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ENGAGING FARMERS IN DIGITAL CO-INNOVATION PROCESSES IN AGRICULTURE IN BENIN

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Abstract

Co-innovation is often considered the most suitable innovation process in digital agriculture, yet empirical evidence on how it operates remains limited. This paper examines farmers' engagement in digital co-innovation processes in agriculture. Using purposive sampling, actors involved in digital co-innovation were identified. Data were collected through participant observation and semi-structured individual interviews and analyzed using a mixed-methods approach combining content and discourse analysis. The findings reveal that digital co-innovation involves not only farmers but also two other key actor categories: leaders and intermediaries. Leaders play a central role in initiating, planning, organizing, and coordinating the co-innovation process, while farmers contribute knowledge and contextual information to adapt digital innovations to local needs. Intermediaries facilitate the flow of information and knowledge between leaders and farmers. The co-innovation process unfolds in four phases: ideation, planning, prototyping, and usage. Although farmers are actively involved throughout these phases, their participation remains predominantly informational, consultative, and deliberative, and less oriented toward decision-making. Strengthening farmers' decision-making participation in digital co-innovation could enhance the adoption and effectiveness of agricultural innovations.

Keywords: Digital co-innovation, Agriculture, Engagement, Process, Benin.

1. Introduction

In recent years, multi-actor approaches have gained significant attention, emerging as a new paradigm in various fields. Consequently, issues of participation (Geza et al., 2021), inclusion (German et al., 2020), knowledge sharing and co-creation (van Ewijk et al., 2021; Moumouni & Labarthe, 2012), and co-innovation (Eriksson et al., 2023; Klimas & Czakon, 2022) have received particular attention. In agriculture where innovation is crucial for sector development (Onumah et al., 2022), innovation processes hold equal importance. Several theories are indeed interested in it (Gouroubera et al., 2022). Within this dynamic of pluralistic approaches, co-innovation in agriculture is particularly significant, having made substantial progress over the past decade (Lacombe et al., 2018). It is commonly referenced in discussions on agricultural issues (Klerkx et al., 2017) as a process where researchers collaborate with other stakeholders to produce innovations (Klerkx et al., 2017). This recent paradigm of collaborative innovation (Saragih & Tan, 2018) arises from the limitations of traditional innovation approaches that reduced farmers to mere users. Such classical approaches often faced challenges in adaptability and effectiveness. In contrast, co-innovation allows for the diagnosis of these issues in advance, facilitating the development of more effective innovations.

Particularly, digital co-innovation in agriculture is strongly recommended (Pigford et al., 2018; Klerkx & Rose, 2020; Agyekumhene et al., 2020; Ebrahimi et al., 2021; Jakku et al., 2022), especially in a context where digital agriculture is considered as revolutionary force (Barrett & Rose, 2022). Despite its benefits for farmers widely demonstrated (Rockström et al., 2017; Anderson, 2020; Barrett & Rose, 2022; Saiz-Rubio & Rovira-Más, 2020; Garske et al., 2021), uncertainties have emerged from this digital agriculture. These uncertainties relate to the effectiveness of proposed digital solutions, which are weakened by farmers' limited digital capacities (Dantan et al., 2018), lack of internet access in rural communities (Bernhardt et al., 2021), poor usability of digital solutions (Tata & McNamara, 2018), and the limited flexibility these solutions offer farmers. Gouthon et al. (2024) has really shown these digital inequalities among farmers in Benin. Additionally, the social sustainability of introduced digital solutions in agriculture remains uncertain (Agyekumhene et al., 2020; Ebrahimi et al., 2021). Consequently, the adaptability of digital innovations raises a real challenge. To face these uncertainties, digital co-innovation in agriculture is so strongly advocated. This innovation process, by engaging stakeholders—including farmers—allows the identification of uncertainties upfront (Paget et al., 2022) and incorporates them into the development of digital innovations. Involving farmers in innovation processes is therefore seen as the most appropriate approach in digital agriculture (Chen et al., 201d9). The engagement of farmers in innovation processes, increases the likelihood of achieving a digital innovation that meets the real needs and contexts of farmers. Therefore, digital co-innovation in agriculture is a determinant of the success of digital innovations. Scientific research must provide extensive knowledge to enhance understanding and application of this process.

In contrast, the available knowledge on digital co-innovation in agriculture is sparse. Most scientific works addressing this topic have focused on highlighting the relevance of this process rather than providing deeper insights for understanding and implementing it. Acknowledging this significant knowledge gap, Klerkx et al. (2019) assert that evidence from participatory approaches involving farmers in digital innovation processes in agriculture remains limited. This study aims to contribute to knowledge on what seems little explained in

literature. Furthermore, research perspectives indicate the need for replication of co-innovation studies in other contexts (Scaringella & Radziwon, 2018; Valkokari, 2015), further underscoring the importance of this research.

