6

Challenges for the future

Providing digital tools to help address the challenges and gaps facing agriculture

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This chapter highlights the needs and challenges linked to the development of responsible digital agriculture in the interests of promoting agroecology, agricultural diversity (including family agriculture) and sustainable food systems. The aim is to look beyond the state-of-the-art (Chapter 3) and to respond to the opportunities presented by digital technology for the agroecological transition and for balancing out value chains (Chapter 4), while avoiding the pitfalls that have been identified (Chapter 5). The focus will be on the challenges facing technological research, while acknowledging the associated economic and organisational challenges, particularly relevant to agriculture.

Based on our needs analysis for promoting implementation of agroecology and balancing out value chains, the chapter is divided into four sections:

- improving collective management, including at the regional level;
- improving farm management;
- balancing out the value chain, both upstream and downstream;
- creating and sharing data and knowledge.

6.1 Providing digital tools for collective management at a regional level

Three key areas have been identified for overcoming the obstacles linked to the use of digital technology for land management (chapter 4.3):

- measurement and monitoring on a large scale;
- data visualisation;
- digital devices for participation, mediation and governance.

Monitoring and measurement at a regional level

The ambition to make agriculture less artificial, getting the most out of local assets and reusing natural resources, will be determined by the capacity to take advantage of material flows, the potential of biological regulation and functions beyond the farm (ecosystem services, land ecology, etc.). Many of the various different interactions can only be understood through a systemic point of view. This extends the scope of our consideration, both in space and in time: some characteristics can only be appreciated at a regional level, such as the extent to which a piece of land can be crossed (which will depend on the intensity of green and blue belts[76] on it); while others must be considered over time, such as the capacity for resilience and speed of recovery when faced with climatic hazards. Therefore, if we want to employ the principles of agroecology, we must quantify parameters which are difficult to detect using traditional methods. This calls on the need for measurement and monitoring, evaluation (modelling) and the management of data on a large scale.

In terms of measurement and monitoring, the aim will be to identify data which is relevant, useful and currently missing for collective agricultural management at a regional level and to develop the tools for obtaining it, with the following challenges:

- Measuring new, difficult-to-grasp parameters (such as biodiversity, soil/water quality, etc.) as non-intrusively and as frugally as possible.
- Adjusting sampling frequency (temporal and spatial), a crucial component of information theory. Systems either collect data regularly – at different levels of granularity in time and space (sensor networks) – or sporadically (through crowdsourcing, mobile applications, mobile collection vehicles, robots, drones, etc.). Networks must adapt to these types of data, which feature different traffic patterns, in order to be able to convey it within the time limit with minimum data loss. This is applicable at all levels and is dealt with in greater detail in section 6.2.
- Managing heterogeneous data. This results from diversity in terms of the objects observed, sensing and collection techniques (including crowdsourcing), stakeholders, parameters measured, formats (value, images, localisation, etc.), metrological properties (precision, frequency, etc.). In order to deal with this heterogeneity, appropriate filtering and fusion methods will need to be developed. It will sometimes be possible to perform fusion at different levels and more or less iteratively, factoring in the uncertainty linked to each piece of data, the variability of this uncertainty and any consequences it may have on the rest of the information chain. These questions are applicable to all types of data – physical, biological, economic, social, etc. In order to produce coherent reports (e.g. on material flows) and the corresponding uncertainties, mathematical and computing tools for data reconciliation will be employed (these tend to be based on constrained optimisation) (*Courtonne et al.,* 2015).

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76. The term "green belt" is used to refer to natural and semi-natural land environments, while "blue belt" refers to wetlands and aquatic environments (rivers, tributaries, ponds, peatlands, etc.). The term "green and blue belt" refers to a set of ecological networks allowing populations of species to move around. These are comprised of wildlife corridors which connect reserves where biodiversity is richest and best represented. These corridors can be linear (hedges, along footpaths, grass strips...) or various different types of landscape structures (https://dicoagroecologie.fr/encyclopedie/trame-verte-et-bleue/).

- Data governance, an issue which is exacerbated in multi-source data systems. This is a general question, which will be explored in 6.4.

In the Global South these needs are becoming ever more pronounced: as outlined in section 4.5, information capital is sorely lacking in these countries at a regional level. This capital is essential for national administrations (for agriculture) and local authorities, producer organisations, research bodies, etc. when it comes to open innovation, anticipating risks (climate risks, health risks) and improving the organisation of regions and sectors. In this context our research will need to take into consideration additional difficulties resulting from the digital divide, illiteracy, multiple dialects, etc. But these difficulties also provide us with avenues to explore with a view towards rethinking our systems and methods and adapting them to this context.

Visualisation

Our visualisation methods will need to be revolutionised for data management at a large regional level. Given its particularities, the agricultural sector has raised research questions with no current equivalents in the field of visualisation, such as:

- visualising multi-scale, heterogeneous data, sometimes in large quantities and sometimes rare: spatial data, symbolic data, temporal data, variable data, incomplete data, uncertain data, erroneous data, semi-quantitative data and even qualitative data depending on variations in structure such as mapping (GIS), images (from satellites, drones), time series, graphs and networks;
- visualising extreme scales, connecting them in a fluid and clear manner – short-range and long-range (time, geographical, etc.) –, and developing suitable and appropriate tools for aggregation and statistics;
- revealing new information semi-automatically by comparing maps or time series, highlighting symmetries, regularities, trends, correlations, etc.;
- meeting contradictory needs such as, for example, the visualisation of massive data, but with mobile applications (mobile phones, tablets, etc.), or guiding users while respecting their autonomy;
- finding innovative ways of representing complex objects, dependencies or models, capable of being used by individuals from a diverse range of backgrounds..

