Creating shared value(s) from On-Farm Experimentation: ten key lessons learned from the development of the SoYield® digital solution in Africa

Chloé Alexandre, Léa Tresch, Julien Sarron, Jéremy Lavarenne, Gaspard Bringer, Hamza Rkha Chaham, Hamza Bendahou, Sofia Carmeni, Philippe Borianne, Jean-Mathias Koffi, et al.

Agronomy for Sustainable Development (2023) 43:38
https://doi.org/10.1007/s13593-023-00888-7

RESEARCH ARTICLE

Creating shared value(s) from On-Farm Experimentation: ten key lessons learned from the development of the SoYield® digital solution in Africa

Chloé Alexandre[1,2] · Léa Tresch[3] · Julien Sarron[4,5] · Jéremy Lavarenne[3] · Gaspard Bringer[3] · Hamza Rkha Chaham[3] · Hamza Bendahou[3] · Sofia Carmeni[6] · Philippe Borianne[7,8] · Jean-Mathias Koffi[9] · Emile Faye[4,5]

Accepted: 28 March 2023 / Published online: 3 May 2023

Abstract

This study is based on the observation that many digital tools and services for agriculture do not put farmers' expectations and interests first, resulting in top-down research and development. On-Farm Experimentation (OFE) contributes to overcoming these limitations because it places farmers at the center of innovation processes, while ensuring rich interactions with various value chain actors. The richness of OFE is in part explained by the diversity of stakeholders involved and the co-learning that results from their interactions. Studies in management and social sciences show that such open innovation processes can be difficult to manage. Aligning the visions and interests of the different stakeholders, fostering the sharing of resources and knowledge to produce value, and sharing the value created in an equitable manner remain a real challenge. Although these issues can refine the understanding of the mechanisms that condition the success of OFE, they have yet to be sufficiently analyzed. Recent publications underline the need to explore the organizational and managerial aspects of OFE to facilitate its implementation in various contexts. This work proposes to fill this gap by providing ten key lessons for conducting OFE with the aim of creating shared value, i.e., developing innovative technologies and practices that benefit all parties but, first and foremost, farmers. These ten key lessons stem from the reflexive monitoring of an OFE process aimed at developing the SoYield® decision support system for helping mango value chain actors to estimate fruit production in Africa. This reflexive monitoring was conducted by the main actors involved in this process, namely, farmers, a private firm and research centers. These key lessons lay the foundations for strengthening a community of practice on OFE implementation and for facilitating its development worldwide. This study also provides insights into the contributions and limitations of digital tools for conducting OFE.

Keywords User-centered design · Value creation and capture · Open innovation · Digital agriculture · Fruit value chain · Mango

1 Introduction

Recent technological developments and analytical breakthroughs have generated high expectations about the role of digital applications and services for supporting farmers and other value chain actors (input suppliers, buyers, transformers, technical advisors, policy-makers) in their decision-making and management of their activities. Digitalization of agriculture is expected to provide technical optimization of agricultural production systems, value chains, and food

✉ Chloé Alexandre
chloe.alexandre@cirad.fr

1 CIRAD, UMR Innovation, 73 rue Jean-François Breton, TA C 85/15, Cedex 5, 34398 Montpellier, France

2 INNOVATION, Univ Montpellier, CIRAD, INRAE, Institut Agro, Montpellier, France

3 FranceSowit SAS, 92110 Clichy, France

4 CIRAD, UPR HortSys, 34398 Montpellier, France

5 HortSys, Univ Montpellier, CIRAD, Montpellier, France

6 CIRAD, DIMS, 34398 Montpellier, France

7 CIRAD, UMR AMAP, 34398 Montpellier, France

8 AMAP, Univ Montpellier, CIRAD, CNRS, INRA, IRD, Montpellier, France

9 National Center for Agricultural Research (CNRA), Regional Direction of Korhogo/Lataha Research Station, BP 856, Korhogo, Ivory Coast

systems (Klerkx et al. 2019; Sarron et al. 2022), and enhance agroecological transitions (Bellon-Maurel and Huyghe 2017). At the farmer's level, digital tools are expected to improve their access to personalized information and to facilitate the exchange of information and knowledge with other farmers, traders, transformers, extension agents, and researchers. For example, the RiceAdvice smartphone app allows rice farmers to obtain personalized recommendations for optimizing fertilizer application (Saito et al. 2015). Digital platforms can also help to solve complex problems such as the identification and management of crop diseases (Plantix app, BXW-App) by helping farmers to exchange information and knowledge with their peers and by making real-time data and contextualized information available across the system (McCampbell et al. 2021).

However, the last decade of experience with digital tools and services designed for farmers in industrialized and developing countries has demonstrated that they are not a panacea (Steinke et al. 2020; Klerkx et al. 2019; Alexandre 2023). The potential of digital technologies is not fully exploited to meet users' expectations. In developing countries, the effects of digital solutions on farmers' decision-making have often been limited (Baumüller 2018). For example, digital tools designed to advise farmers frequently suffer from mismatches with farmers' information needs, technological capabilities, and habits (Aker et al. 2016; Fabregas et al. 2019). They also suffer from inadequate timing of information delivery and insufficient trust in information sources (ibid.). In addition, coming to grips with these digital tools comes at a cost to farmers. This learning cost is sometimes higher than the actual benefit of these tools, which can lead farmers to lose interest in digital technologies (Mendes et al. 2020). Finally, many digital applications and services are not sustained after initial funding ends since they fail to develop into viable and appropriate business models (Steinke et al. 2020). User-centered design approaches are increasingly being used to develop digital tools that are useful, usable, and used by farmers. Nonetheless, the challenges presented above remain common (Steinke et al. 2020). In industrialized countries, the value of digital applications and services for farmers is also questioned. In the absence of clear regulatory frameworks on data ownership and privacy, recent works question the net value that farmers receive from these digital applications and services (Klerkx et al. 2019). Among others, Lioutas et al. (2019) underline the power imbalances concerning access to the value derived from the use of big data. This is corroborated by the survey conducted in Ireland by Wiseman et al. (2019), which reveals that farmers who use digital tools and services generally fear that their data is traded or disclosed to third parties, leaving them unaware of who knows the details of their business enterprises. They are also concerned that advisors and agribusinesses will be the main financial beneficiaries of their agricultural data. In turn, this lack of trust and reciprocity reduces their willingness to use digital applications and services, and to share their data.

On-Farm Experimentation (OFE) initiatives can help to produce digital services and tools that overcome the technical, social, and institutional shortcomings mentioned above. In keeping with Lacoste et al. (2022), we define OFE as "an innovation process that brings agricultural stakeholders together around mutually beneficial experimentation to support farmers' own management decisions" (p. 12). This process of joint experimentation follows action research recommendations that encourage participants to plan, act, observe, reflect, and repeat (ibid.). Because of their open, iterative, and user-centered nature, OFE initiatives could contribute to the development of responsible digital applications and services by increasing understanding among all actors and gathering complementary capabilities, while promoting data privacy and proactive governance (Fabregas et al. 2019). OFE processes that place farmers' needs and knowledge at the center would indeed actively rebalance the control of data and ownership of innovation processes in favor of farmers (Cook et al. 2021).

However, managing open innovation processes such as OFE initiatives constitutes an ongoing challenge (Ollila and Elmquist 2011). As noted by McGahan et al. (2021, p. 4), "at the core, open innovation depends on relationships among actors who are asymmetric in ways that make the collaboration fruitful, but that also introduce competition, power, communication, and coordination challenges. 'Open' does not mean a level playing field." Open innovation is therefore a source of considerable tension, resulting mainly from the diversity of the actors involved, who differ in terms of their expertise, their level of resources, and their interests and their incentives to participate in the innovation process (Chesbrough 2019; Alexandre et al. 2022).

A key issue is therefore to succeed in aligning the interests of these different actors and to encourage them to share their resources, skills, and capabilities to create shared value (Chaurasia et al. 2020; Porter and Kramer 2011). For Chesbrough et al. (2018), leading a successful open innovation process requires, among other things, managing the tensions between value creation (requiring that organizations open their boundaries to share resources and knowledge) and value capture (to ensure that every actor involved, even the least endowed, benefits from the OFE process).

Although management science studies have investigated managerial practices and tools that make it possible to overcome the challenges of open innovation (for example, Rouyre and Fernandez 2019; Stefan et al. 2020), to our knowledge, this issue remains little explored in the literature on OFE processes. Several studies undeniably emphasize the need to reflect on OFE practices (Cook et al. 2013; de Roo et al. 2019) in order to improve the implementation of these processes and their worldwide development.

This study proposes to fill this gap by analyzing the OFE process that led to the creation of the SoYield® Digital Decision Support System (DSS) that allows different value chain actors to estimate, analyze, and share data on mango yields (see Fig. 1 for pictures of the development process).

Objective assessments and productivity monitoring of mango orchards are key elements for farmers to forecast their practices (pruning, harvest, labor requirements) and to sell their production. The development of the SoYield® DSS involved many partners (including farmers, research centers, and a private firm) whose resources, interests, and agendas varied. This diversity of partners has generated tensions regarding the creation of shared value and the capture of this value. However, the design and partnership management approaches that were used in this project have allowed the partners to overcome these tensions and develop a digital tool that benefits all the partners involved, including farmers.