Using a case study approach, this paper analyzes the engagement of farmers in digital co-innovation in agriculture by (i) examining the actors, their respective roles and the process. Klimas and Czakon (2022) have already recommended that future studies on co-innovation should address this aspect. (ii) Then, we will analyze the gap between what is ideally expected from farmers in a co-innovation process and their observed engagement in the studied process.

2. Theorical and analytical frameworks

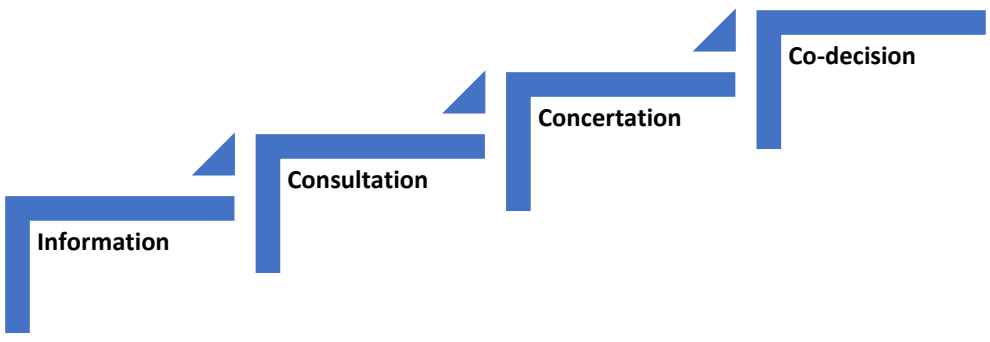
Co-innovation is a collaborative process that engages stakeholders in the development of innovations (Saragih et al., 2019). Before focusing on the specific type of digital co-innovation in agriculture, it is essential to grasp the generic fundamentals of the concept. Co-innovation fundamentally relies on collaboration, complementarity, coordination (Bitzer & Bijman, 2015), co-creation, and convergence (Saragih & Tan, 2018). Collaboration highlights the actors involved in the co-innovation process and their interconnections. van den Broek et al. (2018) emphasize that collaboration facilitates relationships among actors and the creation and learning of knowledge within the engaged stakeholders. Abhari et al. (2017) consider collaboration as a key dimension in designing and managing co-innovation. Thus, collaboration is a crucial factor in co-innovation, which must be intense throughout the process (Fieldsend et al., 2022). Complementarity underscores the convergent combination of various innovations developed at different levels, contributing to the primary innovation to be co-constructed. These innovations can be technical, institutional, or organizational in nature (Bitzer & Bijman, 2015, Moumouni & Idrissou, 2013, Egah et al., 2014). Therefore, knowledge complementarity is necessary in a co-innovation process (Fieldsend et al., 2020), allowing for the convergence of knowledge and resources toward a common goal. Coordination highlights the production and harmonization of activities, linking actors to the resources and knowledge produced. Kormelinck and Bijman (2016) summarize co-innovation as the coordination of innovations developed at various scales. To co-construct an innovation, the different contributions brought by various actors must be oriented toward a shared objective. That is why Lee et al. (2012) also support the importance of convergence in the co-innovation process. Meanwhile, co-creation refers to the ability to engage various stakeholders in developing an innovation (Busser et al., 2019).

In summary, these characteristics illustrate that co-innovation involves actors, interactions, and respective contributions. With this clarification of the generic concept of co-innovation, alongside the definition of digital agriculture as the use of digital tools in agriculture (Rotz et al., 2019), we propose a definition of digital co-innovation in agriculture. It is a collaborative process through which actors from the agricultural and digital sectors, including farmers, converge their respective resources to develop a digitally presented innovation aimed at agricultural purposes. It is often highlighted as the innovation process that addresses the uncertainties related to digital agriculture (Knierim et al., 2019; Klerkx & Rose, 2020; Ebrahimi et al., 2021; Pigford et al., 2018). Optimistic discourses suggest that it is the most suitable process in digital agriculture (Chen et al., 2019). This process is considered as such due to the engagement of farmers, which allows for diagnosing potential obstacles to the effectiveness

of digital solutions in advance and taking them into account. The engagement of farmers thus becomes a central factor, leading us to explore its scope through the theories that frame it, particularly those related to participation.

