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Digital revolution for the agroecological transition of food systems: A responsible research and innovation perspective☆

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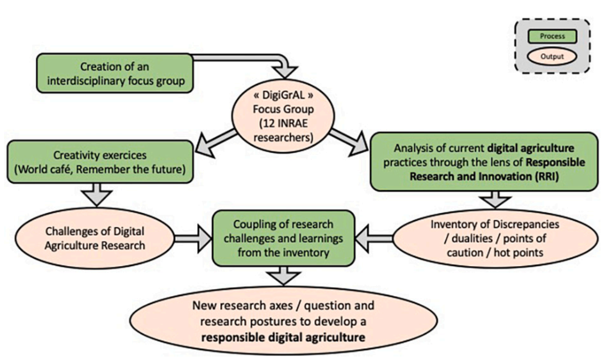
HIGHLIGHTS

- So far, research on digital technologies has focused on precision agriculture and has rarely addressed smallholders' issues.
- Our interdisciplinary group aims at building a research agenda to foster an agroecology-based digitalization of agriculture.
- Three lines of research were built in creative sessions and studied via Responsible Research and Innovation (RRI) principles.
- RRI helped us both to express original research questions and to raise key issues for correctly addressing them.
- RRI has been useful for building this research agenda on smart agriculture, by combatting researchers' own path dependency.

GRAPHICAL ABSTRACT



Acronyms: INRAE, National research institute for Agriculture, Food and Environment; RRI, Responsible Research and Innovation.

☆ The authors of this paper are researchers at INRAE, the French Research Institute for Agriculture, Food and Environment (INRAE addresses a wide range of interdisciplinary research topics that serve society, with particular focus on ethics and responsible research and innovation (RRI) issues. Agroecology is one of its major themes.) and since 2019 constitute DigiGrAL, a focus group, to reflect on the impact of digitalization on the agrifood chain and to stimulate interdisciplinary and responsible research on this hot topic. Veronique Bellon-Maurel and Evelyne Lutton head this group, and authors are listed in alphabetical order.

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ABSTRACT

CONTEXT: So far, digital technology development in agriculture has mainly dealt with precision agriculture, often associated with conventional large-scale systems. The emergence of digital agriculture - based on the triptych of "new data sources / new processing methods / new inter-connection capacities (internet)" - opens up prospects for mobilizing digital technologies to accelerate the deployment of other forms of agriculture, such as agroecology. A specific research agenda must therefore be built to redirect researchers specialized in digital technologies towards these new issues. This construction is significant because digital technology and agroecology are disruptive innovations that shake up the actors' practices, agricultural innovation ecosystems, and value chains.
OBJECTIVE: An interdisciplinary group of INRAE researchers (covering 10 scientific departments) was mandated to carry out this reflection, with the objective of developing a research agenda to better couple digitalization and agroecology, in order to pave the way for responsible digital farming. The group used the framework of responsible research and innovation.
METHOD: Over 18 months, the group met monthly by video-conference, to overcome the interdisciplinarity barrier, and at three face-to-face seminars, where creative design exercises were carried out (based on a world café format, and "remember the future" method). This work gave rise to three prospective lines of research aimed at putting digitalization at the service of agroecology and local food systems. These topics prioritize research that fosters innovations in digital technology, as well as organisations and policies that (1) accelerate the agroecological transition on the farm and in the territories, (2) manage the territories as commons, (3) empower farmers and consumers. Then, the group examined these three prospective lines of research from an RRI perspective as well as three current research topics on digital agriculture (digital soil mapping, precision agriculture, technologies for food wastage reduction).
RESULTS AND CONCLUSIONS: This work allowed us to highlight the gaps between current research on digital agriculture and the RRI expectations, and the tensions (between rationalization and diversity of farming systems, between complexity of agroecological systems and the need for simplification of models, and finally between data speculation and frugality). We were also able to refine the specific scientific questions of each prospective line of research and finally to draw attention to the key levers that will have to be integrated if these research efforts are to be approached from an RRI perspective.
SIGNIFICANCE: This contribution shows RRI can be used not only to reflect on research practices but also as a framework to build a research agenda paving the way for responsible digital agriculture.