These questions open up new prospects for certain basic subjects, including the visualisation of uncertainties (*Boukhelifa and Duke,* 2009; *Potter et al.,* 2012) and progressive visualisation (*Fekete et al.,* 2019), at the interface between visualisation and AI. It is worth noting that, with regard to visualisation, there has not been much discussion on issues surrounding privacy and usage rights for data when it comes to building trust (*Charvat et al.*, 2018). The questions listed above could eventually lead to research being carried out on visualisation and HCI specific to the agricultural sector.

Digital devices for participation, mediation and governance

The multi-actor approach is essential at a regional level and requires support tools: the knowledge production mode is changing, with transdisciplinary research requiring significant contributions from external stakeholders, something which may be easier in the digital era (*Bergez et al.*, 2019). In sectors operating at a regional level, it is increasingly common for individual and collective interests to come into conflict with each other (*Ryschawy et al.*, 2019). New digital devices from regional engineering are anticipated, to facilitate dialogue within the world of agriculture and with other regional stakeholders (figure 2)..

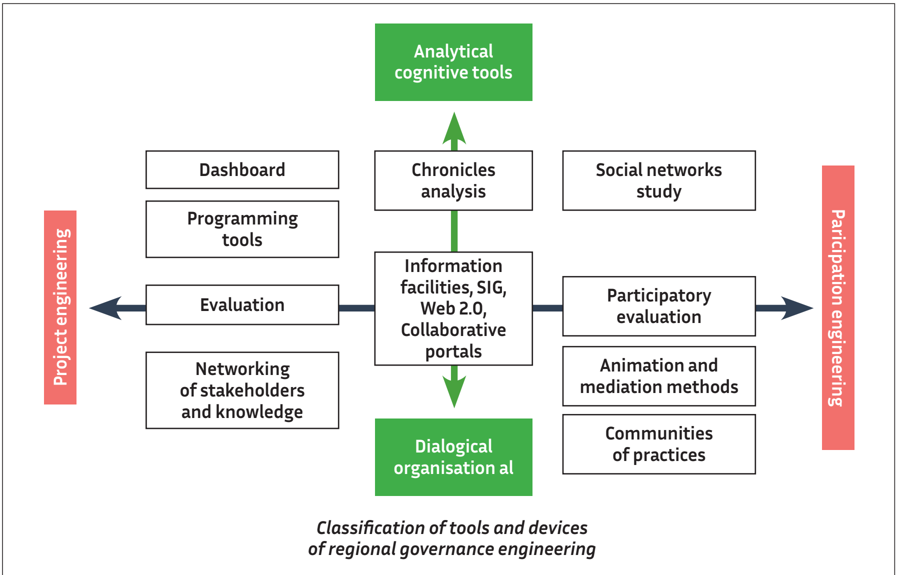

Figure 2: Tools and devices for regional governance engineering (Rey-Valette et al, 2011)..

These digital tools and devices could fulfil a range of functions: analytical, creative, cognitive, interpersonal, decision-based, operational, etc. (*Rey-Valette et al.,* 2011). They could also help to develop collective action by facilitating participation and open innovation, collective decision-making and mediation.

PARTICIPATION AND OPEN INNOVATION

Digital can provide the means to implement open innovation and participation. Confronted with complex problems, analytical approaches (in the lab) and participatory approaches (with stakeholders from a wide range of backgrounds) must be devised jointly – digital technology having the capacity to bridge the gap between the two (facilitating negotiation through modelling and visualisation).

To encourage farmers to engage in the agroecological transition, a gradual approach is the preferred option; the capacity to bring about change collectively will be necessary. It is anticipated that there will be new digital tools available for participatory strategies: support models, digital gamification, digital tools for analysing participatory sessions (video and audio processing for identifying and labelling participants and points of view, etc.).

Open innovation also generates additional research needs, involving management sciences, social sciences and law: on types of collaborations and sources of information in open innovation assisted by digital technology, on economic models, on managing tacit knowledge, etc. (*Enkel et al.,* 2020). Evaluating individual creative contributions in open innovation processes where intellectual protection will come into play, also known as "the paradox of openness" (*Arora et al.,* 2016), raises questions from the perspective of law and economics. Finally, there is the issue of the way in which learning networks are organised so as to facilitate innovation in digital agriculture (*Klerkx et al.,* 2019).

COLLECTIVE DECISION-MAKING

This type of decision-making is based on three different processes: deliberation, negotiation and voting. When it comes to deliberation (*Besnard and Hunter,* 2008), by allowing arguments to be studied in a logical and automatic way, digital technology could help to ensure deliberations are rational, while correcting any erroneous conclusions. With regard to negotiation (*Kilgour and Eden,* 2010), it is argued that a more standardised approach aimed at reaching a fair compromise would lead to engagement and satisfaction on the part of stakeholders and, thus, to sustainable decisions. Lastly, on the subject of voting itself, digital technology could be used to characterise these principles in order to arrive at relevant, desirable decisions, by taking different expressed preferences into account, for example (*Brandt et al.,* 2016).

Tools must be easy to use, complementing other modes of collective decision-making and deliberation, and be capable of being seamlessly integrated into individuals' daily routines (particularly when strategic decisions are being taken) in order to collect their arguments and preferences, for instance. As a consequence, the visualisation of data and decisions is vitally important.