Indeed, in decision-making processes, participation, we have distinguished four levels of participation, as outlined in the work of Karavagna (2013): information, consultation, concertation, and co-decision. Each of these categories plays a crucial role in stakeholder engagement and the quality of decisions made. The first level, information, involves the dissemination of relevant data to stakeholders. This phase is essential for establishing a common knowledge base. In the context of environmental governance, increased transparency and access to technical information are fundamental for improving decision-making quality (Bulkeley & Mol, 2003). However, at this level of engagement, the informed individual only assumes the role of a receiver of information without the ability to provide input. On the other hand, consultation represents a stage where stakeholders are invited to express their opinions and concerns. Studies show that well-designed consultation processes can enrich the decision-making process by incorporating diverse perspectives and improving the quality of outcomes (Beierle, 2002). However, it is crucial that these consultations be conducted in a way that ensures fair representation of all voices to avoid information asymmetries that could distort the process (Frère & Zwarterook, 2016). Concertation, on the other hand, goes beyond simple consultation by seeking to establish a consensus among different stakeholders. This approach is particularly relevant in complex contexts. Concertation processes may sometimes face challenges, particularly due to the fragmentation of actor groups, which can hinder the effectiveness of the decisions made (Mazurek et al., 2019). Therefore, it is imperative to structure these processes in a way that promotes constructive and inclusive dialogue (Hassenforder et al., 2021). Finally, decision-making is the ultimate level of participation, where stakeholders have an active role in choosing the options to be implemented. At this stage, the individual involved in decision-making has already been informed, consulted, and deliberated with. This represents a higher level of engagement. However, it is essential that these processes be designed to encourage genuine and meaningful participation, rather than symbolic, to ensure that decisions truly reflect the needs and priorities of the communities involved (Durand et al., 2021). This general knowledge on participation thus serves as a theoretical foundation to rank the level of engagement of farmers in the process of digital co-innovation in agriculture, as shown in Figure 1.

Figure 1: Framework for analyzing farmers' engagement



3. Methods and materials

3.1. Presentation of a case study

AGriCef Maïs is a digital innovation developed through a co-innovation process as part of DigiCLA project (AGriCef, a digital solution for more effective and efficient ecological management of the Fall Armyworm [FAW] in Northern Benin). This digital innovation exemplifies a case of digital co-innovation in agriculture, justifying its selection. Indeed, DigiCLA project is proposed and implemented by a consortium composed of the private company TIC Agro Business Center (TIC ABC), the NGO Eclosio and the University of Parakou (Benin) through the Research Laboratory for Innovation in Agricultural Development (LRIDA), which leads the initiative. The project's goal is to promote large-scale, sustainable adoption of digital and agroecological practices among young maize producers to increase yields and production in northern Benin. To achieve this, the project promotes *AGriCef Maïs*, primarily designed to provide to farmers, agricultural advice for the ecological management of FAW.

This digital innovation results from a lengthy co-innovation process involving various stakeholders. It is available as an application for smartphone users, as a voice messaging system for users of basic mobile phones, and through video projections for those without mobile phones. The application has five main functionalities: “Best Practices and Techniques” provides farmers with a set of best practices for soil fertility management, maize production, and conservation. “Farm Management” helps users manage their farm accounts and reminds them of production activities and relevant dates. “Input Suppliers” lists suppliers of agricultural inputs and their respective addresses, allowing farmers to contact the nearest supplier based on their geographic location. “Community” connects users who speak the same language, enabling them to share agricultural experiences and interact with each other. “FAW Management” allows farmers to diagnose FAW attacks and offers agroecological management methods for the pest.

The application version of the innovation is available on the PlayStore, while the voice messaging system is accessible via a dedicated phone number for those without smartphones. The agroecological methods delivered through these mobile-based tools, are available as audios and videos translated into local languages. Video projections, designed for farmers without phones, are carried out by the managers of digital service kiosks, conceptualized under the name "Digikiosk," established by the project. The application, the voice messaging system and the video projections are therefore variants of the digital innovation *AGriCef Maïs*, resulting from the co-innovation process that serves as our case study in this paper.

3.2. Key informants

The research unit consists of the actors involved in the co-innovation process that led to the *AGriCef Maïs* innovation discussed above. Knowing exactly who these actors are, we employed purposive sampling to form our sample. This primarily includes members of the consortium implementing the DigiCLA project, specifically from LRIDA, TIC ABC, and the NGO Eclosio. Additionally, farmers themselves are included as key stakeholders. Within each of these organizations, actors at various levels have been selected for the sample. Table 1 provides a clearer overview of key informants for this research.