In this study, we mobilized a reflexive monitoring approach to pinpoint and analyze the issues that have been overcome to achieve the development and early-deployment of the SoYield® DSS in Africa. On the basis of this reflexive approach, we identified ten key lessons for the successful implementation of OFE processes and, more specifically, for creating shared value in OFE. It is hoped that these key lessons on OFE implementation will facilitate the development of other decision support tools and services for farmers. Furthermore, they are sufficiently generic (and therefore replicable in a diversity of contexts) to provide information to the actors in charge of implementing various OFE initiatives, thus contributing to promoting OFE worldwide. In the following, we first describe the nature of the SoYield® DSS and present the main steps of its development process. We also present the reflexive monitoring approach used. In a second section, we then present the ten key lessons practices that led to the development of the SoYield® DSS in an OFE process, which emerged during the reflective

Fig. 1 Field pictures of the iterative co-conception and user-centered design approach at various steps of the development of the SoYield® decision support system. **a** Feedback on research activities to a farmer. **b** Interviews on needs and expectations with a mango wholesaler. **c** Testing the user flow experience with a paper storyboard with harvest technicians. **d** Guided testing of the SoYield® smartapp prototype. **e** *Beta*-test of the operational *beta*-version of the SoYield® smartapp by a farmer on his own. Credits: CIRAD, E. Faye, CNRA, J.M. Koffi, and SOWIT, H.R. Chaham.

monitoring approach. We mobilize the existing literature on open innovation and OFE to discuss the validity of these findings and lessons for other OFE initiatives.

2 Material and methods

2.1 Describing the development process of the SoYield® decision support system

2.1.1 What is the SoYield® decision support system?

Measuring and predicting yield are major challenges for agriculture and, more especially, for fruit crops. The associated uncertainty of such evaluations has multiple repercussions that affect the development of entire value chains, including farmers who do not know their annual yield (usually estimated through tedious manual counting), buyers and wholesalers who struggle to forecast their supplies, local authorities who are unable to design agricultural policies adapted to the value chain issues in their regions, and even scientists who are constantly waiting for reliable quantitative data (Carletto et al. 2015; Burke and Lobell 2017). This is particularly the case for smallholders and agroecological farmers that sell less than 50% of their crop outputs and tend to be more exposed to the negative consequences of production and market information asymmetry (Sarron et al. 2022).

The development of fruit value chains in Africa is severely hampered by the lack of factual or predictive advisory tools to map the state of production over time and space. Today, fruit tree farmers have no other means to monitor their fruit production than performing a rough visual estimate or extrapolating the number of fruits from a visual count performed on a limited number of trees in their orchards. In both cases, yield estimation requires considerable effort and provides low accuracy (the relative error is often above 30%) with weak repeatability (non-objective assessments) (Anderson et al. 2021). Fruit tree farmers lack tools to efficiently assess their fruit yields, leading them to struggle with planning, managing, harvesting and selling their production. Consequently, providing these farmers with a way to objectively and accurately estimate their yields offers a more rational basis for the discussion and more leverage to seize market opportunities, while anticipating and planning the harvest in order to mitigate eventual losses.

In this context, the general ambition of the SoYield® DSS is to provide the actors of the fruit value chains in Africa with an innovative digital solution for the acquisition, analysis, and sharing of fruit production data. Moreover, while meeting the operational needs of the stakeholders of the value chains, the SoYield® DSS helps to address research and development issues by providing objective field data in a ‘data collection in return for services provision’ framework. It contributes as such to the structuring of the fruit value chains and the strengthening of food security in Africa. The SoYield® DSS is a fruit production data management tool (Fig. 2) that is defined by three core ideas:

- (1) a smartphone app for data acquisition based on embedding AI algorithms that predict the orchard’s yield with high accuracy (< 10% relative error) through a sampling of the orchard built on an agronomical model using easily findable parameters such as orchard boundary, tree density, cultural practices, etc.;
- (2) a multiscale analysis and extrapolation of yields performed by agro-statistical models on remote sensing-based land-use mapping on a remote server;
- (3) a data visualization web app for the analysis and sharing of the high value-added data outputs (e.g., orchard

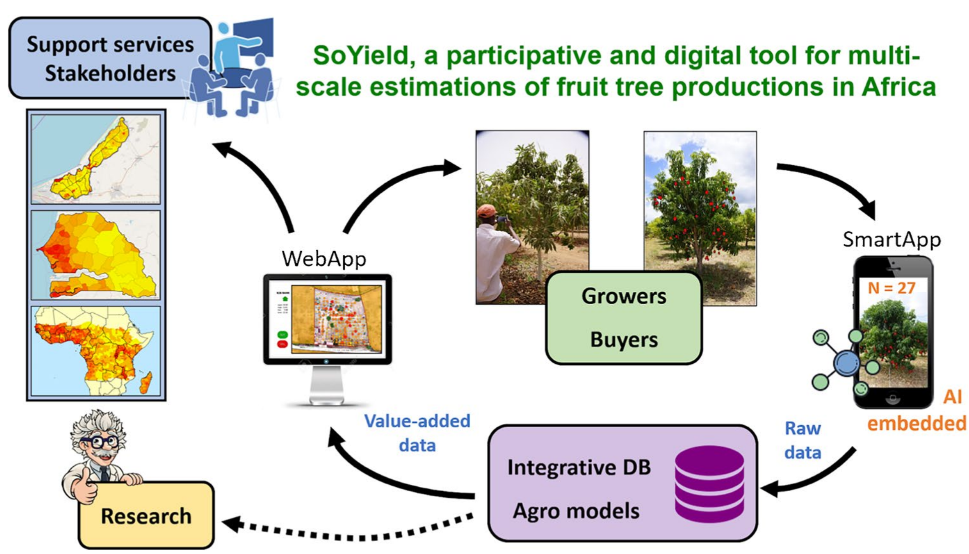

Fig. 2 Schematic workflow of the SoYield® decision support system as conceived by the OFE processes with the actors of the mango value chains in Africa. The SoYield® decision support system is a scientifically-backed, user needs-centered, scalable imagery-based artificial intelligence (AI) solution for real-time analysis and the sharing of mango fruit production data.

productions, average yields in the area, production potential, fruit availability) through an informative geoportal service available for the actors of the value chains (e.g., farmers, buyers, exporters, support services, politicians, scientists).

The objective of the SoYield® DSS is threefold: (1) to inform farmers about their actual yields in order to guide their decision-making through data monitoring and analysis, (2) to facilitate relationships between the actors of the sector based on objectively measured yields, and (3) to build an enriched and spatialized database for fruit production in Africa.

2.1.2 What was the development process of this decision support system?

The first step of the development process of the SoYield® DSS was an academic step driven by research questions. The research focused on determining the drivers of the multiscale variability observed in mango yields in West Africa (at the tree, orchard, and regional levels). Researchers began to build a network of more than 55 orchards representing the mango-based cropping systems and their associated production variability in Senegal and Ivory Coast. From the beginning, the researchers worked with farmers to investigate the drivers of the fruit production in their orchards. The researchers presented their objectives and hypotheses, and confirmed the farmers' interests in these research topics, without initially telling them about the potential applicability of that research. Then, after informing them about the project objectives and with their agreement to contribute to the project, researchers gathered the farmers' knowledge on yield estimates based on their long-term field experience. One main insight from farmers at this step was the procedures and methods they used to perform yield estimations in their orchards (how, where and when) and the performances of this estimation (precision and time cost). Based on the results of these interviews and scientific knowledge, researchers designed and conducted various on-field experiments (including more common quantitative interviews on agronomical practices) in the 55 orchards from 2016 to 2018. Thus, during this period, a large amount of data was acquired in the studied orchards (e.g., agronomical practices, climate, orchard land uses, tree production, orchard yields, tree images, fruit annotations). These first academic works allowed researchers to produce agro-statistical models combined with artificial intelligence (AI) algorithms for image analysis that estimate the biological yield of a tree (total number of fruits per tree), depending of the cultivar and cropping system (Borianne et al. 2019), and a high-tech toolbox to achieve mango yield mapping at the orchard scale (Sarron et al. 2018). A tipping point in the process of SoYield® DSS development was to provide feedback to the farmers on the results of the research activities conducted in their orchards. While presenting and discussing these results on the basis of an orchard-specific report provided to each farmer, researchers realized that the conventional statistics that validated the performances of their models were of no interest to the farmers, who were instead interested in the potential applicability of this research and the applied results of the models (i.e., comparing the estimated vs. observed yields, orchard yield between orchards). These discussions helped researchers to pinpoint the way to ideate the SoYield® DSS and made them aware of the needs of the farmers faced with the problem of estimating their yields.

The second step of the SoYield® DSS development was a pre-maturation step**.** During this step, participants focused on the ideation and co-design of a tool that could fulfill the needs of the variety of actors involved in the fruit value chains who have expectations in terms of yield estimation, including farmers as well as harvesters, wholesalers, support services, etc. In order to maximize adoption, researchers and developers were willing to place the end-users at the center of the research and development processes. Applying this user-centered design approach helped to develop and scale the SoYield® DSS (Abras et al. 2004). So as to involve the end-users in the ideation process, researchers invited two farmers who represented proto-personas (see below) to participate in a first workshop in 2019. Farmers had the opportunity to exchange their field expertise and needs with a team of experts (researchers, developers, computer scientists, engineers) in the fields of agro-physiology, statistics and modeling, software development, AI and machine vision, digital agronomy, and fruit value chains in Africa. Support services such as the mango interprofessional organization were also consulted. One of the objectives here was to bring the experts closer to the constraints and expectations of different types of users (e.g., type of farmers, fruit buyers). Researchers then used a large user-centered survey in Africa in order to better understand the context, constraints, and needs expressed or deduced from the potential users of the SoYield® DSS. The five group profiles interviewed in Senegal and Ivory Coast were smallholder farmers (17), intensive commercial farmers (10), trackers and harvest technicians (13), transport and packaging factories (6), and support services. The latter included national institutes for agricultural research (3), national mango interprofessional organizations (8), non-governmental organizations (6), technical institutes (3), and governmental organizations (3). These surveys confirmed the actors' interest in such a DSS and demonstrated the need for informative data with different levels of analysis at various tie points in the value chain. It also highlighted some key issues to focus on to enhance the adoption of the SoYield® DSS (e.g., illiteracy, use of digital technology, smartphone penetration rate). Thus, the results of these surveys strongly influenced the development of the SoYield® DSS (Table 1) and the establishment of an innovative business model (see point 5 of the "Results and discussion" section).