MEDIATION

Digital is reshaping boundary objects (*Trompette and Vinck,* 2009) – through which social groups of diverse interests, practices and codes are able to enter into dialogue and reach a mutual understanding – and intermediary objects (*Vinck,* 1999), which retain a trace of the different stages involved in the collective design of a project or system, helping to boost acceptance and reuse. In Africa and the Global South, the use of commons such as land (agropastoralism, forestry) or water (irrigation) remains widespread. In this context, digital technology could also be employed to reshape management methods. Ongoing experiments with collective learning, living labs and joint, participatory management in places such as West and North Africa could be analysed and replicated.

6.2 Helping farmers to manage their technical journey

Three levers could be applied in tackling the obstacles identified in 4.2 with a view towards the scaling up of agroecology:

- systems for monitoring animals, plants and their environment;
- decision-support tools;
- robotics.

Acquisition and diagnostic systems

The challenge here lies having access in farm to accurate, reliable data at a low cost and with a low environmental impact, providing farmers with rapid, easy-to-understand information about the status of their systems (animals, plants, harvests, etc.), enabling the early detection of malfunctions and assisting them with the decision-making process. Mass, comprehensive capture of data could also help to promote large-scale phenotyping on farms, the goal being to develop new knowledge in the field of agroecology. For livestock breeding, we can add constraints linked to measurement and transmission, ethical questions and a recognised need for unconventional forms of livestock breeding. In the context of agroecology, one key issue is detecting malfunctions, with the compromise of "coverage" (the area covered by the detection system) versus specificity. Specific measurements (e.g. detecting a virus or bacteria) are complex due to the need to establish contact, the cost, energy supply and the issue of false alarms in livestock breeding (*Dominiak and Kristensen,* 2017). Research must be inclusive, geared towards "moderate levels of instrumentation" and devices accessible to all farmers (*Bergez et al.,* 2019; *Dumont et al.,* 2018).

Research on acquisition systems, sensors and IoT, data management systems and associated digital models linked to farmers' core business and consistent with their strategies could focus on:

- **creating new sensors while respecting constraints typical of agriculture (frugality, cost, energy use, etc.).** It will be necessary to seek compromises between the autonomy of the sensor, its environmental impact, its spatial and temporal resolution weighed against specificity, measurement quality, durability, suitability with regard to the object under study and to the measured environment simplicity of use and maintenance, the last two factors being essential for solution acceptance. With the same goal of simplifying human-computer interfaces, research could be devoted to the development of audio devices enabling farmers to input information (e.g. electronic crop registers): voice recognition, ontology alignment, etc. Finally, in order to improve understanding of these agroecological systems, it is becoming increasingly clear that we must take into account not only the physical parameters of an environment, but also its biological parameters (animal/soil microbiota), which would generate needs in terms of omics methods.
- **Optimising the mode of data transfer so that data is transferred automatically to processing centres, practically eliminating co** (*Wolfert et al.*, 2017), a major factor for large-scale phenotyping on farms; this raises research questions linked to power supplies for sensors, sensor networks (e.g. swarm intelligence), etc.
- The desire to limit the number of sensors (in line with frugality) and to make it easier to measure certain parameters in a non-invasive way also calls for research into smart sensors, i.e. combinations of data from "simple" sensors for estimating these complex parameters through appropriate data processing (e.g. machine learning). The impact of these developments on the quality and uncertainty of information has still to be assessed.

Once collected, information can be used for diagnostic purposes, for characterising the state of agricultural systems and detecting any malfunctions that might require a response. Research could explore the building of diagnostic models. Although this issue is not specific to agriculture and affects other sectors as well, research must incorporate knowledge of the domain (agriculture) in order to address the following priorities:

- selecting which indicators to integrate, factoring in the natural variability of indicators, the propagation of uncertainty from these indicators, sensitivity and specificity adapted to use, adapting to local conditions (farm type and location, risk acceptance, agricultural practices, etc.);
- fusion of big data with point data from varied sources, specific processing (SVM, deep learning), data sharing (individual or collective);
- the hybridisation of data-driven approaches developed in artificial intelligence, based on big data, with modelling approaches which are more concept-driven but less suited to real-time data (*Ellis et al.,* 2020). This will require research into the explainability of data-driven approaches, in addition to research on knowledge-based systems (ontologies).

In a general sense, it is to be hoped that these developments linked to acquisition, communication and processing tools can be made in an integrated and scalable way in order for the system as a whole to be capable of adapting dynamically to each crop or livestock profile, size of farm or agricultural strategy, which all throw up a real scientific and methodological challenge.

The challenges posed by robotisation and the digital transformation of agricultural labour

Digital tools are transforming agricultural labour. How can these be directed in a positive way so that the labour of farmers and agricultural employees is made less arduous and is better respected? Robotics could provide a way of shifting human labour to tasks with higher added value, but there are still a range of scientific and technological obstacles to overcome in the following areas:

SCENE PERCEPTION AND INTERPRETATION IN DYNAMIC ENVIRONMENTS

Improvements will need to be made in scene perception and interpretation in order to boost detection capacity (fruit, leaves, diseases, etc.). Deep learning and, in particular, machine learning will open up avenues, especially given that robots will be equipped with sensors and will therefore generate data. One alternative is to utilise human expertise in perception, which raises questions in relation to human-robot cooperation. Finally, it must be possible to explain and interpret decisions taken by robots, and robots must be able to refer to experts for difficult detection or decision. This will involve determining confidence criteria for decisions and clarifying decision-making rules taken from learning, an open theme.