Table 1: Key informants

Actors	Sample individuals	Number
LRIDA	Director of the Laboratory / Coordinator of the DigiCLA Project	01
	Plant Protection Officer	01
	Sustainable Land Management Officer	01
TIC ABC	Director of the Company	01
	Assistant to the Director	01
Eclosio NGO	Coordinator	01
	Monitoring and Evaluation Officer (M&E)	01
	Facilitators	02
Farmers	Key Farmers Involved in the Process	10

3.3. Data collection

3.3.1. Participatory observation

Comprehensive monitoring of the co-innovation process allowed the use of participatory observation as a data collection method to gather necessary observable data. There are two types of observation utilized in data collection: participatory observation and direct observation (Kawulich, 2012). The former requires interaction between the researcher and the subjects being studied, making the researcher both a participant and an observer. In contrast, direct observation involves the researcher observing without interacting with the subjects. Participation in various co-innovation activities necessitated exchanges with engaged actors to better understand or verify the accuracy of certain observed data. Thus, participatory observation proved to be the most suitable method for this study. Using a designed observation grid, participation in planning workshops, co-construction meetings, project evaluations, and deployment missions allowed for insights into the actors involved in the process and their respective roles. Participatory observation also facilitated the identification of the phases and stages that constitute the digital co-innovation process leading to the *AGriCef Maïs* innovation. Non-observable data were collected through semi-structured interviews.

3.3.2. Semi-Structured Interviews

Semi-structured interviews primarily assessed the interactions among the actors involved in the digital co-innovation process in agriculture. Through individual interviews, these sessions collected information on the types and dynamics of relationships developed during the process, any conflicts encountered, their management strategies, and the resources and knowledge contributed by each actor to the innovation's development. The semi-structured interviews also clarified how the respective contributions of stakeholders were harmonized to result in the *AGriCef Maïs* digital innovation.

3.4. Data Analysis

For this study, various methods and analytical tools were employed based on the nature of the collected data and their intended purpose. Three specific objectives are associated with this research. To analyze (i) the actors and their roles in the digital co-innovation process in agriculture, qualitative data were analyzed using qualitative methods. Content analysis was

applied to observed data, while discourse analysis was used for interview data. These analyses enabled the clear mapping of stakeholders and their respective contributions to the innovation's development. Conversely, for analyzing (ii) the co-innovation process itself, observed data proved particularly useful. Content analysis helped reconstruct the chronological steps and sub-steps of the process.

4. Results

4.1. Actors and roles

Various players are involved in the process of digital co-innovation in agriculture. It should be remembered that the digital innovation developed through the co-innovation process studied aims to help farmers in the agroecological management of FAW. The analysis carried out for this purpose, allows to distinguish three (03) types of actors, conceptualized as follows: (i) leaders, (ii) beneficiaries of the process who are the farmers and finally (iii) intermediaries. In a co-innovation process, farmers are the most expected actors. It's their involvement that gives co-innovation its full meaning. They have indeed been engaged in this process, but to what extent?

(i)Leaders are those actors who are at the helm of the digital co-innovation process in agriculture. They are the first leaders of the agricultural research (LIRDA), non-governmental (NGO) and digital business (TIC ABC) organizations involved in the co-innovation process. A heterogeneous college of agricultural and digital actors then leads the co-innovation process. As a single actor, these leaders initiate, plan, organize and coordinate the digital co-innovation process in agriculture. Initiation is associated to the consolidation of ideas to develop digital innovation to face agricultural concern. Planning refers to the pre-definition of the activities and actors required for co-innovation, organization highlights the various negotiations involved in actually carrying out these activities, while coordination refers to the orientation of individual contributions towards the same goal, the development of digital innovation. This leadership is observed not only jointly. Individually, these leaders lead their respective organizations to play their part. LRIDA has conducted research that has contributed, both from a digital and agricultural perspective, to the development of digital solutions. The other leaders have also brought theirs to fulfill their respective responsibilities. The ones were responsible for the digital aspect in the development of digital innovation (TIC ABC) and others, for supporting farmers in the use of innovation in its forms (NGO Eclosio). Two types of leadership were then observed during this co-innovation process: global leadership, which federates the contributions of all actors in the process, and sectoral leadership, which is more specific to each level of the process.