The third step in the development of the SoYield® DSS consisted in prototyping and iterative *beta*-testing, while still respecting the user-centered design approach. The first on-field prototype, aimed at testing the user flow experience and the understanding of the SoYield® DSS, was tested in the form of a paper storyboard with farmers, harvesters, and exporters (Fig. 1c). In 2021, a second series of *beta*-tests consisted of guided tests of the first *beta*-version of the smartphone app of the SoYield® DSS. These *beta*-tests were conducted by field experts of the project team with over 50 farmers, trackers, and harvest technicians in Senegal and Ivory Coast. Results of these *beta*-tests permitted the refinement of the user experience and strongly improved the functioning of the SoYield® DSS (critical back-end functioning decisions had to be taken at that time). On-field *beta*-testing validated the embedding of the computer vision models in the solution (by performing an extensive comparison of the measured/observed yields). Finally, last but not least, in 2022, a test of the actual *beta*-version of the SoYield® smartphone application was performed with 35 farmers (among the 150 end-users of the smartphone application in 2022) that used the SoYield® smartphone application on their own (Fig. 1e) and then gave their feedback during interviews. These iterative tests are to be continued for the operational and release versions of the SoYield® DSS to further improve and better adapt it to the needs and expectations of the users.

2.2 Developing the SoYield® decision support system as an OFE process

- Table 2 below summarizes the characteristics of the SoYield® DSS development, allowing us to identify this case study as an OFE process since it follows the five principles presented by Lacoste et al. (2022).

2.3 Data collection and analysis

We mobilized a reflexive approach to assess the development process of the SoYield® DSS in order to identify key prerequisites for creating shared value in an OFE process. This approach invites practitioners to take their own actions and mental functioning as an object of analysis (Schön 1984). Schön (1984) differentiates two processes of reflexive analysis: reflection-in-action, which allows a practitioner to think consciously as events unfold and to react to unexpected situations, and reflection-on-action, in which a practitioner analyzes what has happened and evaluates the effects of his or her action. Reflexive monitoring approaches are, among other disciplines, commonly used in educational sciences and management sciences (see, e.g., Minshall et al. (2010)). The objective is for practitioners to analyze their own actions in order to identify blockages on a specific topic and work on improving them. Reflexive monitoring is also increasingly used in agricultural development and innovation (Arkesteijn et al. 2015). Nevertheless, these approaches generally aim to determine whether the innovation project in question is achieving its intended effects and impacts, e.g., by ensuring that the assumptions made about theories of change are correct (Millstone et al. 2010). Reflexive approaches that allow actors developing an agricultural innovation project to identify and correct the collaborative challenges that arise are less common, especially in the context of OFE processes.

Table 1 Main results of the end-user surveys that influenced the development of the SoYield® DSS. Respondents were smallholder farmers (17), intensive commercial farmers (10), trackers and harvest technicians (13), transport and packaging factories (6), and support services (23).

Main points raised by interviewed	Consequences on the development of the SoYield® DSS
Users with various level of facilities and ease with ICTs.	Make friendly user and mutli-language interfaces which recall the main apps already used.
Most of the users do not have internet connection when on-field.	Tool must work without internet connection. Embed the models into the smartphone app.
The added value of such tool is unclear for most of the smallholder farmers.	Highlight the connecting farmers with buyers through the SoYield® DSS, helping them to sell their production.
Working with or within a network of orchards, with different access rights to the data.	Design a user management system with a multilevel hierarchy of accesses.
Sensitive to data sharing: need for explanation on how the data will be used	Provide sufficient information on how the data will be used, and receive inform consent in a context of lack of general knowledge on the subject, illiteracy, or language barriers.
Yield estimation is expected but other aspects are important for the users (yield forecast, fruitsize, maturity, aspect…)	Anticipating the future research and development of the tool.

Table 2 Five OFE principles that led the development of the SoYield® decision support tool.

Key OFE principles	Characteristics of the case study
User-centered	The SoYield® tool was developed following a user-centered design approach that sought to identify and better respond to farmers' needs and expectations.
Real systems	The experimentation process was mainly held in farmers' orchards. Field experiments were critical to ensure the calibration and validation of the models and the relevance of the SoYield® tools.
Evidence-driven	Essential data were produced based on field experiments and discussions with farmers to (1) develop the models described above and (2) to develop the SoYield® smartapp (surveys and discussions with farmers and in situ observations and *beta*-tests made it possible to refine various prototypes). The SoYield® decision support tool (smartapp and webapp) allows farmers, retailers, and policy-makers to access high value data about fruit production to make informed decisions.
Specialist-enabled	Researchers and IT developers coordinated the iterative development of the SoYield® decision support tool.
Co-learning	Thanks to their interactions, all the actors involved learned throughout the development process of the SoYield® decision support tool. What researchers and developers learned: - Farmers' expectations and constraints - Intellectual property and data sharing - Farmers' perceptions of the yield components - Growers' expertise for yield estimations - New topics of investigation (fruit maturity and sizing) What farmers learned: - Agronomic concepts (e.g., within-orchard production variability) - Agronomic knowledge (e.g., adapting a sampling strategy to the heterogeneity of the orchard) - Identification of the drivers of tree yields - Potential uses of digital technology, especially smartapps - Awareness of the data challenges: data production, sharing, the value of their own data, data protection (personal data and sensitive data) - Farmers become data suppliers
Scalable	While the SoYield® decision support tool was initially designed to fulfill the needs of the stakeholders of the mango value chains in Senegal and Ivory Coast, the embedded models, part of the PixFruit® expertise of CIRAD, can be adapted to estimate mango production in other countries, and tuned to fit other fruit value chains with similar expectations (e.g., citrus, litchi, avocado, cacao). Moreover, the innovative business model developed in this work ensures an adaptive scaling-up (see below).

The partners most deeply involved in the development of the Soyield® DSS have therefore engaged in a process of reflection on action, with the aim of identifying (1) the difficulties that can hinder the creation of shared values during an OFE process and (2) the practices or tools that can be used to avoid or overcome these difficulties. To facilitate this reflexive process, they were accompanied by a researcher in management sciences specialized in open innovation and familiar with reflexive monitoring approaches.

The reflective monitoring process took place in four phases (Fig. 3):

- Phase (1): From the beginning of the project in 2016, these partners documented the collaboration difficulties they encountered and those they were able to avoid thanks to specific collaboration practices or tools.
- Phase (2): As of January 2022, the external project researcher conducted interviews with the key partners involved in the OFE process. In total, 12 individual semi-structured interviews were conducted with representatives of the three organizations involved in the development of the SoYield® DSS, and with two farmers who *beta*-tested the SoYield® smartphone application prototypes (Table 3). Each interviewee was asked more specifically to identify tensions (past, current, and potential) related to creating shared values or sharing added-value in this OFE, and to reflect on practices that allowed them to overcome these tensions and facilitate the OFE process in order to create a digital decision support tool that benefits all the actors considered. The external researcher also analyzed secondary data such as meeting minutes and summaries of surveys with the actors of the value chains in order to identify potential difficulties in the OFE process, as well as lessons generated by partners' interactions. A compiled list of challenges to shared value creation was produced based on the 12 interviews and secondary data analysis.
- Phase (3): Then, in February 2022, a collective workshop allowed these partners to identify the ten key lessons that would allow them to avoid these challenges in order to create shared value from an OFE process.
- Phase (4): This workshop resulted in the writing of this article by the partners involved in the development of the SoYield DSS and the external researcher.

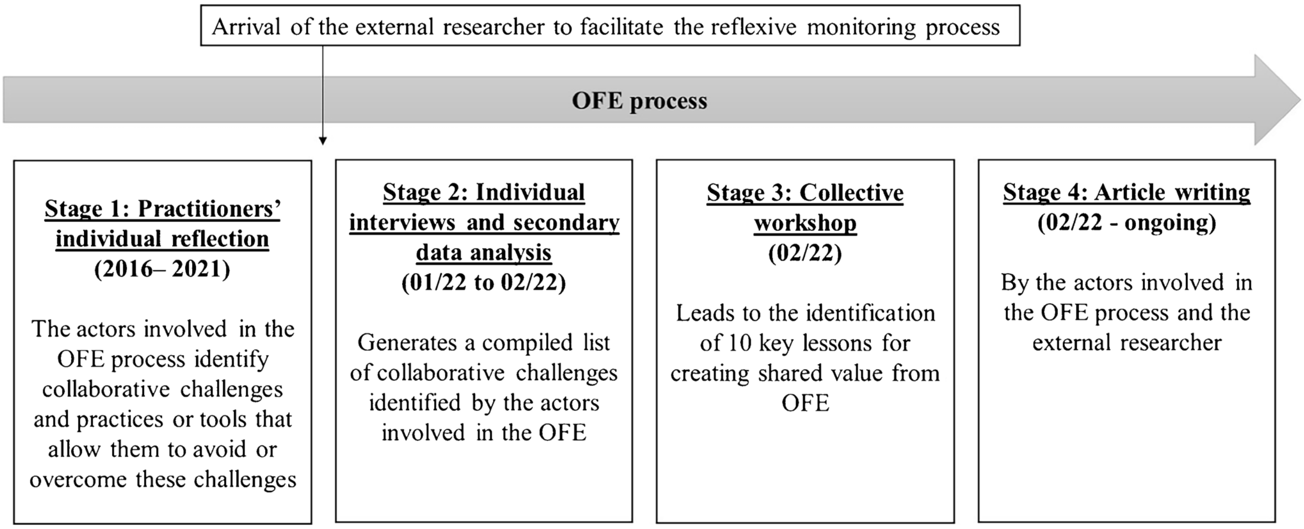

Fig. 3 A reflexive monitoring approach structured into four phases.