ADVANCED APPROACHES TO DECISION-MAKING

Robots are currently limited to one single operating mode. For complex tasks, shifts between command modes are sequential and planned in advance. It is anticipated that significant breakthroughs will be made in the realm of situation and scene recognition (the robot's dynamic, its operating environment, agroenvironmental constraints, etc.), borrowing from artificial intelligence (*Hill et al.,* 2019) for the purposes of adapting features. These problems go beyond the boundaries of autonomous navigation, and are also applicable to active tools so that they work with precision.

DESIGNING NEW ACTIVE TOOLS

Innovation in the field of agricultural robotics is currently focused on autonomous navigation; tools worn are either passive or controlled independently (*Wu et al.,* 2019). For greater repeatability and enhanced execution speed, active tools capable of being synchronised with mobile carriers are expected. In order to achieve this, research will need to be carried out on mobile handling and coordination with a moving carrier.

HUMAN-MACHINE INTERACTION AND SHARED AUTONOMY

In addition to issues surrounding perception or communication interfaces, human-machine interaction also raises questions on autonomy and collaboration: when and how should control be given back to a remote operator? How can robots cooperate with humans? In agriculture cobotics is starting to emerge commercially, with assistance robots (*Laneurit et al.,* 2016), people-carrying robots and, to a lesser extent, exoskeletons – particularly passive exoskeletons – aimed at facilitating the lifting of heavy loads. With more complex levels of collaboration, it will be necessary to interpret human behaviour in order to adapt the actions of robots. Such an approach will help to popularise robots, which will still not replace humans, just as we must ensure that these devices operate safely.

OPERATIONAL SAFETY

This is a crucial aspect for autonomous machinery operating in open environments. Scientific, technological and legislative progress will need to be made, drawing on driverless vehicles but factoring in difficulties linked to natural environments: (i) maintaining precision in terms of positioning (avoiding obstacles or not crushing crops), (ii) navigating within a pre-determined space, (iii) guarding against the risk of collision, or loss of stability or controllability. Infrastructure and protocols will be needed to validate operational safety and other types of performance (technical, environmental, etc.).

ADAPTING TO NEW PRODUCTION SYSTEMS

Robots must be designed with frugality and inclusion in mind: the choice of materials and components (minimising the use of rare-earth elements), limited energy requirements, reduced maintenance, repairability, the scalability of robots and their capacity to be updated. Similarly, robotics must provide solutions for all types of agriculture, with levels of sophistication and autonomy adapted to production systems. New crop systems, with a mix of species and the possible introduction of trees (agroforestry), will present problems for navigation.

There are also issues relating to the humanities in terms of how digital technology and robotics are transforming labour, on the loss of autonomy (deskilling) as a result of the use of machinery to replace humans and the rationale of practitioners. In order to avoid these risks, one of the challenges will be to incorporate – from the design phase onwards – the conditions for use, impact on the work and satisfaction of farmers (*Hansen and Straete,* 2020; *Vik et al.,* 2019) and other categories of workers (employees, associates, sub-contractors, etc.).

Modelling to incorporate systemic effects and build practical, usable decision-support tools

Challenges for research involve a number of aspects linked to the building of models and, in particular: representing and understanding interactions; including expert knowledge; building practical, integrated models for farmers; and dealing with uncertainty. Details of these can be found below.

REPRESENTING THESE NEW SOCIO-AGROECOLOGICAL SYSTEMS

This is a first challenge in that agroecological systems are much more far-reaching (incorporating value chains) and much more complex (based on interactions) than is the case with conventional agriculture. Difficulties with modelling are linked to selecting which characteristics and parameters to include (determined by measurement capacity), natural variability in terms of how these characteristics are expressed to the other factors inherent to plants or animals, environments, production or breeding systems (factoring in other individuals from their group), the equipment used and the agricultural strategy employed.

Data-driven approaches (based on statistics, artificial intelligence, etc.) could be combined with concept-driven approaches (biological, economic or social models based on known mechanisms). Consideration may even be given to creating "digital twins", integrating models developed for sub-systems, in order to test scenarios at a system level (e.g. climate change, local supply on a mass scale, etc.). However, this integration will bring with it alignment difficulties[77] when there is no guarantee of concept correspondence between sub-models or between digital twins and the system being studied.

THE LEVEL OF INTEGRATION FOR EXPERT KNOWLEDGE

This second challenge to overcome in the building of decision-support tools (description, prediction, prescription, see 4.2) is of interest to the humanities: will it be necessary to go as far as prescription, or is observation (or possibly a diagnostic) sufficient, leaving the decision (prescription) up to farmers for precision livestock farming, as suggested by *Ingrand* (2018)? With regard to risk management, other formalisms could be actionable, such as the theory of viability (*Aubin,* 1991), which in principle is compatible, but which poses problems for researchers owing to the fact that models must provide a framework for small (<10) dynamic systems which are both controlled and constrained (*Brias,* 2016). This opens up research questions: what should be done if the model is not dynamic and constrained (compartmentalised models, multi-agent systems), or is even unknown? How can weak signals be utilised in time series (tipping points)? How can a compromise between complexity and control be reached (*Anderies et al.,* 2019)?, etc.