1. Main motivations and objectives

Our starting point is found at the intersection - be it synergetic or antagonist? - between two transitions in agriculture, ecologisation and digitalization, which seems to be a recent and growing interest in the scientific community (Bellon-Maurel and Huyghe, 2017; Wittman et al., 2020; Schnebelin et al., 2021; Fraser, 2021; Ditzler and Driessen, 2022). Does the current digital revolution contribute to the ecological transition of agriculture and agri-food systems? This question is a matter of academic debates. Some papers, in line with political statements (FAO, OECD, see Lajoie-O'Malley et al., 2020) highlight the potential of digital technologies to support the ecologisation of agriculture - by providing new knowledge, improving the management of complex and diversified systems, fostering exchanges and innovations and reducing workload (Bellon-Maurel and Huyghe, 2017; Bonny, 2017) - while also renewing food chains (Jouanjean, 2019; Wittman et al., 2020).

But most social science papers are more critical about the compatibility between agroecology and digital technology (Bronson and Knezevic, 2016; Carolan, 2017; Rotz et al., 2019): digital technologies could lead to a loss of autonomy and knowledge, and to standardizing and homogenizing food systems, promoting high capital agriculture (Carolan, 2017) and reproducing current power balances, which are to the benefit of upstream and instream large corporations (Bronson and Knezevic, 2016). This would induce a form of path-dependency to the detriment of agroecology (Wolf and Buttel, 1996). Such ideas are often supported by ontological analysis (Plumecocq et al., 2018), empirical analysis of values and actor perceptions (van Hulst et al., 2020).

Paradoxically, in many contexts, digital technology adoption remains low (Barnes et al., 2019) and little is known about the interactions between digital and agroecological transitions (Klerkx et al., 2019; Schnebelin, 2022). This paradox stems from the fact that social sciences study the existing digital technologies in agriculture, which, until recently, were mainly dedicated to precision agriculture/ precision livestock, more suited to big capitalist farms, while prospective political and research analyses study how the digital assets, which emerged in the 2010s (multiplication of connected objects, smartphone diffusion, artificial intelligence, connectivity), make it possible to develop other avenues of agricultural digitalization, e.g. related to agroecology. Agroecology is described as a science, a movement, or an agricultural practice (Wezel et al., 2009), which encompasses production methods taking advantage of natural, ecological processes to produce and supports local and sovereign food systems. It has been more precisely defined by FAO (FAO, 2019a), based on 10 elements (diversity, recycling, efficiency, resilience, synergies, human and social values, co-creation and sharing of knowledge, culture and food traditions, circular and solidarity economy and responsible governance). INRAE has made digital sciences and agroecology two of the five main axes of its strategy (INRAE, 2020). Therefore, a crucial question is "how to put the digital revolution at the service of agroecology and agrifood systems?". In other words: how can new public research programs be built aiming to develop digital technologies that would support diverse trajectories of agroecology transition, while avoiding to contribute to a form of path-dependency by aligning digitalization to a standardised model of industrial agriculture?

The objective of this paper is to demonstrate how the theoretical advances in Responsible Research and Innovation (RRI) can foster the reflexivity of public institute researchers, and enhance their contribution to digitalization trajectories supporting the transition of agriculture towards agroecology.

2. Assumptions

Our main assumption is that public research is not neutral regarding the direction and speed of technological trajectories on economic sectors. Quantitative economists have been exploring for decades the complex relations between innovation and growth of a sector and investments in Research and Development (Griliches, 1979). More recent and qualitative research has highlighted that there are (power) relations between research and the dominant paradigm of a sector like, for instance, in wheat genetic engineering (Vanloqueren and Baret, 2009). Supporting reflexivity when designing a public research agenda that would contribute, directly or indirectly, to technical change in an economic sector is, therefore, essential (Cowan and Hultén, 1996). Equally, digital technologies in agriculture pose a challenge as they are both exogenous and disruptive. We hypothesize that RRI can serve our purpose of building a public research agenda on the digitalization of agrifood systems.