Table 3 Profile of the interviewees.

Organization/type of stakeholders	Profile of interviewees
Research centers on agronomy and agriculture (CIRAD, France and CNRA, Ivory Coast)	Researcher in digital agriculture
	Researcher in agronomy
	Researcher in deep learning
	Legal support services
	Ph.D candidate in the agro-physiology of mango
Private firm specialized in digital agriculture (SOWIT)	CEO
	CTO
	Product owner
	Product manager
	R&D Lead
Farmers who tested the prototypes	Agrobusiness farmer
	Smallholder farmer

3 Results and discussion

On the basis of the SoYield® DSS experience, ten key lessons were identified to be able to conduct successful OFE processes and to create shared value. Each of these lessons has come into play at different steps in the SoYield® DSS development process, as shown in Fig. 4.

3.1 Building trust in partnerships

Each partner's interests and objectives must be brought together so that they can share a common ambition. While the interests of each partner may be different, they have to be compatible. Figure 5 illustrates the different values for each partner and how the values of the three parties intersect to create shared value. In our case study, the research center is interested in sourcing data to produce science and impacts, as well as to valorize the research center's own knowledge via its transfer into the SoYield® solution, and to perceive returns on investment to amortize the initial R&D financial efforts. The private firm focuses mainly on the adoption and/or expansion rate of a product, its profitability, and impacts. Finally, end-users are more interested in the actual service provided by the solution, its reliability, and its costs (cost/benefits approach). However, all partners agreed on the fact that the SoYield® DSS must contribute to achieving a societal impact, in this case, structuring the fruit value chains in Africa to the benefit of the stakeholders, increasing farmers' income and, to a larger extent, improving food security. This common objective of achieving a societal goal strengthened

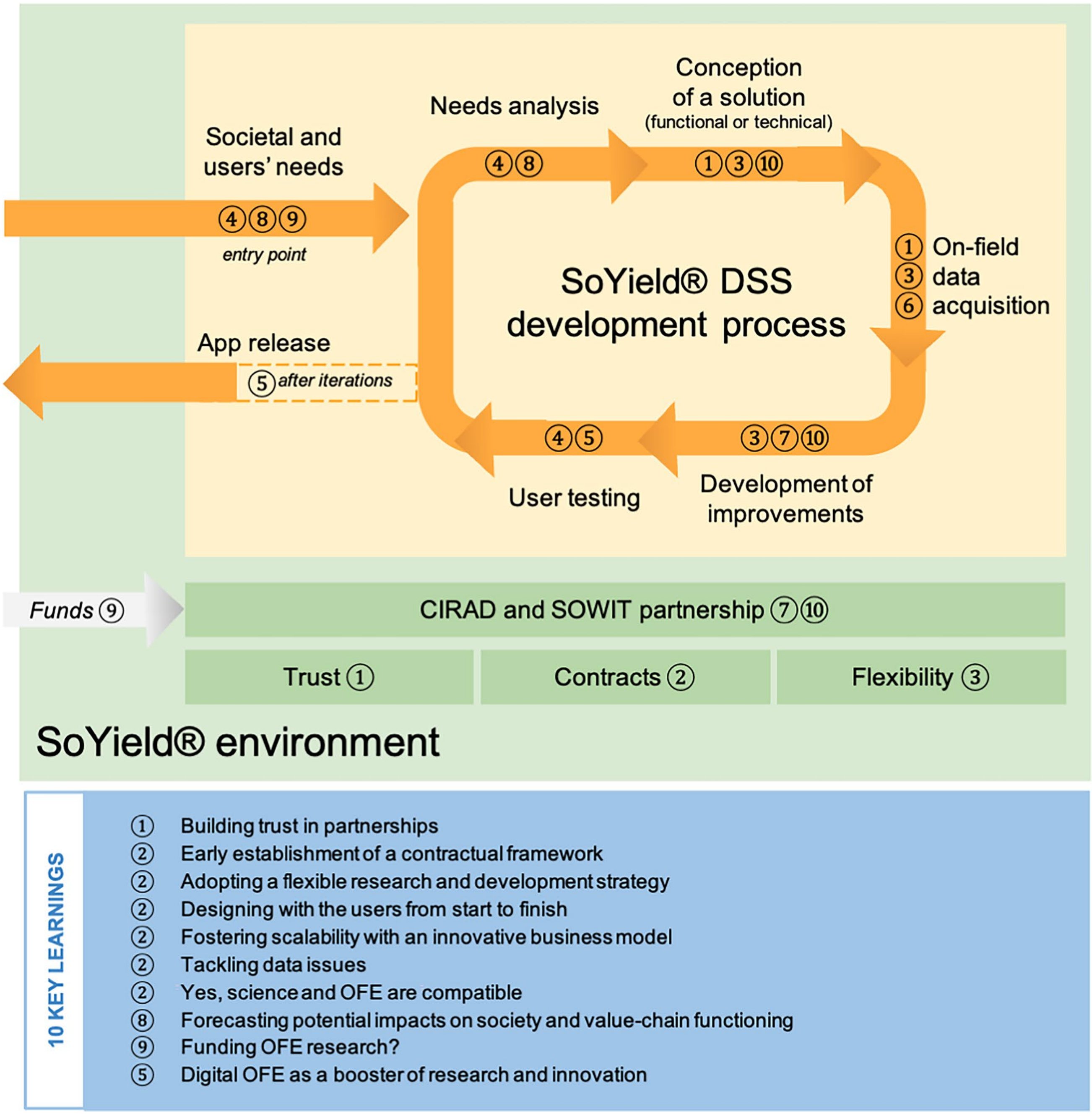

Fig. 4 Use of the ten key lessons during the development process of the SoYield® decision support system.

the collaboration between the three partners, despite their differences in the other objectives.

Thus, a key point is to manage expectations and to set the rules for participation and the use of data. One way to do this is to build a productive relationship based on mutual trust. It however implies a high level of transparency in the communication and actions carried out by the different partners. Overall, this relationship of trust seems to strongly rely on the interpersonal skills of the group, especially regarding compromise and the understanding of the constraints of the different partners. In the SoYield® DSS case study, the building of this relationship of trust between partners relied on the conviction of the leading team (three people) in this way of working and on its ability to instill it in the team. Moreover, spaces for communication and free expression for everyone were set up using project management tools. Presential and virtual meetings were held on a bi-monthly basis and included open discussion times as

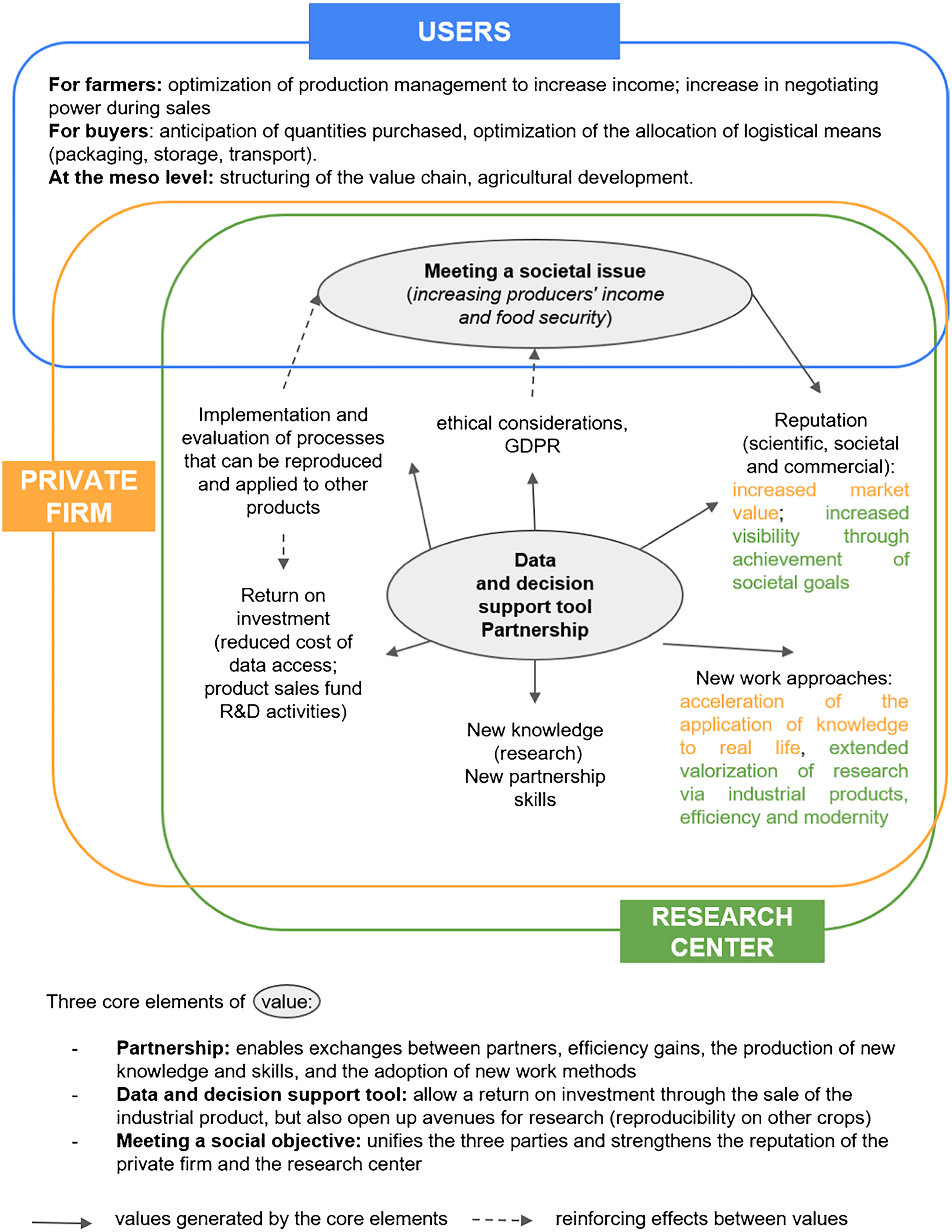

Fig. 5 Representation of the different values that partners attribute to the SoYield® decision support system experience.

well as topics specified in advance. Meeting minutes were held using collaborative text processing tools that allowed every participant to express concerns and point out details both verbally and in a written manner. When discussions reach a certain level of complexity, implicit or verbal agreements are not sufficient since information may be lost and misunderstandings may occur. At this point, collaboration programs appear preferable. In practice, flexibility, listening, and adaptability are essential to building reliable trust between partners. Still and overall, beyond a certain level of complexity in the project, or in anticipation of possible misalignment of the different parts (such as presented in Roo et al. (2019) between farmers and researchers in the context of participatory development programs), trust cannot exist without the support of a contractual framework that establishes the rules of the game for all of the players (see point 2 below). In the SoYield® DSS case study, the built-up trust proved to be beneficial during the negotiation of the different terms.