BUILDING PRACTICAL DECISION-SUPPORT SYSTEMS FOR FARMERS

The issue of practicality is central to the design brief, and there are a number of key points that any future research must take into consideration:

- ***the user interface:*** both for visualising inferred outputs, which are essential to effective decision-making, particularly in the context of multi-criteria optimisation (*Lepenioti et al.,* 2020) or in the context of collective approaches (cf. part 6.2), but also for gathering data and identifying strategic objectives or preferences among farmers and incorporating these into decision models: visualisation of compromises, gamification (e.g. the serious digital game *C-Real Game*). It could be worthwhile to explore human-machine interfaces based on oral communication in order to make it easier to input and reproduce data and information in situations where farmers must handle...
- ***the "personalisation" of inferred information*** i.e. adapting models to individual farms or farmers in order to avoid one-size-fits-all prescriptions, to be in alignment with farmers' strategies and factor in their objectives (turnover, revenue, operating modes, etc.). Current prescription models are taken from "broad spectrum" knowledge models from experts in the field; how can it be

77. Alignment involves indicating that a concept outlined in one ontology is semantically identical to another concept outlined in a different ontology, even if the two concepts have different names.

made so that only – or primarily – data collected on individual farms is used, the goal being to infer prescriptions which are more compatible with farms and farmers? This obstacle has raised questions relating to the integration of knowledge from farmers in order to "personalise" inferred information and to increase its relevance in relation to their farm, similar to personalised medicine.
- ***the capacity to create scalable model*** capable of being adapted to environments which are liable to change as a result of both internal factors (strategy) and external factors (environmental, regulation, economic, etc.). This also raises questions linked to updating models (what is known as 'concept drift');
- ***the security of the recommendations made,*** i.e. the guarantee that a recommendation will not lead to a worsening of the situation, particularly in relation to automatic control. This problem is down to the stacking of models and the propagation of uncertainty (*Trnka et al.,* 2007), as well as the characteristics of the actuator. The latter must be made part of the model in order for relevant decisions to be taken (see *Tisseyre and McBratney's* opportunity index, 2008).

UNCERTAINTY AND ITS PROPAGATION

Uncertainty is mentioned in 76% of articles on modelling (*Lepenioti et al.,* 2020): how can it be reduced, how can it be characterised (epistemic, ontological, random) and how can it be represented (*Caquet et al.,* 2020; *Crespo et al.,* 2010; *Groot et al.,* 2012)? How can the issue of incomplete and noisy data and the subjective nature of human knowledge be addressed, particularly in the context of prescription (*Lepenioti et al.,* 2020)? How can a compromise be reached between overly complex, unmanageable modelling and modelling which is simplistic and not sufficiently relevant (*Caquet et al.,* 2020)? Exploring different ways of simplifying models would certainly be useful (stochastic models, mechanistic-stochastic models, metamodels, etc.).

Looking at the Global South in particular, decision-support systems must be designed in such a way as to incorporate the characteristics of agriculture in these countries; these must be multifunctional, with a prevalence for spatial-temporal reasoning and high levels of uncertainty. Decision-support systems and associated information systems must prioritise: (i) introducing or continuing agroecological practices and collective learning (collecting and exchanging data using digital technology); (ii) improving the management of resources (water, organic materials, etc.), from individual plots to whole regions, and harvests (dates, quantities), (iii) building new knowledge based on data and expertise in the context of rare data, but also emerging big data (see 6.5).

6.3 Transforming relationships between stakeholders within sectors

Balancing out sectors to better integrate farmers and consumers will be vital in order to keep family farming attractive and to meet the expectations of consumers with regard to food. In response to these challenges, three key points have been especially identified, both upstream and downstream:

- service: advice, insurance;
- traceability;
- platformisation[78] and the reconfiguration of distribution networks.

Service: advice and insurance

Regarding advice, each of the obstacles identified in chapter 4 (access to digital, the individualisation of decision-making and maintaining decision-making autonomy, the imbalance between upstream and downstream) open up avenues for research on advice and digitalisation in both digital science and the humanities, with three primary areas of focus:

- **developing decision-support tools capable of integrating the specific features of individual farms (pedoclimate, the agronomic techniques employed, agricultural equipment) and the preferences of farmers.** In addition to the points discussed in 6.2, the development of these tools could also draw on a deeper understanding – based on agronomic, sociological, managerial and ergonomic analysis – of the role of advisors and the bonds of trust they form with farmers in the usage profiles of digital solutions;
- **continuing the economic analysis of the modes of decision-making employed by farmers and the dynamics for the adoption of digital innovations** in a context impacted as much by the diversification of how farmers seek out information as by the fragmentation of services as a result of the privatisation of advice. Research could also be conducted to identify sustainable economic models for digital advice;
- **institutional analysis of the governance of the digitalisation of agriculture,** taking us back to the issue of transparency regarding the use of data, the regulation of power relationships and advice as a key factor in the digitalisation process.

78. Platformisation is a business model in which organisations employ the use of a web platform in order to act as an intermediary between consumers, as opposed to a supplier of goods and services. To find out more: https://www.decideo.fr/Entreprise-3-0%C2%A0-vers-une-ineluctable-%C2%A0plateformisation%C2%A0-du-Business-de-l-IT_a9280.html

On the subject of insurance (section 4.2), technological breakthroughs will still need to be made in order to reduce the baseline risk for index-based insurance; this could draw on new data sources (satellites, connected stations, etc.) or suitable types of processing (*De Leeuw et al.,* 2014; *Ghahari et al.,* 2019). Finally, usage-based insurance – which has emerged in the transport sector (*Husnjak et al.,* 2015) – is still unknown in agriculture, but it could be a useful avenue for exploration in the context of connected agriculture. Could this usage-based insurance assist with the adoption of agroecological practices – more complex to implement given the need for greater monitoring, but more resilient in the event of a health or weather disaster – by guaranteeing revenue, provided that crops or herds have been correctly monitored and recommendations from decision-support tools applied? A multidisciplinary approach must be taken when addressing these questions.