(ii) The beneficiaries, i.e. the farmers themselves, are one of the actors involved in the process of digital co-innovation in agriculture. They are the actors for whom the results of the co-innovation process are intended. Above all, they have brought adaptability to the digital innovations developed. From a digital point of view, their inclusion in the process allowed to realize the needs and digital inequalities between them, and to take them into consideration during the co-innovation process. They contributed to co-define the functionalities of digital solutions, and the forms they will take. From an agricultural point of view, their involvement in the identification, testing and validation of agroecological methods disseminated through digital tools, helped to reassure of their adaptability and adoption. Farmers have certainly been engaged in the co-innovation process, but their participation has largely remained

passive rather than active. They have often found themselves on the sidelines of decision-making spheres, adopting a posture of appreciation toward the proposals of the leaders in the process. This situation has limited their ability to genuinely influence the innovations that concern them. From a digital perspective, their engagement has been very minimal. However, a higher level of engagement on their part would be essential to develop truly accessible digital solutions tailored to their needs. By fostering more active participation, farmers could not only benefit from innovations but also contribute to shaping tools that better address the challenges of the sector. From an agricultural standpoint, although they have been more engaged, their level of involvement is not without criticism. This passive role assigned to farmers has made the co-innovation process quite constrained and has led to innovations that were largely pre-defined by the leaders, albeit adjusted in some areas.

(ii) Those we refer to as intermediaries in the process of digital co-innovation in agriculture, are also members in the above-mentioned structures, with the difference that they are hierarchically inferior to the leaders. They are research assistants, NGO facilitators, digital technicians. While the leaders play a strategic and responsible role, the intermediaries are much more operational. The term “intermediaries” is not an arbitrary one. Indeed, they act as a bridge between the process leaders and the farmers. In the development of digital innovation, they essentially channeled resources, knowledges and contributions from the farmers to the leaders, and in return had the leaders' resolutions implemented at farmer level. Factually, they facilitated FFS and other research work. They facilitated the collection of inputs needed to design digital innovations, and supported farmers in their use.

4.2. Phases of digital co-innovation process in agriculture and famers engagement

4.2.1. Ideation phase

The ideation phase is the one that results in the initiative to develop a digital solution to an agricultural problem. It is mainly carried out by the leaders of the digital co-innovation process, i.e. the actors in the agricultural sector and those in charge of the digital component. It began with (i) analyzing the context and choosing a problem of interest. Stakeholders’ analysis led to the idea of developing a digital solution in response to the extensive damage caused by FAW. These actors then (ii) defined and analyzed the specific needs of farmers that enable to respond effectively to this problem. They agreed that the digital solution should provide farmers with effective and appropriate methods for agroecological management of FAW, good agricultural production practices in general. It must also meet farmers' needs in terms of managing their operating accounts, accessing inputs, and creating virtual communities for sharing farming experiences. This ideation phase ended with (iii) the identification of other stakeholders to be involved in the process. It is at this stage that the actors we refer to as “intermediaries”, as well as farmers, are included in the process. During this phase, in which farmers were also involved, they were engaged from two complementary perspectives: one based on the level of engagement (consultative engagement) and the other based on the content (diagnostic engagement).

The consultative engagement in this ideation phase allowed for the gathering of farmers' opinions on the relevance of FAW (Fall Armyworm) as an agricultural constraint, as well as their views on the initiative to address it through digital solutions. The engagement of farmers at this ideation stage was therefore not decision-making. Although their role was not decision-

making, their input was invaluable in confirming whether this issue was indeed a major barrier to agricultural production and whether there was a real opportunity to address it through a digital response. It thus helped refine the initial diagnosis made by the leaders of the process. Therefore, the diagnostic engagement observed in this ideation phase refers to the consultative role of farmers, but also to how it enabled the leaders to solidify a confirmed diagnosis regarding one of the relevant agricultural issues and a potentially useful digital solution for the targeted communities. These farmer engagements thus helped lay the groundwork for the next phase by strengthening the legitimacy and viability of the initiative.

However, a decision-making engagement or concerted engagement by farmers, which would have been more active than the one observed in this ideation phase, would have ensured that the developed initiative truly addressed their pressing priorities and specific challenges. By being directly involved in the decision-making process, they could have influenced the very definition of the problem to be tackled, ensuring that the chosen initiative was relevant and truly adapted to their needs. This would have strengthened their sense of ownership of the initiative, ensuring that it was aligned with their goals and the realities of their farming practices. Furthermore, their active involvement would have promoted better acceptance of the actions to be undertaken, increasing the chances of long-term success. Finally, this engagement would have legitimized the action by ensuring that the decision to address this issue came from those who are directly affected by it.