RRI is a rather new concept based on four principles upon which research & innovation processes should rely: inclusion (of stakeholders), anticipation (of risks), responsivity (to evolving context) and reflexivity (on the methods carried out) (Owen et al., 2012). It is challenging to apply, due to the variability of its definitions (Hahn and Ladikas, 2014). In the domain of digital agriculture, RRI has been reported only from the late-2010's (Eastwood et al., 2019; Rose and Chilvers, 2018; Bronson, 2019; Klerkx and Rose, 2020) and is currently put into practice in some European Research projects (projects FAIRshare or NIVA of the H2020 programme, for instance). In Australia, the RRI framework was used to assess the RRI dimensions of the innovation projects developed in the Digiscape Future Science Platform, a 6-year program (2016–2022) aiming at "harnessing the digital revolution for Australian farmers and land managers" (Jakku et al., 2022); after showing that the application of RRI was not straightforward, the authors synthetized recommendations to "operationalize" the RRI approach in digital agriculture projects. van der Burg et al. (2021) applied it to develop a research agenda for digital twins in agriculture. The purpose of our work is precisely to design a research agenda, more widely dedicated to digital agroecology, ie to the development of digital technologies and appropriate environment, in agriculture and associated supply chains. This idea relies on two contentions:

- Firstly, to take full advantage of digitalization and to avoid the tech fallacy (Kane et al., 2019), the design of a research agenda cannot be left to individuals: there is a need for collective thinking and learning;
- Secondly, this collective thinking must encompass a strong and large multidisciplinary dimension that associates agricultural sciences, economic and social sciences, and digital sciences (Regan, 2021).

These assumptions have been the basis to build a public research agenda in our institute INRAE (the French National Research Institute for Agriculture, Food and Environment). The main objective was to foster research on the digitalization of the agrifood system, which is scientific, relevant, trustable, and socially desirable.

3. Methodology

How to design a "responsible research" agenda in digital agriculture has been addressed by the authors, who have based their approach on the preceding assumptions, i.e., collective, and interdisciplinary reflexivity following the RRI principles, above-cited. The authors all work at INRAE, and in this first exercise, the focus group was limited to this group, highly interdisciplinary though internal to INRAE, mainly due to a tight schedule and the difficulties to meet in Covid time. This choice will be discussed in section 5.

Tricarico et al. (2020) make a distinction between (i) internal RRI, which is more focused on the design of the research lines of the project with interdisciplinary features and (ii) external RRI, which is more "innovation-oriented" and involves civil society stakeholders. We have developed an internal RRI approach that has been synthetized in Fig. 1.

3.1. Creating an interdisciplinary group

In 2019, the authors of this paper set up a 12-researchers focus group. The focus group is strongly interdisciplinary with representative experts from ten scientific departments of INRAE. Academic disciplines represented include: economics, cognitive psychology, food sciences, animal science, plant science, soil science, hydrology, ecology, agricultural engineering and applied mathematics. Activities took place in monthly visio meetings over 18 months and three face-to-face workshops including a special session on Responsible Research and Innovation (training and analyses), and two creativity and design thinking sessions, i.e. World Café, brainstorming and "remember the future" methods, which had been recommended to the group by a colleague from the Learning Planet Institute, a higher education institute dedicated to interdisciplinarity (https://learningplanetinstitute.org/en).

3.2. Designing a research agenda for digital agriculture dedicated to foster transition towards agroecology and sustainable food systems