3.2 Early establishment of a contractual framework

OFE results in the co-design of new knowledge and/or innovation. Thus, issues concerning the sharing of intellectual properties, of added-values, and of the products developed (e.g., models, tools) arise. Asymmetrical technological and economic valorization of this knowledge must be avoided, particularly between partners that may be very different in nature (e.g., private firms, research centers, smallholders) or in economic size (e.g., companies vs. farmers, agribusiness farmers vs. smallholders). Thus, the creation and sharing of values (Fig. 5) must be managed contractually in order to safeguard the interests of each partner in the project and to formalize reciprocal commitments. From our perspective, a healthy and satisfactory partnership stems from finding a balance between each partner's inputs and expected outcomes (whether scientific, financial, reputational, industrial or commercial), which can be different or prioritized differently depending on the partner. Regarding the relationship between the owners and main developers of the innovation, contracts are notably necessary tools to avoid misunderstandings before they arise. Internal or external supports have to be incorporated and associated as early as possible, all the more when the project depends on seasonal timing for on-field experiment and data collection.

In the SoYield® DSS case study, attention was first given to identifying the priorities of each partner and figuring out the order of said priorities. The partners then focused on determining the balance between their respective inputs in the project and the outcomes they expected in light of said priorities. Both steps presented relative challenges to overcome. For instance, in the first step when partners confronted their priorities, some came as a surprise to the others due to a lack of knowledge or to misconceptions about the other partners' goals and constraints. In the second step, the partners faced challenges in agreeing on the balance between their inputs and expected outcomes due, in particular, to the difference in each party's abilities to absorb the risk of not succeeding in the development and commercialization of a new product.

These steps took place in a rather constrained context since when developing a new product in an extremely competitive environment, timing is of the essence. The partners had to work quickly with much transparency to create a flexible yet sufficiently safeguarded contractual framework in order to avoid delaying, as much as possible, the development of the innovation. Ultimately, co-building a satisfactory contractual framework demanded efforts from the partners to adjust their inputs and expected outcomes with regard to the interests, priorities, strengths, and constraints of each partner, therefore stressing the importance of building a collaboration between partners with compatible goals, assets and constraints.

Regarding the relationship with the farmers, care must also be given to define a well-balanced contractual framework. In such cases, the existing legal framework plays an important role in defining each partner's rights and safeguards (such as consumer rights when defining the terms of service of the finished product and, notably, data rights when personal information is collected, whether during the research and development phase or the exploitation phase; see point 6). In the SoYield DSS case study, the legal framework pertaining to the use of personal data collected played an important role during the research and development phase and for the preparation of the business model and the terms of services of the innovation.

3.3 Adopting a flexible research and development strategy

The different partners may evolve in environments defined by very different time cycles. In our example, agricultural research in OFE is by nature performed on long cycles (multiple seasons/years), while the decision support tool market for the private partner may face various market opportunities per year, which is a fast time step in comparison with horticultural research. In the middle, farmers use the solution on a season-to-season basis, while also needing to adapt to rapid environmental and economic changes, adding a third timescale. Thus, a certain amount of flexibility is required to fill the time gap between the expectations of applied research, the private sector and users. One solution is to anticipate as best as possible the research activities to be performed, keeping in mind that these differences in development cycles may open opportunities towards the complementarity of R&D activities. Flexibility and adaptability can be reached by a high frequency of return to the field in order to ensure a regular monitoring of the context in which the value chain stakeholders evolve. Any change of context (e.g., climatic events, market variation) must be identified in order to best adapt the tool for the next production cycle. At the research level, a research activity is mainly achieved depending on whether it is being funded or not. However, a research center can also make a deliberate choice to dedicate non-funded research time to the development of the innovation, based on (i) financial retribution contingent on the commercial success of the innovation and (ii) a firm belief in the positive impact of the innovation on the value chain (i.e., strategic priority) and novelty of the innovation. Consequently, flexibility can be achieved by alternating between crucial activities supported by a cluster of funded projects and the self-financing of strategic research activities or research fronts (i.e., research aimed at developing new options to the tool such as fruit maturity assessment and fruit sizing estimation in our case) over a longer time period.

3.4 Designing with the users from start to finish

The development of DSS often leads to misadapted solutions that are not relevant to the users. In Africa, for several reasons, including poor technological infrastructure, inappropriate policies, and the low level of user skills — especially of farmers — in using the technologies, DSS developed without user inputs are quickly abandoned or have only a minor adoption rate (Ayim et al. 2022). User-centered design and co-design approaches are key elements of OFE that enhance the development and scaling-up of digital solutions (Abras et al. 2004). Even if the technological challenge of developing a relevant solution is essential, it should never overshadow the efforts of designing a tool that is needed and usable by the users, especially by farmers in their fields. Indeed, any technology, regardless of the level of innovation, is useless if the intended target is unable to handle it or has no use for it. User adoption is particularly challenging in Africa where the structure and nature of the farming systems and smallholders are highly variable. This variability implies that even at the farmer level, there will be heterogeneity in the type of users, depending on the economic importance of the targeted crop (e.g., cash crop, subsistence crop), the type of market targeted (local or international, fresh or transformed), and the technical and logistical constraints, as well as access to communication services (smartphone, internet) (Ayim et al. 2022). To maximize adoption of the SoYield® DSS, we focused on the user's experience and involved them in the processes from the very beginning of the project: as of the ideation and prototype phase, and then regularly during the development of the tool, until the *beta*-testing iteration phase, and up to the evaluation of the tool.

First, the long OFE experience acquired by our team (value chain functioning, mango cropping systems, interviews with farmers) can be considered as the first user inputs in the development of the decision support tool. Then, the design of key proto-personas assisted by the intervention of two farmers and one support services institute (see above) helped to define the features of the tool to be developed. The presentation of an un-designed draft of the DSS on paper (Fig. 1c) permitted a first round of feedback from different users identified as belonging to each group of proto-personas. This work can be considered as an early *beta*-test phase because it provided a critical contribution to the design and development of the tool. Second, the storyboard of the user experience of the DSS for each type of user (proto-persona) was designed in order to anticipate user' expectations as best as possible, according to an approach of design thinking (Urbieta et al. 2021). Moreover, these storyboards made it possible to "bring the IT developers to the field" in order to clarify the user experience and validate, through the coherence of the story of the use of the DSS, the relevance of the proto-persona (Sumberg et al. 2013). Third, multiple surveys were undertaken to assess the expectations anticipated of the personas compared to the reality of the interviewees. This approach avoids deviating too much from field reality in the definition of the product and is an essential iteration to consider the users' opinions and needs. For instance, for the development of the smartphone application of the SoYield® DSS, these surveys showed that 97% of farmers declared that immediate results were critical in adopting such a solution, and 81% of the respondents reported having access to a low-cost smartphone. Thus, real-time smartphone-based yield estimation became a priority for the SoYield® DSS to upscale. These surveys highlighted the importance of an innovative free-to-use bundled multilingual smartphone application designed for low-cost smartphones and low-connectivity environments, as highlighted in other studies (Ayim et al. 2022; World Bank 2019).

Once the surveys were carried out and their feedback considered, the personas were established and the expectations of the users were clear enough to move on to the design of a proper prototype. The prototype was designed based on the results of the surveys and the design thinking deliverables. The fourth user-centering step was the *beta*-testing of this prototype. The tool that was just developed was tested in situ by some pre-identified users, under the watchful eye and advice of the project team. The purpose of this process was to collect as much feedback as possible about the ability of using the tool by a user. This feedback was then gathered regarding the personas the users belong to, and the underlying problems of the feedback were synthesized and prioritized before being integrated for development in the next *beta*-version to be tested. This process was repeated as many times as necessary to achieve a satisfactory working prototype. In the user-centered approach adopted for the SoYield® DSS, user feedback literally sets the pace for the design and development of the tool.

Involving the users at all steps is time-consuming for both the project team and the users. Care should be taken to appropriately request the users to participate in the research and development processes. However, iterative conception at all the steps of the process is essential to either encourage the design and development or to refine the usability and relevancy of the tool developed (Abras et al. 2004). One way to overcome this issue is to seek the interest of the users in the project. In our case, rather than sharing analytical results on our models' performances or survey outputs (conventional statistics are of no use for most farmers), we constantly ask the users to evaluate if the DSS in development actually fulfilled their needs by using it in real conditions (i.e., with in-field mango production estimations).

