of literature. The first relates to a large number of contributory projects initiated by scientists and carried out with the purpose of contributing to science (i.e. by collecting data for large-scale monitoring schemes). These projects usually have a low potential for enhancing participants' knowledge of science although some activities may target education. There is a second body of literature where participation is applied in developing countries in the context of agriculture, sustainability and development in general. Such projects are more aligned with socio-ecological change than contributions to science. Besides the different outcomes for the types of participatory projects, we speculate that costs to researchers and individuals and local communities explain why participation is applied differently in developed and developing countries. Contributory projects are expensive to establish and maintain for scientists. They are also expensive to individuals as they require time and commitment to data collection. Collaborative and co-created projects are expensive to establish too, but this cost is supported by scientists whereas implementation and maintenance costs supported by local communities are low.

6.3. How do the outcomes relate to the expectation of the participants?

The outcomes reported in Sections 3.4, 4.4 and 5.4 do align with the expectations from participants of Sections 3.1, 4.1 and 5.1 respectively. The outcomes also align with the degree of participant involvement. In general, contributory projects result in a better scientific process through data collection whereas co-created projects are suitable for social change and promoting sustainability of the agroecosystems. We found, however, a lack of reporting on long-term impact, both on the learning outcomes of participants and on effects on socio-ecological systems. Long-term impacts are difficult to measure because they may occur more than a decade after the project is initiated (Shirk et al., 2012). Not reporting long-term learning outcomes of participants is also not specific to soil research and management studies, as this issue was also abundantly reported in the literature in ecology (e.g. Shirk et al., 2012). Recently, several lines of work have contributed towards a better understanding of the long-term sustained impact of participatory projects and proposed a framework for evaluating impact. Such frameworks are proposed in Phillips et al. (2018) and discussed in Jordan et al. (2012). Often, these are often based on a retro-fitted design which first determines the desired outcomes and then the type of participation that can achieve such outcomes (Phillips et al., 2012). Evaluating impacts would certainly make a valuable contribution to understanding the role of participatory soil projects in improving human well-being and securing the soil.

6.4. Is participation transient or is it here to stay?

Recall that the participation of non-experts in science is not new and that there are many examples in the natural sciences of interactions between laypeople and scientists. Soil science makes no exception. While there is a nearly complete absence of a record of soil investigation up to the mid-19th century (McCall, 1931), soil research and management in the 20th century was also made in collaboration with non-experts. An example reported in Hartemink (2021, p. 92) is the Corn Pacemaker Program, started in 1952 in the USA, where 167 participant farmers were asked to follow prescriptions for the addition of nitrogen to the soil. The program was assisted by the distinguished professional soil scientist Emil Truog. The farmers participating achieved a 3-fold maize yield compared with the national average, which resulted in considerable attention to the program, and more participation (up to 600 farmers) gathered in a “Pacemaker Corn Club”. This project was initiated and driven by professional scientists with the aim of increasing crop yield and informing science by implementing a new test to estimate the amount of nitrogen in the soil. Today's participation still facilitates data collection but is also driven by an imperative of democratization of science: participation is often seen as a desirable feature in our modern societies. Participation is also recognized as a tool of communication between science and the public and of overall people's education. No doubt that it is here to stay. Information technologies and digital convergence in soil science (Wadoux and McBratney, 2021) are facilitating participation. Cell phones and applications can promote data collection and enable crowd-sourcing of soil data by non-experts, several contributory projects of which are underway and reported in Section 3.

6.5. Does participation enhance any aspect of soil science research?

The monitoring of soils benefits from participation. Networks of non-experts offer the possibility of enhanced knowledge of the soil cover by enabling the density of observations that are required. This was also discussed in Rossiter et al. (2015): non-specialists act as observers or experimenters. This benefits in the first instance the scientists and digital soil mappers who may use this information to produce or improve maps of soil properties. There is also the opportunity for soil scientists to improve their knowledge of soil by accounting for local knowledge. Soil users, such as farmers and rural communities, have tacit knowledge or experience accumulated from practice, as so may recognize soil features that do not correlate with map legends. Often this knowledge or observations are defined in a local terminology whose vocabulary is not readily accessible to soil scientists. The challenge to accessing this information is to define a common language to transfer the knowledge from the soil user to the soil scientist. This is often referred to as ethnopedology (Barrera-Bassols and Zinck, 2003). Finally, co-created projects have the advantage of passing on information to the soil scientists about phenomena of interest which are of concern for local communities but may not correlate well with clearly defined processes understood by soil scientists. Understanding disagreements between soil knowledge and local phenomena will undeniably trigger new hypotheses which can then be tested. Participation in this sense is a useful tool as a local soil phenomena information carrier.

6.6. Where to look next with participation?

The next step with participation is to have the public and nonexperts generate questions about soils: what they would like to know. For this to happen we need a public with a sufficient level of understanding of basic soil science. This could be achieved through better communication in mass media and digital tools. The public could then start to generate useful, hopefully tractable, questions about soils, and work together with soil scientists to generate data.

7. Conclusions

A literature review on participatory approaches to soil research and management and a synthesis were conducted. The studies were classified by the participant's participation in the various phases of research, and then further refined by the quality of participation in each of the phases. We draw the following conclusions:

- Participation in soil science emerged to tackle complex issues which do not have a single best solution but instead have a number of possible outcomes balancing the expectations of the different parties.
- Participation is usually associated with citizen science, but citizen science represents a narrow part of participatory approaches in which participants mostly contribute by collecting data to inform soil monitoring schemes.
- Contributory approaches labelled "citizen-science" and "crowd-sourcing of scientific data" and where the participants participate in the data collection are the most common types of participation for soil research and management.
- There were only a few co-created projects where participants define the object of study and come up with the questions, for which scientists only provide guidance, technical and scientific expertise. These projects mostly occurred in developing countries and concerned soil rehabilitation and conservation.
- We found that nearly all projects were initiated from a scientific rather than from public interest.
- By relating the outcomes to the participant expectations, we found that the outcomes aligned generally well with the expectations and degree of participant involvement.
- Overall, there is a lack of reporting on long-term impacts, both on the learning outcomes of participants and effects on the socio-ecological system.

Data availability

No data was used for the research described in the article.

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