Traceability, full supply chain transparency, data life-cycle

As shown in section 4.3, in the current context, the traceability of flows and products in agriculture is crucial in the interests of establishing trust between farmers and consumers. There is a growing interest in the blockchain, for example, for sharing and distributing details on a product's entire life while also limiting fraud. But there remain a number of challenges to overcome in relation to data management at a technical and institutional level, particularly with regard to the overall traceability of practices and products.

THE TECHNICAL CHALLENGES OF THE BLOCKCHAIN

How can current blockchains, which were designed for banking information, be adapted to this new type of data, linked to flows of products which are often perishable, in order to monitor it and archive it efficiently without violating the basic principles of storing data in a blockchain? How can the flow of information which characterises traceability in blockchains be unquestionably linked to the flow of products? How can the costs of identification systems be lowered and who should cover these costs, which benefit everyone along the chain? How can data be protected within an ecosystem with a growing number of data sources?[79] Similarly, as explored in chapter 3, public blockchains use up a lot of energy – in order to be unquestionable, the validation of information is open to a huge number of participants "in virtual competition with each other", known as 'miners', resulting in a huge number of simultaneous calculations. Preference may be given to a private, less energy-intensive blockchain (based on a restricted number of

79. White paper published by the US National Institute of Standards and Technology, outlining security problems affecting the Internet of Things (IoT), in October 2018 (https://csrc.nist.gov/CSRC/media/Publications/white-paper/2018/10/17/iot-trust-concerns/draft/documents/iot-trust-concerns-draft.pdf)

authorised participants) that is also better suited to use in agriculture. However, this raises the issue of the governance of blockchains.

THE STORAGE OF DATA FROM THE AGRICULTURE AND FOOD CHAIN

This data can be said to be industrial in that it relates to agricultural production, but also to upstream and downstream industries. Should it be stored in specific locations or in a distributed manner? How can data sovereignty be ensured? Should certain operators be avoided in light of the Cloud Act?[80]

DATA INTEGRATION

This is an important aspect when it comes to facilitating subsequent analysis. Owing to the significant increase in the volume of data, the need to verify its quality and the value of the information, systems capable of enabling access by relevant and reliable information will become value sources. This will involve verifying company information systems – such as ERP (Enterprise Resource Planning) and CRM (Customer Relationship Management) – and engaging them in dialogue with data generated by connected objects managed through the Internet of Things (IoT). It will also involve evaluating and recognising the value created by each individual component of the data production and processing chain, exploring the following questions: what ways are there of getting more out of data in value chains, particularly vis-a-vis consumers? How can these raise awareness of virtuous transitions within agriculture among consumers?

BLOCKCHAIN GOVERNANCE

The challenge here lies in designing a fair and secure system involving all stakeholders in an equitable way, without any individual stakeholder imposing its vision on others or taking control of data usage. This raises a number of questions: how should the data that is generated be shared? What must be put in place in terms of data governance? To what extent will accessibility to information impact the improvement of supply chain governance (*Gardner et al.,* 2019) and power shifts in value chains? What impact will digital technology have on trustworthy relationships and the ways in which value is shared within the sector (*Jakku et al.,* 2019)? How can we prevent the value that is created from being collected exclusively by digital giants (*ANRT,* 2018)? Is there a risk that digital technology will exacerbate existing power imbalances (*Bronson and Knezevic,* 2016; *Carolan,* 2017, 2018; *Wolf and Buttel,* 1996).

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80. The "Clarifying Lawful Overseas Use of Data Act" ("CLOUD Act" 162[(*)]) was passed by the US Congress in March 2018: Its primary aim is to reaffirm the right of US authorities to demand that technical intermediaries subject to their jurisdiction share all data stored, even data stored overseas. Independently, it also provides for specific, reciprocal bilateral agreements with the United States. (https://www.senat.fr/rap/r19-007-1/r19-007-13.html)

Platformisation and reconfiguration of channels

Platforms, new virtual meeting places, are helping to change the economic model within agriculture, facilitating dialogue and collective dynamics. Automatic data input in agriculture, hyperconnectivity, the Internet of Things and automation produce real-time information for optimising the running of the value chain, either individually or as a whole. This growing computerisation has led to increased agility capacities on the part of distribution and processing channels. It will be necessary to introduce agile planning for agricultural and food production in order to meet the growing need for local supply in towns and cities and contract catering. In the interests of promoting family agriculture for towns and cities and contract catering, major issues linked to production planning, coordination between different levels of the supply chain and logistics will need to be overcome in order to ensure everyone's expectations are met and to be resilient to crises (as illustrated by the Covid-19 pandemic). These three points are explored below.

In agriculture production planning is a reality for farmers contracted to agribusiness industries, particularly for frozen, tinned or ready-to-eat vegetables (*Ahumada et al.,* 2012; *Li et al.,* 2015). The challenge now lies in production planning for fresh products in order to guarantee supplies for contract catering, incorporating uncertainties (weather, health, social, etc.) and to factor in demand (*Balaji Prabhu and Dakshayini,* 2020).

One solution to the issue of coordination is the creation of "food hubs", innovative commercial models which bring together small producers in order to meet wholesale demand (*Berti and Mulligan,* 2016). The most integrated "food hubs" are intermediary organisations which use the internet for commercial transactions and which pool together, distribute and market food products from the source (small local and regional producers) to customers (individual consumers or wholesalers). These hubs must have access to production and distribution chain models featuring realistic characteristics, including soft information, logistical integration, risk modelling, the regulatory environment, and the quality and safety of products. Stochastic modelling could be useful in this context (*Ahumada and Villalobos,* 2009).