4.2.2. Planning phase

Having agreed on the need to develop a digital solution for FAW's agroecological management, the leaders then planned the rest of the process. First, together with the farmers, they (i) chose the digital technology to be developed. Cause of digital inequalities among farmers, it was decided that the digital solution would take the form of an application for smartphone owners, a voice messaging system for farmers using simple phones, and projected videos for farmers with no phone at all. (ii) The various functionalities to be integrated into these digital tools and the different digital services to be provided to farmers, in line with the specific needs previously identified, have been co-defined with farmers. Also, in order to ensure effective use of these digital tools, (iii) their usage process is also defined, again with farmer participation. All these forecasts are then (iv) formalized in a set of specifications, to serve as a roadmap for the actors in charge of designing these digital tools, particularly those in charge of the digital component. During this planning phase, we recorded informational**,** consultative and predictive engagement from the farmers.

On aspects related to the digital dimensions of the solutions to be co-constructed, farmers were only weakly involved. Their role was primarily that of information receivers, which characterizes informational engagement. They were informed about the technological choices being considered, but they had no direct influence on the selection of digital technologies to be developed. Decisions regarding the tools to be used were largely made by the leaders of the process. This informational engagement kept farmers updated but did not give them an active role in defining the technologies to be deployed. However, regarding the definition of the functionalities of the digital solutions to be developed, which is also part of the planning phase, a consultative engagement approach was adopted. Farmers were consulted to ensure that the proposed functionalities of the solutions effectively addressed their specific needs in managing FAW. For example, discussions took place between the leaders and farmers about

the different local languages for translating the videos to be broadcasted through the digital technologies. At this stage, their role was to provide feedback on the proposed functionalities to ensure they were adapted to the constraints and realities of their daily work. This consultative engagement allowed the process leaders to consider the real needs of the farmers while refining the technical characteristics of the solutions to be developed. Both informational and consultative engagements helped plan the digital and agricultural aspects of the digital solutions, leading us to understand that, to some extent, the farmers' engagement was also predictive in nature.

A farmer engagement beyond simple consultation would have ensured an active involvement in the definition and co-construction of the digital solutions. By being directly engaged in the decision-making process, farmers could have significantly influenced the choice of technologies to develop and the functionalities of the proposed tools. This would have also enhanced their sense of ownership of the project, thus increasing the chances of buy-in and adoption of the digital solutions. Such engagement would have also facilitated the identification of more innovative and sustainable solutions, while ensuring better alignment with future challenges in managing FAW.

4.2.3. Prototyping phase

This is the third phase of the process. This is the phase in which what has been jointly defined takes shape. It is carried out by one of the leaders, the one in charge of the digital component. This involved firstly (i) developing the digital supports for the chosen tools. The application and messaging system have been developed, but at this stage, don’t yet contain the agricultural content intended to help farmers in the agroecological management of FAW. This content is also being (ii) mobilized by agricultural stakeholders with the participation of farmers, who also attest to the relevance and adaptability of this agricultural content to their needs and contexts. This content is essentially agroecological methods to be promoted through digital tools. To this end, research involving farmers is being carried out to assess the most effective methods. Other methods known and relevant to farmers are also identified. Images are also taken, all of which is then (iii) digitized and introduced to the digital supports to result in a first version of the planned application and messaging system. Some videos of these relevant methods were also put on other support for projection. The first two tools, in particular, are (iv) tested in the field with farmers. Adjustments are made accordingly and a better version of the digital solution, presented in these three forms, is available at the end of this phase.

During the prototyping phase, which was primarily focused on the design of agricultural and digital solutions, a clear lack of engagement from farmers in the digital dimension was observed. Indeed, farmers were almost entirely absent from the development of the digital tools and the digitization of agricultural content, areas that required specialized digital skills, which they did not possess. These tasks were solely handled by the digital actors involved. However, in the mobilization of agricultural content, farmers were much more actively engaged, going beyond mere consultation. They were involved in discussions with other stakeholders, such as during the Farmer Field Schools process, where farmers tested the effectiveness of certain agroecological methods for managing FAW. These activities, carried out directly in the farmers' villages, allowed for their strong involvement, not only in monitoring the tests but also in evaluating the results obtained. The methods deemed