3.5 Fostering scalability with an innovative business model

The "Go to Market" of such innovative tools is key to enable the digital transformation across all the actors of the value chain, particularly in the African market where the end-users range from smallholder farmers to big agribusinesses, representing a wide variety of skills (World Bank 2019). Understanding how all these stakeholders function is crucial in order to propose a targeted business model that merges high value propositions, profitability for the tool, and scalability. OFE is a big part of the user research, as previously mentioned, and makes it possible, through user surveys, to identify the needs of each actor and to quantify their potential in terms of investment of money in a digital solution rather than in inputs for their crops. The objective is to develop a business model that will (i) be adapted to the technical capacity of the farmers (use of mobile money, cash payments, etc.), (ii) optimize the attractiveness of the digital innovation for farmers, and (iii) allow the DSS to capture enough inputs (data, field feedbacks, users' experience and needs, etc.) to continue its technical development.

The solution implemented by the SoYield® DSS is to build a freemium business model where the free part is focused on the smallholder farmers obtaining more data on their fields, and the premium part on the agribusinesses who need the consolidated data of these farmers. The idea here is to create the virtuous circle of data where smallholders acquire enough information about their yields in order to have more leverage when faced with intermediaries, and to consolidate this data so that organizations like agribusinesses, exporters, governments, non-governmental organizations, and financial institutions acquire valuable information about where to find the fruit production they need. This in turn benefits the smallholders who are more visible when they need to sell their production or to negotiate with the financial institutions.

This virtuous circle of data is essential for the sustainability of the SoYield® DSS since it will build bridges between farmers, local buyers, research institutes, and governments, enabling the valorization of large amounts of data through platforms fed by OFE-based, citizen, and crowdsourced science (see point 7). As a result of a caveat regarding the use and valorization of aggregated personal data, linked with international and local regulations, this approach requires us to anonymize these datasets before processing and to provide aggregated data to the above organizations that would not allow them to pinpoint a specific farmer, unless the farmer authorizes it beforehand (see point 6).

The year 2022 was the first year that the SoYield® DSS was actually used. During that time, it accrued approximately 150 end-users, 280 orchards, 3500 ha with 32,000 tons of fruits estimated for two crops, and 11 cultivars in three countries (Senegal, Ivory Coast, Morocco).

3.6 Tackling data issues

The development of digital tools, especially those based on a data against service business model, raises the issue of data conformity — a legal obligation for companies operating under the laws and regulations of countries that have enforced personal data regulations. In some cases, the digital tool will fall under the scope of different regulations. For example, some digital tools will have to be both GDPR-compliant (European General Data Protection Regulation) if the company commercializing the tool is established in the European Union, but also respect the data protection laws of the country in which the tool will be commercialized if it is outside the European Union and a specific legislation exists. Other issues should be closely considered. For instance, the very definition of what an informed consent is, particularly among populations less aware of the value of their personal data and the stakes attached to their consent, can be a challenge. How to build trust with potential customers that are wary about the use of their personal data due to general concern or unsatisfying prior experiences with data against service business models is also an issue to be addressed. If these issues are to be considered to ensure compliance with data regulation laws, they are also crucial for companies that aim to adopt a more ethical stance on personal data collection and use. Beyond the moral prism of an ethical stance, immediate and lasting positive commercial outcomes can be sought out, such as ensuring better product adoption and securing customer loyalty over the long term.

Therefore, data protection is a key value of OFE and DSS and demands sufficient understanding of data values and challenges from all stakeholders. Developers must build the "data against service" business model with these issues in mind. The SoYield® DSS requires users to share personal data to provide its different services. Because the SoYield DSS will be commercialized by a company established in the European Union in countries outside of the European Union, the DSS developed has to be GDPR-compliant in its collection, storage, management, and use of data, as well as with the applicable national data protection laws of Senegal (for the moment, Ivory Coast does not have specific regulations). Moreover, the team aims to tackle the different issues pertaining to informed consent and building trust with its future users by seeking the help of data protection officers and legal experts to better understand and comply with the regulations, interviewing future users or *beta*-testers, and organizing brainstorm meetings where solutions are proposed and analyzed in light of the different stakeholders' points of views. Analyzed solutions include providing different levels of services compared to a more or less permissive use of each user's data; identifying different ways of providing sufficient information to the user on how their data will be used in order to tackle issues such as lack of general knowledge on the subject, illiteracy, or language barriers; seeking alternate solutions where consent may not be given, such as data anonymization; and determining the appropriate trade-off between data privacy and market valuation.

3.7 Yes, science and OFE are compatible

At first glance, science may seem incompatible with OFE because it requires controlled conditions that participatory experiments in farms do not allow. Similarly, one may think that the OFE approach has to keep a distance from science because the innovations that result from science are generally top-down. However, even if the results of OFE science might be considered to be of limited value by scientific peers (Kool et al. 2020), innovative projects must consider the knowledge, needs, and interests of farmers, while dealing with real-life environments at the same time that are way more complex than controlled environments. Facing the complexity of the real world is a key challenge for agronomical research today. OFE makes it possible to address this issue by bridging science-based (artificial intelligence and agronomical models) and farmer-based (field experiences, practices) knowledge together in order to solve the issues of stakeholders in more scale-relevant, non-top-down and innovative ways. Thus, the spatio-temporal diversity of real-world conditions implies that OFE-based research is more suitable for real-life applications.

OFE has existed for a long time but is starting to gain popularity in institutional research. The idea is to break the barrier between the production of knowledge issued from fundamental science, and the production of innovations accessible to all and evaluated by participatory methods and protocols (Stitzlein et al. 2020). In the coming decades, citizen and crowdsourced science based on digital data collection tools (such as PlantNet® or Inaturalist® apps) already has and will continue to have many opportunities to prove its efficacy to achieve reliable science (Beza et al. 2017). The experience with the SoYield® DSS supports the idea that science and OFE are compatible and that each can benefit from the other. During the project, two Ph.D. theses were conducted in the field to produce knowledge and to calibrate and/or validate models based on in situ data, allowing for more effective models adapted to local conditions (e.g., farmers' practices, orchard structure, cultivar grown).

During the research process, co-designing with farmers that have socio-technical knowledge and local experience of the fields helped to build scientific protocols adapted to the agro-environmental, social, and value chain context. For instance, yield estimation based on sampling models in complex orchards where multiple mango cultivars are grown implies knowledge of the farmer's preferences and practices between estimating the yield of the orchard by cultivar or all at once. Thus, understanding farmers' experience is a prerequisite for developing relevant models, making an innovation functional. However, to incorporate both farmers' and researchers' knowledge into a functional solution can lead to difficulties since they exist in different reference frames and require great effort to be seamlessly merged. On the technological side, having the constraints of in-field use can lead to innovation breakthroughs (the SoYield® smartphone application is planned to have an embedded IA in order to limit white spot issues), as well as to scientific opportunities (the next models to be developed are fruit sizing, yield forecast, fruit maturity, etc.). Ultimately, OFE is about challenging current research practices so that they better incorporate the value chain actors and meet their expectations. Usually, a top-down approach is used that is reversed in OFE. This changing paradigm is currently happening and will promote more applied research and development centered on the main issues faced by farmers worldwide.

3.8 Forecasting potential impacts on society and value-chain functioning

When considering impacts, digital innovations differ from other technological innovations. For example, they are often not time- and place-restricted (Heeks 2018). They can reduce or remove existing boundaries and hierarchies in agricultural systems or create new ones (ibid). Thus, digital technologies have a strong disruptive potential for agricultural innovation systems (Ezeomah and Duncombe 2019). They can generate both positive and negative, direct and indirect effects for users and non-users. There is indeed a growing recognition of the "dark side" of digitalization in the agricultural sector in the global South (see, e.g., Coad et al. 2020; Klerkx and Rose 2020). Studies in the field of information and communication technologies for development have shown, for example, that data-driven technologies can lead to new inequalities (Heeks 2018) and even a sort of new colonialism (Schopp et al. 2019). Thus, anticipating these impacts and their effects on farmers' livelihoods is critical, but can be difficult. For example, Iazzolino and Mann (2019) analyzed the consequences of Kenyan smallholder farmers' easier access to financial services. They showed that access to these services initially increased farmers' inclusion but, in the long run, led to decreased access to financial services and increased the vulnerability of farmers who could not repay their debts. As McCampbell et al. (2021) pointed out, it is therefore essential to anticipate the short- and long-term impacts of digital innovations. Indeed, anticipation is one of the four dimensions of responsible innovation, along with inclusiveness, reflexivity, and responsiveness (Stilgoe et al. 2013). This requires, among other things, "defining who is responsible for anticipation, when and with whom is present" or "considering and understanding the possible consequences of an innovation with the stakeholders and defining the moral values and rights involved" (McCampbell et al. 2021). Several methods, such as the Impress approach (Blundo-Canto et al. 2019), were developed to reflect on the impacts of innovations generated by research by actively involving the various stakeholders and the users who will be affected. Anticipation and evaluation of the direct and indirect impacts of digital innovation are therefore key issues, which makes it possible to reflect on their implications for future users and non-users, and to verify that the initial objectives and ambitions were achieved (de Roo et al. 2019).

Although not specifically measured yet, the forecasting of potential impacts of the SoYield® DSS was widely discussed by the researchers and developers of the project. The project team naturally reflected on the impacts of the solution, even if finding the forecasting methods to measure potential impacts was difficult at some point (especially the indirect ones). Based on the information and needs of the field users, the project team sought to understand what the impacts of the solution might be to the value chain actors, particularly for farmers. For the latter, the effects could be easily predictable, especially in terms of increased fruit sales, e.g., by measuring their harvest loss and predicting the impact of yield prediction on marketing, or by using a potential market place for mangoes. In this context, OFE and interaction with end-users interestingly improved the understanding of potential impacts of the solution. However, the prediction of benefits is more difficult at higher and longer-term scales because the solution has not yet been sufficiently tested. Predicting the negative impacts is not straightforward either. For example, assessing how the SoYield® DSS can eventually unbalance the mango market in Africa will require the implementation of an appropriate methodology. Measuring impacts is also more complex for more qualitative criteria such as the benefit of OFE in the relationship between the research institute and the private firm.