In order to build urban logistics distribution networks for suburban production with shorter commercial channels, it will be necessary to improve inventory management and distribution planning (particularly for cold products) in order to reduce food waste and the resulting carbon footprint. Little research has gone into planning applied to food supply chains compared to the industry. In particular, there is a clear lack of adequate models for planning operational decisions for the production, harvesting and distribution of fresh agricultural products (*Ahumada and Villalobos,* 2009). The environmental dimension will need to be taken into consideration (*Melkonyan et al.,* 2020)

In the Global South, challenges linked to improving supply in local distribution channels are even more difficult: this will involve reducing post-harvest losses through organisational support and improved logistics management (channel modelling and optimisation, cold chain logistics, etc.). For longer channels, it is anticipated that frugal, secure traceability systems will be developed for national and international chains.

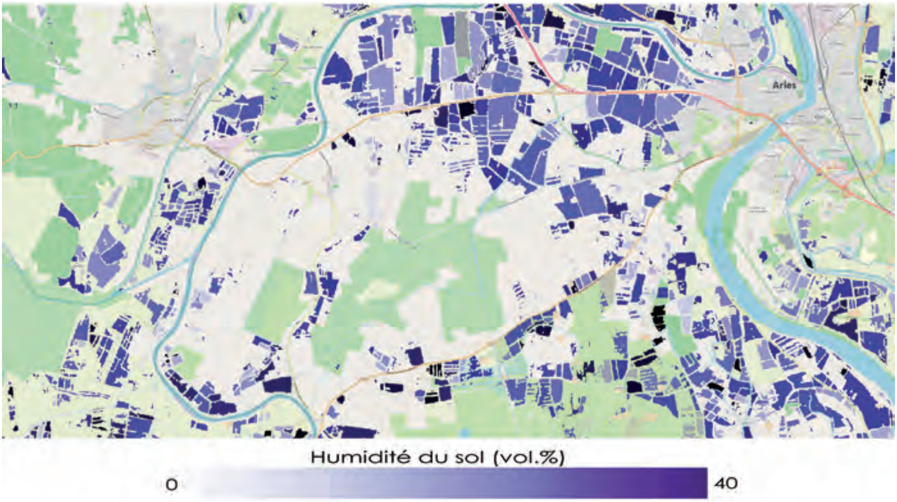
Finally, there is also the possibility of a move towards personalised food production. *Svetlin et al.* (2016) have proposed "online" and individualised co-design of products through linguistic analysis of consumer preferences and translation into formulation parameters (applied to an orange drink). This type of approach could be employed with more complex food items produced in accordance with demand, restrictions, budgets and individual needs, and delivered ready-made to people's homes (*Académie des technologies,* 2021). This would also make it easier to connect to personalised health monitoring applications.

6.4 Creating and sharing data and knowledge

Data and knowledge are central to digital technology helping to promote agroecology: data feeds into knowledge and knowledge feeds into agroecology. This information capital has brought about new technological, regulatory, organisational and institutional challenges. These challenges relate to the origin, the quality (crowdsourcing) and the governance of data, but also to the formalisation and sharing of knowledge, challenges which will require a response in order to build an ethical digital agriculture.

PARTICIPATORY DATA (CROWDSOURCING)

With the development of connectivity and acquisition systems (smartphones, precision agriculture, connected objects, etc.), the collection of data by operators (farmers, advisors, etc.) or laypersons (citizens) has developed, adding to more conventional methods for the gathering of experimental data by scientists. There are technical challenges relating to participatory data collection for environmental documentation or research purposes (4.4): what infrastructure is needed for managing and exchanging this participatory data? How can the quality of data collected through crowdsourcing be ensured? How can the data that is produced be traced in the interests of the fair sharing of intellectual property? There are also questions of interest to the humanities and economics: what has to be done to encourage farmers to share their data and information and to build trust-based relationships with their advisory and training environments (*Sutherland et al.*, 2013; *Wiseman et al.*, 2019)? How can value be attributed to the data that is produced? What impact will this new role of data collector have on the evolution of the job of being a farmer?



Subcellular and weekly mapping of soil moisture by remote sensing based on Sentinel 1 and 2 images. *© Theia et INRAE.*

GOVERNANCE AND THE SHARING OF DATA AND KNOWLEDGE

When talking about regions or sectors, we have shown that data is increasingly coming from various actors (multisource data). Given that data is generated by separate parties through different systems and is potentially hosted across multiple sites, it will be necessary to determine what the data usage rights are; needs can be contradictory from the point of view of data sharing and data protection (collaborating while remaining competitive). What modes of governance should be employed, in a context in which digital firms and upstream stakeholders are investing heavily in the management of data on agricultural risks and in which agricultural innovation systems are being digitalised (*Fielke et al.*, 2019)? Within chains, an understanding must be reached as to the role played by information in the emergence of cooperation and compliance between stakeholders from different sectors and at different levels of global supply chains (*Gardner et al.*, 2019). How can "ethical and secure" data circulation and state sovereignty be promoted[81]?

81. The French Academy of Technology has recommended *"the introduction of a label for circulation solutions at a European level to prove that they are ethical and secure"* and "emphasise the importance of developing solutions for bringing European clouds together". See https://www.academie-technologies.fr/blog/categories/publications-de-l-academie/posts/pour-une-circulation-vertueuse-des-donnees-numeriques

Clearly, these issues relating to data governance and the risk of power being seized by certain stakeholders within sectors (agricultural supplies, downstream) or by digital companies specialising in artificial intelligence and networks are even more acute in the Global South, where there are fewer regulations.