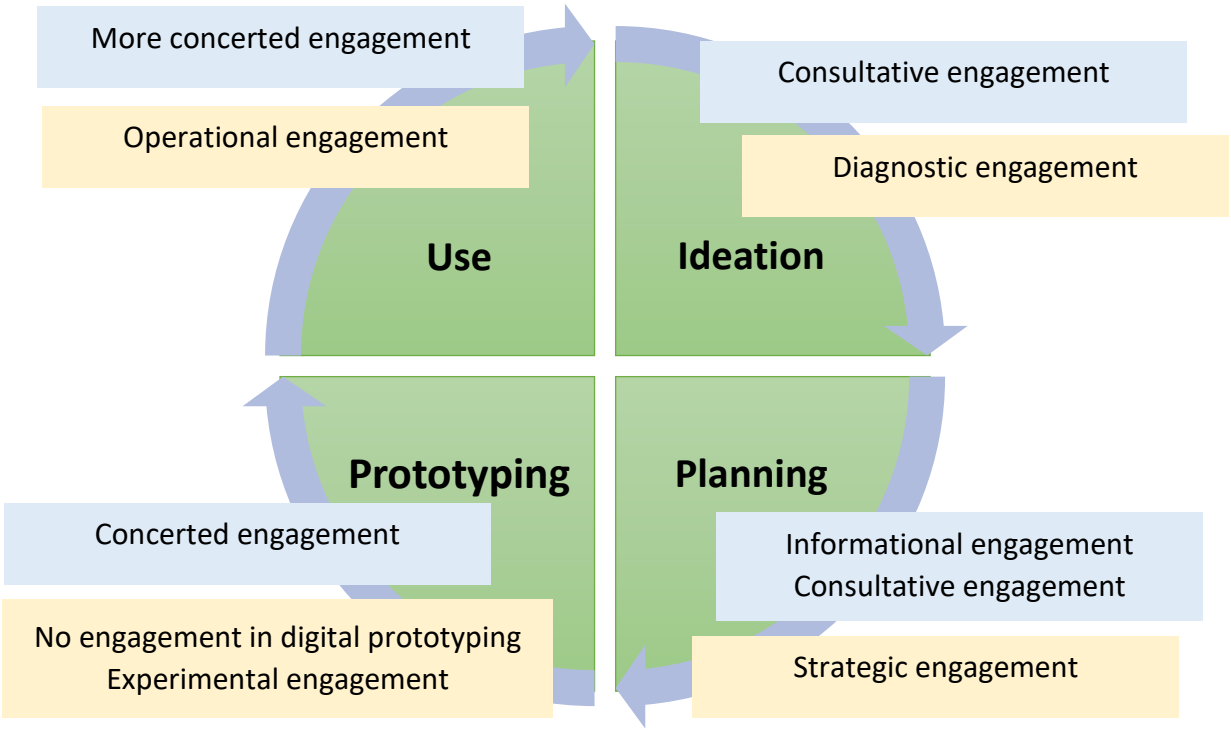
effective were then translated into videos, incorporated into the digital tools, and disseminated through the developed technologies. Thus, this phase revealed an absence of engagement in the digital design of the tools, but a concerted engagement from farmers on the agricultural aspects. Furthermore, these engagements were mainly experimental, aimed at validating and testing the solutions. Farmers' involvement in the testing process helped identify the imperfections of the developed digital solutions and led to improvements. In summary, the prototyping phase was characterized by a lack of engagement in technological design, followed by concerted engagement on the agricultural side and experimental engagement in evaluating and adjusting the solutions.

4.2.4. Use phase

This is the phase that gives meaning to co-innovation. At the end of the prototyping phase, the digital solution (*AGriCef Maïs*) in its various forms must now be introduced to the target community. So, farmers are first (i) trained both theoretically and practically in the use of these digital tools (Application and voice messaging system), which are then (ii) deployed. The manager of Digikiosk, who is a member of the farming community and chosen by the farmers, also trained, project videos for farmers. These trained managers (iii) continually support farmers in accessing and using *AGriCef Maïs* in its forms.

The usage phase was marked by a concerted engagement from the farmers, which was both more spread out and more structured than in the previous phases. Prior to this phase, all the stages of co-innovation involved regular consultations between the farmers and the lead actors of the process. For example, the training sessions on using the digital technologies were carefully planned with the farmers to ensure that the training met their specific needs and was tailored to their field realities. These sessions included not only theoretical aspects of the technologies but also practical applications, allowing farmers to familiarize themselves directly with the digital tools. Furthermore, the Digikiosks, which are digital devices enabling access to innovations resulting from this co-innovation process, operate within an ongoing framework of consultation between farmers and other stakeholders. This continuous interaction allows farmers to fully take ownership of these tools and incorporate them into their daily lives. In this phase, the engagement of farmers shifts to an operational engagement, where they are directly involved in the use of the developed digital innovations. In other words, farmers are no longer merely participants in the development or testing of the tools; they become the primary users, integrating these innovations into their day-to-day management of FAW. This marks an evolution in their role, placing them at the heart of action and the implementation of the co-constructed solutions. Figure 2 summarizes the phases of the digital co-innovation process in agriculture and the types of engagement observed among farmers at each phase.