3.9 Funding OFE research

For agricultural innovation projects, finding funders for an OFE project can be critical. The implementation of OFE projects may seem longer due to the multiplicity of parties involved who must find a common synergy. It is almost impossible to find funders to finance the time needed to build a solid working relationship and framework, whereas, as described above, it is one of the key steps for the success of such projects. In addition, the scientific basis of the SoYield® DSS OFE process brought together different thematics from ecophysiological modeling, agronomy, statistics, social science, and computer science that require a variety of experts. In contrast, top-down innovations seem easier to implement because it is a matter of replicating and promoting a solution that was developed and works in one context (e.g., in an experimental station) in a new context.

However, it is important to note that top-down innovations have reached their limit and that their impact remains limited compared to the investments (Berthet et al. 2018). This fact constitutes one of the major criticisms of the top-down approach. The OFE approach allows a more consistent impact due to its user-centered design. The challenge is to attract funding for innovations based on the OFE approach. To do so, it is necessary to demonstrate the benefits and impact of OFE in terms of science, innovation, impacts, and return on investment for all actors (from users to developers). The multiplicity of actors involved in OFE approaches should make it possible to diversify the sources of financing and to involve, for example, NGOs, farmer organizations, the private sector, national and international public institutions, and research centers.

In the case of the SoYield® DSS, the primary investors are the research center and private company that developed the DSS, as well as two national R&D funders (see the "Funding" section below). However, several other actors have shown that they would become financially involved once the *beta*-test phases are over. These interests highlight the importance of iteration and field validation included in the OFE approach. The fact that the SoYield® DSS is a digital solution developed for and with the stakeholders of the value chain must be used as arguments to attract funds.

3.10 Digital OFE as a booster of research and innovation

One of the difficulties for agronomic and environmental research is to be able to acquire data in sufficient quantity and with sufficient accuracy to describe the diversity of the observed environments. In addition, data can be expensive to acquire in terms of labor and time if, for example, acquisition is based on traditional methods of measurement (e.g., visual counting of tree yield). Digital tools are seen as an opportunity to improve research and innovation by improving the repeatability of data acquisition, analysis and dissemination. In the field of agricultural and environmental research, digital technology can support the characterization and understanding of complex systems. Because of their adaptability and reliability in describing farming contexts, OFE-based digital solutions facilitate data acquisition and scaling-up that can be used by researchers. Many digital solutions were developed to be used in a participatory mode in order to increase the acquisition and feedback of data used for research purposes (e.g., PlantNet®, Plantix®, Inaturalist®).

In the example of the SoYield® DSS, research is motivated by the added value of acquiring data in a more reliable way and with a higher throughput than traditional methods of yield assessment. In this specific case, the OFE design makes it possible to have data and solutions validated in the field, with the objective of being diffused to the largest number of users. Eventually, thanks to this tool, a stream of crowdsourced data will be put in place and made available for research. User-centered design, field iteration and validation ensure the reliability of such data upstream. In the longer term, digital tools can be used to address key agricultural research and development issues (e.g., food security, climate change) in regions where data is currently still scarce (Sarron et al. 2022).

4 Limitations of the study and insights for future research

If the reflexive monitoring exercise conducted allowed to identify 10 key lessons to facilitate shared value creation in OFE processes with farmers, it still presents some limitations that open up perspectives for future research. First, it should be noted that such a reflective monitoring exercise, even when combining multiple sources of data as is the case in this article, can be influenced by the subjectivity of the participants (Mruck and Breuer 2003) or biases in data collection or analysis. For example, it is possible that some actors did not dare to publicly report certain collaboration difficulties encountered during the OFE process for fear of jeopardizing their organization or offending certain partners. We sought to limit these biases by proposing anonymous individual interviews where the participants would feel more comfortable reporting difficulties or failures.

Second, it is necessary to emphasize that the decision support system created during the OFE process is still in its infancy, even though it is used by some 150 users. Future research could verify in several years whether this DSS has lasted and produced the expected effects and impacts; and whether participants identified new challenges to create shared value in an OFE process.

Third, it should be noted that the list of ten key lessons practices presented in this article is not intended to be exhaustive. Other practices that promote shared value creation have been identified by OFE stakeholders but have not been included in the list because they appear to be less of a priority for successfully conducting an OFE process.

Finally, this list of key lessons may need to be adapted to fit other types of OFE and contexts. Where data on the organizational aspects of other OFE cases were present in the existing literature, we discussed them in the previous section, thus establishing the validity of these key lessons in other situations. Nevertheless, as pointed out by Richardson et al. (2021), there is no one-size-fits-all operational recipe for OFE. We therefore invite OFE practitioners and researchers to test and complement these key lessons to facilitate the implementation of OFE in order to create shared value in agriculture in various contexts.

5 Conclusion

OFE processes can become a vehicle for transformational change in agriculture and contribute to the development of innovative technologies (including digital technologies) that meet farmers' expectations and interests. Moreover, placing farmers at the center of the research and development processes, producing farmers' demand-driven research, and involving farmers in the ideation, creation, development, implementation, and testing processes are critical to maximize tool adoption and further impacts. However, these OFE processes are often hampered by organizational and managerial challenges that stem mainly from the diversity of the stakeholders involved. Yet, these challenges remain little studied. The authors of this article (i.e., employees of the research centers and the private firm) have therefore mobilized a reflexive monitoring approach to analyze the development process of an OFE initiative that they implemented and managed in order to develop the SoYield® digital DSS. This reflexive monitoring process resulted in the identification of ten key lessons to facilitate the implementation of OFE processes in order to create shared value. As such, this article lays the foundation for reinforcing a community of practices on OFE implementation and for promoting its development worldwide, as envisioned by Lacoste et al. (2022). It shows that when well-managed, the diversity of the stakeholders involved in OFE offers unique opportunities to co-innovate and create shared value.

Acknowledgements We thank the two anonymous reviewers for their helpful and insightful comments that helped to significantly improve this manuscript.

Authors' contributions For each role, the authors are listed in alphabetical order.

- Conceptualization: Chloé Alexandre, Emile Faye, Rkha Chaham Hamza
- Methodology: Chloé Alexandre
- Investigation: All authors
- Writing — original draft: Chloé Alexandre, Emile Faye
- Writing — review and editing: All authors
- Funding acquisition: Emile Faye
- Visualisation: Chloé Alexandre, Emile Faye, Léa Tresch
- Supervision: Chloé Alexandre, Emile Faye

Funding This work was supported by the French National Research Agency under the Investments for the Future Program, with the project #DigitAg, referred to as ANR-16-CONV-0004, and by the Région Occitanie, France, with the PixFruit® app project (ESR-PREMAT-00224).

Data availability Audio records of interviews and some secondary data reports may be provided by the authors at the reader's request, subject to the consent of the interviewees and the developers of the SoYield® decision support system.

Declarations

Ethics approval This article does not contain personal or sensitive data that require ethics approval.

Consent to participate and for publication Informed consent was obtained from all individual participants in the study. The authors affirm that research participants provided consent for publication of this article.

Conflict of interest The authors declare no competing interests.

References

Abras C, Maloney-Krichmar D, Preece J (2004) User-centered design. In: In Bainbridge W (ed) Encyclopedia of human-computer interaction. Sage Publications, Thousand Oaks

Aker JC, Ghosh I, Burrell J (2016) The promise (and pitfalls) of ICT for agriculture initiatives. Agric Econ 47:35–48. https://doi.org/10.1111/agec.12301

Alexandre C (2023) Digital technologies with untapped potential to facilitate farmers' learning: a study of eleven digital agricultural advisory services in Burkina Faso. Innovations 70(1):49–81. https://doi.org/10.3917/inno.pr2.0139

Alexandre C, Toillier A, Mignon S (2022) Exploring the nature of dynamic capabilities and enabling environments for service innovation in the Global South: the case of digital agro-advisory services in Burkina Faso. J Innov Econ Manag 39(3):241–273. https://doi.org/10.3917/jie.pr1.0127

Anderson NT, Walsh KB, Wulfsohn D (2021) Technologies for forecasting tree fruit load and harvest timing—from ground, sky and time. Agronomy 11:1409. https://doi.org/10.3390/agronomy11071409

Arkesteijn M, van Mierlo B, Leeuwis C (2015) The need for reflexive evaluation approaches in development cooperation. Evaluation 21(1):99–115. https://doi.org/10.1177/1356389014564719

Ayim C, Kassahun A, Addison C, Tekinerdogan B (2022) Adoption of ICT innovations in the agriculture sector in Africa: a review of the literature. Agric Food Secur 11(1):1–16. https://doi.org/10.48550/arXiv.2006.13831

Baumüller H (2018) The little we know: an exploratory literature review on the utility of mobile phone-enabled services for smallholder farmers. J Int Dev 30:134–154. https://doi.org/10.1002/jid.3314

Bellon-Maurel V, Huyghe C (2017) Putting agricultural equipment and digital technologies at the cutting edge of agroecology. OCL 24:D307. https://doi.org/10.1051/ocl/2017028

Berthet ET, Hickey GM, Klerkx L (2018) Opening design and innovation processes in agriculture: Insights from design and management sciences and future directions. Agric Syst 165:111–115. https://doi.org/10.1016/j.agsy.2018.06.004