Design thinking exercises were applied to allow prospective lines of

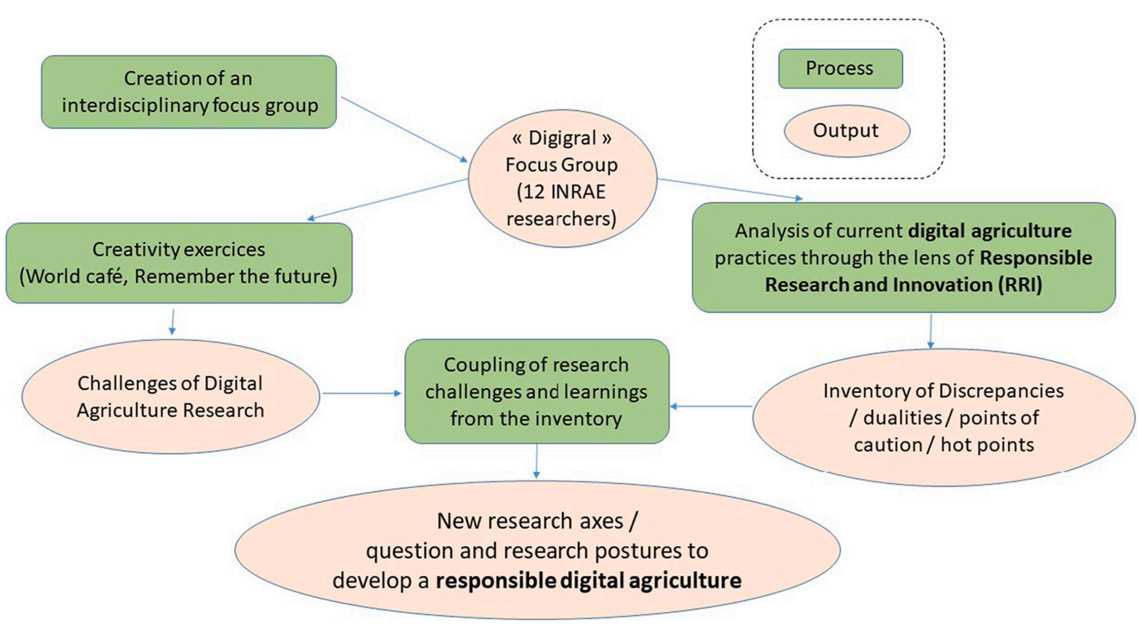

Fig. 1. The internal RRI process applied at INRAE to build a research agenda on responsible digital agriculture

research to emerge that were seen as principal challenges to be faced in the development of digitalization for sustainable food systems. Specific and strong ethical core values were set to guide design thinking, like the five ones identified by FAO,[1] namely: (i) food values (universal right for food), (ii) human well-being, (iii) human health, (iv) natural resource conservation (for further generations), and (v) limits of human power over nature. This led to the emergence of three main lines of research (see results).

3.3. Analyzing research related to digital agriculture through a RRI prism

To support our reasoning, we applied RRI to both existing research on digital agriculture and to three prospective lines of research for future development. We started by considering three examples of digital agriculture implementation which cover the whole agrifood system (upstream, instream and downstream agricultural production). These are 1) digital soil mapping (at it is a strategic asset for land management and for cropping system design on a farm); 2) precision agriculture and precision livestock farming (as these are tactical assets used to reduce inputs during production); and 3) digital tools for food wastage reduction (as food wastage contributes to the food environmental footprint, with 40–60% wastage at the distribution/ consumption steps of the food chain in developed countries[2]). We analysed them according to the four RRI principles, which led us to extract generic features intersecting all of them and outlining the tensions between ecologisation and digitalization, as already mentioned by other authors (Schnebelin et al., 2021; Rotz et al., 2019). Such tensions should be considered when designing a responsible research agenda for agricultural digitalization.

4. Results

4.1. Prospective research challenges to orientate future research

Three prospective research challenges for agricultural digitalization have emerged from the creativity and brainstorming exercises, which are considered by the group as key levers for the transition towards sustainable agrifood system, namely (1) Digitalization to accelerate agroecological transition at both the farm and territory scale, (2) Digitalization to place agriculture at the centre of fair management of territorial commons (natural and environmental risks, global warming), and (3) Digitalization to ensure empowering consumers and farmers in supply chains.

Challenge 1 (Accelerate the agroecological transition at both farm and territory scales) refers to digital technologies that accompany the farmers but also the local communities (farmers, local authorities, inhabitants) to engage and then manage agroecology both at territory level and in the farm. The farm scale (down to the plot / plant / animal scales) has been the target of precision agriculture, which can be seen as the precursor of today's digital agriculture, and therefore still appears to numerous stakeholders as the most obvious place to develop digital agriculture (Rijswijk et al., 2019). Considering the agroecological transition, digital tools help either the farm strategic setting (Colbach et al., 2017) or the operational management through sensors and decision support systems (Bellon-Maurel and Huyghe, 2017), or both (Colas et al., 2020). As the territory level plays a major role in agroecology (landscape management, circular economy of bioresources, collective management of natural resources), it should also be the focus of dedicated digital tools. First, these tools could help collectively design landscapes most adapted to agroecology, as the landscape scale has to be taken into account as the farm scale in agroecology (Smeding and Joenje, 1999; Petit et al., 2021). They may also help farmers and other users of natural resources (e.g. water) to better negotiate the share of these resources, in participative meetings aided by companion models (Barreteau, 2003). Last, the territory scale is the very one where circular economy is most relevant (Gonçalves et al., 2021), especially with organic matter exchanges, agricultural wastes of ones being turned into valuable resources for others; in that frame, digital technologies may help identifying resources and connecting people (Klerkx et al., 2019).