Figure 2: Farmer's engagement in the different phases of digital co-innovation process in agriculture



5. Discussion

The strong endorsement of digital co-innovation in agriculture could create the illusion that it's a ready-made, mechanical and ready-to-use solution. Many challenges litter this collaborative innovation process (Klerkx and Nettle, 2013). Specifically, we focused on the involvement of farmers in this process and the findings reveal that their engagement is globally passive.

Indeed, digital co-innovation in agriculture is a process in which different actors, farmers in particular, have jointly contributed to the development of an innovation in digital form, intended for agricultural purposes. According to our fundings, farmers are engaged passively. To reach this conclusion, we examined the other actors involved in the process and their respective roles. Apart from the farmers, the leaders who drive the process and the intermediaries who facilitate the transition between the two are the actors involved in the digital co-innovation process in agriculture. Klimas and Czakon (2022) argue that leadership is a role played by certain actors in co-innovation process. Gouroubera et al. (2023) also mention this leadership role in the use of digital technologies in agriculture. However, farmers were essentially assigned to assessing the adaptability and applicability of the leaders' agricultural proposals in co-innovation process. The identification of the problem for which it is decided to provide a solution is carried out without the farmers decision, thus creating opportunities to develop a digital solution for which the need may exist, but is not sufficiently pressing. Farmers had also little involvement in the digital aspects of innovation development. This leads us to describe farmers' involvement as passive. They appreciated what was proposed to them, rather than proposing it themselves. Improving the level of involvement of farmers in

both agricultural and digital aspects of digital co-innovation in agriculture thus becomes a challenge for leaders in such a process, which nonetheless has its own specificities compared to other types of co-innovation. Furthermore, it must be recognized that the contexts in which these digital co-innovation processes in agriculture take place, especially in developing countries, also favor this partial involvement of farmers in the development of digital innovations. ACED (2023) indicates, for example, that 76% of digital solutions available in Benin are supported by subsidies. At the same time, Tsan et al (2019) postulate that the emergence of digital agriculture on the African continent is significantly linked to development partners. These donors generally lunch calls for projects with clearly defined deadlines. Applicants seeking to secure this as yet uncertain funding, bow to the demands of stiff competition, which only gives them the resources to put together a project that is only theoretically relevant, in which the ideas for digital solutions must already be formulated without the farmers. If funding is obtained, farmers will only be involved in the execution phase, when ideas are already very well developed, thus distorting the co-innovation process.

What are the inherent specificities of the digital co-innovation process in agriculture? One clearly apparent specificity of the digital co-innovation process in agriculture is its significant heterogeneity. While Weststar (2015) describes video game developers as a unique social group deeply rooted in social relations within the industry, the digital co-innovation process in agriculture exhibits a highly hybrid innovation ecosystem. Indeed, the stakeholders come from quite distant sectors—some from agriculture and others from digital technology. This combination of actors within a single innovation system might have once seemed implausible, but it is a reality today. As a result, the contributions of stakeholders are specific to their respective sectors, making digital co-innovation in agriculture a particularly sensitive and fragile innovation process. The materialization of innovation in this context includes a programming sub-stage, that requires specific skills, completely excludes other stakeholders. Consequently, the realization of digital innovation is heavily dependent on the digital actor, despite the efforts made by other participants. This strong reliance on a single actor contributes to the sensitive and fragile nature we attribute to this process in digital agriculture. This digital actor thus has a central responsibility. This is supported by findings from ACED (2023), which reveal that TIC ABC, a private company operating in the digital sector in Benin, is the most influential actor in the country’s digital agriculture landscape.

6. Conclusion

In this study, where we primarily analyzed farmers' engagement in the digital co-innovation process in agriculture, we initially conducted an analysis of the actors and their roles, as well as the phases of the process itself. Indeed, apart from the farmers, actors classified as "leaders" and "intermediaries" are those involved in the process. During the phases of ideation, planning, prototyping, and usage that constitute the digital co-innovation process in agriculture, farmers' engagement is informational, consultative, and concerted, but not decision-making. The decision-making spheres were more occupied by the leaders. However, these levels of engagement served purposes such as diagnosis, strategic planning, experimentation, and operationalization of digital solutions throughout the process. These levels of engagement created opportunities to get ineffective solutions. However, the ideal type of farmer engagement in a digital co-innovation in agriculture remains a challenge that other studies could further investigate.

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Statement of No-Conflict of Interest

The authors declare no conflict of interest in the paper.

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