Beza E, Steinke J, Van Etten J, Reidsma P, Fadda C, Mittra S, Mathur P, Kooistra L (2017) What are the prospects for citizen science in agriculture? Evidence from three continents on motivation and mobile telephone use of resource-poor farmers. PloS ONE 12(5):e0175700. https://doi.org/10.1371/journal.pone.0175700

Blundo-Canto G, Triomphe B, Faure G, Barret D, de RomemontA HE (2019) Building a culture of impact in an international agricultural research organization: process and reflective learning. Res Eval 28:136–144. https://doi.org/10.1093/reseval/rvy033

Borianne P, Borne F, Sarron J, Faye E (2019) Deep mangoes: from fruit detection to cultivar identification in colour images of mango trees. arXiv:190910939. Accessed 21 April 2021

Burke M, Lobell D (2017) Satellite-based assessment of yield variation and its determinants in smallholder African systems. Proc Natl Acad Sci. https://doi.org/10.1073/pnas.1616919114

Carletto G, Ruel M, Winters P, Zezza A (2015) Farm-level pathways to improved nutritional status: introduction to the special issue. J Dev Stud 51:945–957. https://doi.org/10.1080/00220388.2015.1018908

Chaurasia SS, Kaul N, Yadav B, Shukla D (2020) Open innovation for sustainability through creating shared value-role of knowledge management system, openness and organizational structure. J Knowl Manag 24:2491–2511. https://doi.org/10.1108/JKM-04-2020-0319

Chesbrough H (2019) Open innovation results: going beyond the hype and getting down to business. Oxford University Press, Oxford

Chesbrough H, Lettl C, Ritter T (2018) Value creation and value capture in open innovation. J Prod Innov Manag 35:930–938. https://doi.org/10.1111/jpim.12471

Coad A, Nightingale P, Stilgoe J, Vezzani A (2020) Editorial: the dark side of innovation. Ind Innov 1–11. https://doi.org/10.1080/13662716.2020.1818555

Cook S, Cock J, Oberthür T, Fisher M (2013) On-farm experimentation. Better Crops 97:17–20

Cook S, Jackson EL, Fisher MJ, Baker D, Diepeveen D (2021) Embedding digital agriculture into sustainable Australian food systems: pathways and pitfalls to value creation. Int J Agric Sustain 0:1–22. https://doi.org/10.1080/14735903.2021.1937881

de Roo N, Andersson JA, Krupnik TJ (2019) On-farm trials for development impact? The organisation of research and the scaling of agricultural technologies. Exp Agric 55:163–184. https://doi.org/10.1017/S0014479717000382

Ezeomah B, Duncombe R (2019) The role of digital platforms in disrupting agricultural value chains in developing countries. IFIP Adv Inf Commun Technol 551:231–247. https://doi.org/10.1007/978-3-030-18400-1_19

Fabregas R, Kremer M, Schilbach F (2019) Realizing the potential of digital development: the case of agricultural advice. Science 366:eaay3038. https://doi.org/10.1126/science.aay3038

Heeks R (2018) Information and communication technology for development (ICT4D) (1st ed), Routledge, New York

Iazzolino G, Mann L (2019). Harvesting data: who benefits from platformization of agricultural finance in Kenya? Blog Developing Economics. https://developingeconomics.org/2019/03/29/harvesting-data-who-benefits-from-platformization-of-agricultural-finance-in-kenya/. Accessed 21 April 2022
Klerkx L, Rose D (2020) Dealing with the game-changing technologies of Agriculture 4.0: how do we manage diversity and responsibility in food system transition pathways? Glob Food Sec 24:1–7. https://doi.org/10.1016/j.gfs.2019.100347
Klerkx L, Jakku E, Labarthe P (2019) A review of social science on digital agriculture, smart farming and agriculture 4.0: new contributions and a future research agenda. NJAS - Wageningen J Life Sci 90–91:100315. https://doi.org/10.1016/j.njas.2019.100315
Kool H, Andersson JA, Giller KE (2020) Reproducibility and external validity of on-farm experimental research in Africa. Exp Agric 56(4):587–607. https://doi.org/10.1017/S0014479720000174
Lacoste M, Cook S, McNee M et al (2022) On-farm experimentation to transform global agriculture. Nat Food 3:11–18. https://doi.org/10.1038/s43016-021-00424-4
Lioutas ED, Charatsari C, La Rocca G, De Rosa M (2019) Key questions on the use of big data in farming: an activity theory approach. NJAS - Wagening J Life Sci 90–91:100297. https://doi.org/10.1016/j.njas.2019.04.003
McCampbell M, Schumann C, Klerkx L (2021) Good intentions in complex realities: challenges for designing responsibly in digital agriculture in low-income countries. Sociol Rural. https://doi.org/10.1111/soru.12359
McGahan AM, Bogers MLAM, Chesbrough H, Holgersson M (2021) Tackling societal challenges with open innovation. Calif Manage Rev 63:49–61. https://doi.org/10.1177/0008125620973713
Mendes J, Pinho TM, Neves dos Santos F, Sousa JJ, Peres E, Boaventura-Cunh J, Cunha M, Morais R (2020) Smartphone applications targeting precision agriculture practices—a systematic review. Agronomy 10(6):855. https://doi.org/10.3390/agronomy10060855
Millstone E, Van Zwanenberg P, Marshall F (2010) Monitoring and evaluating agricultural science and technology projects : theories, practices and problems. IDS Bull 41(6):75–87. https://doi.org/10.1111/j.1759-5436.2010.00185.x
Minshall T, Mortara L, Valli R, Probert D (2010) Making “Asymmetric” partnerships work. Res Technol Manag 53(3):53–63. https://doi.org/10.1080/08956308.2010.11657631
Mruck K, Breuer F (2003) Subjectivity and reflexivity in qualitative research—the FQS issues. Forum Qualitative Sozialforschung Forum: Qual Soc Researc 4(2):14. https://doi.org/10.17169/fqs-4.2.696
Ollila S, Elmquist M (2011) Managing open innovation: exploring challenges at the interfaces of an open innovation arena. Creat Innov Manag 20:273–283. https://doi.org/10.1111/j.1467-8691.2011.00616.x
Porter ME, Kramer MR (2011) Creating shared value. Harvard Business Review. https://hbr.org/2011/01/the-big-idea-creating-shared-value. Accessed 21 April 2021
Richardson M, Coe R, Descheemaeker K et al (2021) Farmer research networks in principle and practice. Int J Agric Sustain 0:1–18. https://doi.org/10.1080/14735903.2021.1930954
Rouyre A, Fernandez A-S (2019) Managing knowledge sharing-protecting tensions in coupled innovation projects among several competitors. Calif Manage Rev 62:95–120. https://doi.org/10.1177/0008125619885151
Saito K, Diack S, Dieng I, N’Diaye MK (2015) On-farm testing of a nutrient management decision-support tool for rice in the Senegal River valley. Comput Electron Agric 116:36–44. https://doi.org/10.1016/j.compag.2015.06.008
Sarron J, Malézieux É, Sané CAB, Faye É (2018) Mango yield mapping at the orchard scale based on tree structure and land cover assessed by UAV. Remote Sensing 10:1900. https://doi.org/10.3390/rs10121900
Sarron J, Beillouin D, Huat J, Koffi JM, Diatta J, Malézieux É, Faye E (2022) Digital agriculture to fulfil the shortage of horticultural data and achieve food security in sub-Saharan Africa. Acta Horticulturae 1348:239–246. https://doi.org/10.17660/ActaHortic.2022.1348.33
Schön DA (1984) The reflective practitioner: how professionals think in action. Basic Books, USA
Schopp K, Schelenz L, Heesen J, Pawelec M (2019) Ethical questions of digitalization in the global south : perspectives on justice and equality. TATuP - Zeitschrift Für Technikfolgenabschätzung in Theorie Und Praxis 28(2):11. https://doi.org/10.14512/tatup.28.2.s11
Stefan I, Hurmelinna-Laukkanen P, Vanhaverbeke W (2020) Trajectories towards balancing value creation and capture: resolution paths and tension loops in open innovation projects. Int J Proj Manag S0263786320300442. https://doi.org/10.1016/j.ijproman.2020.06.004
Steinke J, van Etten J, Müller A, Berta Ortiz-Crespo B, van de Gevel J, Silvestri S, Priebe J (2020) Tapping the full potential of the digital revolution for agricultural extension: an emerging innovation agenda. Int J Agric Sustain 1–17. https://doi.org/10.1080/14735903.2020.1738754
Stilgoe J, Owen R, Macnaghten P (2013) Developing a framework for responsible innovation. Res Policy 42(9):1568–1580. https://doi.org/10.1016/j.respol.2013.05.008
Stitzlein C, Fielke S, Fleming A, Jakku E, Mooij M (2020) Participatory design of digital agriculture technologies: bridging gaps between science and practice. Rural Ext Innov Syst J 16(1):14–23
Sumberg J, Heirman J, Raboanarielina C, Kaboré A (2013) From agricultural research to ‘product development’ what role for user feedback and feedback loops? Outlook on Agriculture 42(4):233–242
Urbieta M, Firmenich S, Zaraté P, Fernandez A (2021) Web-augmentation, design thinking, and collaboration engineering to foster innovation in DSS for agriculture: a case study. In: Agriculture value chain-challenges and trends in academia and industry. Stud Syst Decis Control, vol 280. Springer, Cham, pp. 1-18. https://doi.org/10.1007/978-3-030-51047-3_1
Wiseman L, Sanderson J, Zhang A, Jakku E (2019) Farmers and their data: an examination of farmers’ reluctance to share their data through the lens of the laws impacting smart farming. NJAS - Wagening J Life Sci 90–91:100301. https://doi.org/10.1016/j.njas.2019.04.007
World Bank (2019) Future of food: harnessing digital technologies to improve food system outcomes. World Bank Report, Washington, DC. https://doi.org/10.1596/31565