Challenge 2 refers to the fact that agriculture is at the crossing of private (i.e. the farmer's revenue) and collective (public) interests, linked on the one hand to the use of natural resources and on the other hand, on the delivery of services. As reminded in territories, the clash of individual and collective interests is increasingly frequent (Ryschawy et al., 2019) and has to be dealt with in a preventive mode whenever possible. Mediation assisted by digital technologies, e.g. computer simulation and visualization (Becu et al., 2008), can help stakeholders find trade-offs (Jackson et al., 2013). Ecosystem services assessment is expected to be improved in the future for more accurate payments to agriculture for delivery of ecosystem services (ES). Remote sensing could be used to directly account ecosystem services (e.g. Carbon content of soil), and data collected from on-farm digital technologies could be used for assessing ecosystem services. However, a prerequisite for using agricultural data as intervening variables is to have better models of agriculture–ES interactions (Green et al., 2021).

Challenge 3 deals with the disruption that digital technologies cause to supply chain, which changes the relationships between actors. At the end of the supply chain, it could empower consumers which can be embedded in product co-creation processes (Di Guardo and Castriotta, 2013) and be better informed about the products. At the bottom, in addition to be assisted in production (challenge 1) farmers can, on the one hand, develop new supply chains, finding brokers who pay higher prices (Kumarathunga et al., 2021) and being directly connected to consumers. Or, on the other hand, in classical supply chain, farmers can better communicate about their products through automatically generated guarantied labels (Wittman et al., 2020) and information about their environmental footprint (Bellon-Maurel et al., 2014).

For each challenge, a first set of research issues has been established (Table 1), in order to design "responsible digital agriculture". It is important to note that there are two blocks of questions; the upper one (general thematic research issues) refers to questions which are related to the objective of the design, i.e. the three thematic axes; the bottom one (RRI-based issues) refers to issues that will be more specifically encountered if a RRI approach is to be carried out to address those questions.

Common general issues related to the three thematic axes deal with the complexity of modelling of the system, which intertwins social, physical and cyber dimensions. (Rijswijk et al., 2021) consider the system complexification itself as a risk and propose to model those dimensions altogether in order to better anticipate. The second general issue deals with technical questions related to data collection and sharing. The scientific challenge will be to satisfy the trade-off between having specific and precise data on large spatial areas or numerous individuals (e.g. animals), without multiplying the sensors. The third issue refers to the way relevant metrics to assess the agroecological transition on a farm (FAO, 2019b) will be quantified using collected data and easily communicated to the stakeholders, although multivariate by essence. Last, but not least, data governance is a crucial question (Micheli et al., 2020; Carolan, 2017; Bronson and Knezevic, 2016) as data confers power to the one who has access to it and has the capacity to process it. Research in political and social sciences as well as philosophy and economy is necessary to address this last issue.

[1] https://www.fao.org/3/x9601e/x9601e03.htm

[2] https://www.madr.ro/docs/ind-alimentara/risipa_alimentara/presentation_food_waste.pdf

4.2. RRI analysis

The prospective research challenges have also been analysed through the filter of the four RRI principles. This led us to draw up a series of points that appear essential to the group to put RRI into practice to address the prospective lines of research (see Table 1). These points may have been seen also in preceding attempts to follow the RRI approach in smart farming (Regan, 2021; Rijswijk et al., 2019; Rijswijk et al., 2021).

The most difficult criterion to address appears to be anticipation of risks, as digital technologies are very disruptive and should be considered at the organization level (Rijswijk et al., 2019). Anticipation of risks is nevertheless essential to avoid "misconfigured innovation" (Fraser, 2021); this would lead to appropriate design not only of technologies, but also of organizations, as "*impacts can induce modifications of existing dynamics, both in the social and in the business context, causing a redistribution of risks, benefits, and burdens among actors*" (Rijswijk et al., 2021, p. 83). This would therefore give clues to build public policies in order to reduce the pace of the change of risks, benefits and burdens among stakeholders. Inclusion is also an issue as digital agriculture research is not only highly interdisciplinary - due to the "cyber" space

Table 1
Specific research questions and RRI special issues raised by applying RRI to the three prospective research axes.

	Prospective Research Axis (for developing digital technologies to foster agroecology)		
	Challenge 1: Accelerate agroecological transition at the farm and territory scale.	Challenge 2: Put agriculture at the center of fair management of territorial commons.).	Challenge 3: Empower consumers and farmers' roles thanks to digital networks.
General thematic research issues			
Common issues	• How to deal with the complexity of the systems, which is increased with agroecology and local food systems (vs monoculture & conventional global chains): impacts on modelling complexity, on uncertainty, etc.? How to switch food system modelling from optimization-driven models to resilience-driven models.? • How to design systems of data collection & sharing all along food system that ensures appropriate acquisition, with issues dealing with, e.g., spatiotemporal resolution, heterogeneity of sources, privacy (personal, strategic data), data quality, reuse. • How to build relevant information from collected (big) data, and to communicate to consumers. • How to manage power offered by access to information/data and power networks (data governance).		
Specific issues	How to create new knowledge thanks to automated and increased observations. How to create new models by combining formal models, data-driven models and the farmer's knowledge? How can decision support tools be designed to reconcile strategic objectives, resources, operating conditions, land management, and market and consumer demands? For tasks with lower added value (repetitive, tiring, dangerous), how can we develop robots that farmers can easily acquire, maintain and repair? What observation and diagnostic systems should be used to manage production systems with a holistic vision on the scale of a territory, while considering resources (water, circular economy of organic matter) / loads (induced pollution) of the territory?	How can the data collected and shared by the agricultural ecosystem (farmers, cooperatives, etc.) and citizens be processed to quantify ecosystem services to be paid to farmers? How can these data support public policies and justify changes? How can the territory's commons (water, biodiversity) be monitored and managed collectively thanks to digital technology? How to improve the human/ digital interface in the case of groups of users?	How will the value chains be transformed by digital technology, in particular the relationships and the balance of power between actors of the agri-food system (producers, processors, distributors, consumers, public authorities)? How can the sharing and transparency of information on food (agricultural production methods, processing and supply chains) be directed to increase the power of farmers and consumers?
RRI-related issues			
Anticipation: Common issues	How to use existing data/information/knowledge for prospective? What are the possible future controversies? How to ensure to set up a secure and fair data governance? How to anticipate public policies to accompany digitalization in these three areas (farms, territories, value chains)?		
Anticipation Specific issues	How to evaluate sustainability and the agroecological transition performance, using muticriteria tools (e.g. FAO, 2019b)? How to assess and take into account the environmental footprint of digital technologies? What is the responsibility of each actor when developing and using decision support tools? How to manage risk linked to uncertainty? How to deal with false alarms, information overload? How to improve the human/ digital interface?	How to deal with the tension between private / common/ public benefits (risks of the dominance of private economic interests among public ones, lack of aggregating metrics)?	How to ensure a good sharing of value created by digital technologies among all the actors.
Reflexivity Common issues	How to give access to appropriate, understandable, and secure information? How to design appropriate visualization (scales, uncertainty, needs for cognitive frugality)? How to deal with uncertainties? How to reconcile this increased complexity with the need for digital frugality?		
Reflexivity Specific issues	How can we integrate in models the biotechnical and pedoclimatic specificities, and strategic, environmental, ecological and economic objectives, while remaining sufficiently explicit to facilitate the participation of stakeholders (farmers, industrial processors, consumers, public authorities, decision-makers) and mobilize their knowledge? How to design interpretable and transparent models?	What is the role of the commons? What is a fair management of commons?	How can we build a stakeholder network ethics?
Responsiveness	How to evaluate responsiveness and improve it in a dynamic and uncertain context.		
Inclusiveness/ transparency	How to adopt a transdisciplinary posture? How to evaluate that actors involved are autonomous, free and diverse enough? How to share value/benefits created by the actors with the help of digital technologies, in an equitable way?		

which is superimposed to socio-physical space (Rijswijk et al., 2019) – but also calls for practitioners and public deciders to be included. This can pose a problem to certain scientists (Regan, 2021), and this will also have consequences about which stakeholders to involve in open innovation (Fraser, 2021). According to the role and function of stakeholder in the innovation process, one will also have to tackle challenges related to co-creation with multiple stakeholders, i.e. finding and engaging the appropriate stakeholders, conflict stemming from stakeholder diversity, and management of stakeholder co-created knowledge (Kazadi et al., 2016). The reflexivity criterion refers to the assumptions research has made and to the approach that has been followed. It differs from reactivity which is related to the capacity to adapt research orientations to a changing (technical, business, regulatory, political) environment. Reflexivity can be seen as a "control process" to regularly check that the three other RRI principles are followed. In the case of smart farming, reflexivity will also have to carefully monitor if the conditions for "creating positive impacts and counteracting negative effects of digital transformation" – i.e. "design, access and system complexification" (Rijswijk et al., 2021) are dealt with. The general reflexivity issues which emerged from the group were related to the system complexification (e.g. modelling uncertainties, reconciling complexity and frugality) and on the design (information delivery, visualization) (Table 1).

In addition, when attempting to design new lines of research to develop a responsible digital agriculture, two trade-offs seem particularly worthy of consideration:

- *Diversity* vs *rationalization.* Standing at the border between "chaos and order" helps complex systems to be adaptive and resilient (Chaté and Muñoz, 2014). For sustainability sake, it is clear that such a balance should be preserved or even encouraged in agrifood systems. However, as said in the introduction, current digitalization is often associated to rationalized systems of conventional – "industrial" – agriculture. We prone the development of digitalization that preserves a balance between monitored/controlled systems and more "disordered" ones, i.e., including a large diversity of biotechnical conditions and farmer's strategies. In addition to the preservation of diversity, this may also foster the whole food system adaptability and resilience (including supply chains, circular economy networks), respect for individuals, societies, and the environment, through an adapted governance, which will, eventually, result in a better acceptance by users. An essential feature is that, as there are different types of agriculture, there will be different types of digitalization.
- *Frugality* vs. *Speculation.* Digital agriculture often refers to (big) data-driven agriculture (Fraser, 2021) with mass observation where data is collected per se, without any clear specific intention, which may be seen as a kind of speculative effort. The dilemma is that such data can later prove to be extremely useful, but it goes against principles of frugality and limitation of misuses. Along the same line, computationally intensive research should be avoided, but could lead to frugal applications. One important point is that it is essential to evaluate the footprint of any action linked to digitalization in order to account for both environmental footprint reduction, that digitalization is often said to induce in agricultural practices, and also for the environmental impact due to the digital technology. A concept of "balanced frugality" takes account of both needs for digitalization (including data collection per se) and the global reduction of the environmental footprint of agricultural practices assisted by digital tools.

Last, not least, the RRI approach revealed that research dedicated to sustainable agri-food systems should be more heavily oriented towards a constant search for balance and resilience rather than as a mere means of optimization of these complex systems.

5. Conclusion / perspectives

In order to build a relevant future research agenda on responsible digitalization of food systems at INRAE, we have developed an original methodology divided into three steps: (1) Creation of a multidisciplinary group of scientists, (2) Identification - through design thinking - of three lines of research regarding digitalization for sustainable food systems (Accelerate agroecology transition at farm and territory levels, Manage territorial commons, Empower consumers and farmers), and (3) RRI analysis of three existing digital solutions to identify discrepancies with RRI principles and, thereafter, of the three above-mentioned prospective research axis to help us to identify of essential questions linked to the sustainability of a RRI-based scientific approach.

Two types of questions have emerged: some are specific to the RRI methodology and its implementation, whereas other ones are specific to the three prospective lines of research.

In conclusion, this work is essentially a first endeavour made by French public researchers to reflect on their practices, in a responsible way, as well as from an interdisciplinary perspective in order to design a research agenda for responsible digitalization of agriculture and food systems. Around the world, other groups have already started this process of reflection on how to make RRI work in practice and make it ground in research programs (Regan, 2021; Rijswijk et al., 2021; Rijswijk et al., 2019). The big strength of the present work was that it was carried out with a highly interdisciplinary group, which was essential to proceed towards the "social shaping of technologies" (Williams and Edge, 1996), although requiring more transaction costs (Brown et al., 2015). However, this first step suffers some shortcomings regarding the methodology, as the group was limited to INRAE researchers. In the future, it would be valuable to validate, refine and complement these prospective lines of research in association with other stakeholders, using participatory approaches, as done by Ingram et al. (2022).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

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

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