FORMALISATION AND SHARING OF KNOWLEDGE

Digital technology can help to promote the co-construction (participation) and exchange of knowledge, but there remain a number of challenges: how can knowledge be constructed in such a way as to incorporate the uses and knowledge of farmers (expertise gathering, contextualisation, etc.) in order to increase the likelihood of it being adopted? How can satisfactory governance be developed, not only in terms of data but also the knowledge generated through this data? How can the construction of digital commons be accelerated in order to establish knowledge and, in particular, to compare it and gather it together? This raises non-trivial questions regarding the gathering of expertise and ontologies. In particular, how to make ontologies built on different principles compatible (stackable, associable): different uses, different authors, different foundamental ontologies, etc.? Lastly, in the interests of frugality and efficiency, moving away from multiplying tools and getting the most out of existing resources, might it be beneficial to mobilise non-specialist social media sites and platforms for exchanging knowledge? If so, how can this be achieved?

In the Global South, a first challenge is to use digital technology to rethink participatory approaches for collective learning and co-innovation – through "enhanced" interdisciplinarity (cognitive psychology, ergonomics, immersive serious games, design thinking and management science) – and evaluating their impact (*Tesfaye et al.,* 2019). The goal will also be to facilitate communication with farmers and between farmers, in a context of low network coverage, plurality of languages and dialects, etc. (see 4.5).

Conclusion

In light of the risks and issues discussed above, the challenges identified in this chapter should be considered within a general overall context, enabling a multi-faceted framework to be built:

- **The need for a systemic vision for agriculture and digital technology.** Systems and sectors in agriculture are complex systems, comprising multiple elements and stakeholders interacting with each other at different levels (farms, regions, sectors, etc.). Anticipated digital developments will need to be designed and evaluated in light of their direct impact at the level at which they are applied, but also their indirect impact throughout the system and society as a whole, from a biotechnical, economic, social (e.g. labour), environmental (biodiversity, resources, etc.) and ethical perspective. Considering these indirect impacts and developing methods through which they can be evaluated will be essential in order to have the capacity to ensure that overall energy costs fall some way below the benefits of the development of a given type of technology, therefore without the risk of increasing complexity (see 5.4). Furthermore, developing systemic approaches will be essential in order to anticipate retroaction, such as the rebound effect[82] that often occurs with digital technology. Research is faced with major methodological and conceptual difficulties, primarily relating to the systemic analysis of problems. Approaches must be fundamentally transdisciplinary; certain frameworks, such as the concept of "complex thought" introduced by Edgar Morin, could be useful here (*Morin,* 2014).

- **Searching for frugality.** This involves reducing energy expenses, consumption of other resources (both renewable and non-renewable) and pollution caused by the use of technology. It must incorporate all stages of the data chain, from collection and gathering to reproducing and decision-making. The development of digital solutions must take costs into consideration, whether this is the cost of materials (e.g. components used, size, number, particularly for sensors, robotics, etc.), of the data produced (type, quantity, storage, etc.) or of the processing power required in order to be economic with regard to natural resources (water, minerals, etc.) and energy. This analysis must factor in the entire life cycle of the materials used (resource extraction, manufacturing, transport, use, end-of-life). Although digital calls for a reduction in the use of agricultural inputs and resources (such as water, for example), its own environmental footprint must be taken into consideration when calculating the overall environmental footprint of any new agricultural practice. This will also mean taking a sober, cautious approach when developing and scaling up technological solutions, beforehand exploring organisational and sociopolitical solutions and alternatives which do not use up directly resources or emit pollution.

- **Searching for resilience.** Optimising production and sectors from a cost point of view has guided technological innovations for decades, resulting in specialisation, reductions in stock levels, less room for manœuvre and less autonomy on the part of different stakeholders. This has resulted in a

82. More efficient technology often leads to increased consumption of the resource that is sought to be preserved as a result of changes to consumer behaviour; see https://ecoinfo.cnrs.fr/2015/12/23/les-effets-rebond-du-numerique/

reduction in the resilience of agricultural systems and sectors, i.e. their capacity to resist and to adapt to – at different levels – external crises such as weather events, scarcity of resources and supply chain breakdowns, and economic or health crises (*Biggs et al.,* 2015). Digital solutions must endeavour to promote this resilience, by being the component within a complex system which is based on the seven principles of resilience outlined by *Biggs et al.* (2015),[83] avoiding the trap of complexity, which results in technical or social dependency or security risks (data, operational, etc.), contributing factors to fragility.

- **Cybersecurity.** Although not specific to agriculture, this remains a crucial topic in agriculture given the impact it has on food sovereignty. This is as much about maintaining continuity of food and agricultural production and distribution as it is about the security of information relating to agricultural production. Cybersecurity was covered in detail in a previous white paper (*Inria,* 2019). The European Union is behind the project *GAIA-X* (www.data-infrastructure.eu), the aim of which is to develop autonomous, sovereign data infrastructure which respects European standards, chiefly through a cloud computing network. Agriculture is one of the themes identified in *GAIA-X*.

Factoring in these aspects will help to promote responsibility, relevance and sharing in relation to digital technology, helping to make food systems sustainable, particularly in the context of the agroecological transition.[84] Plotting this course will guide research, not just in terms of the choice of research topics – identified in this chapter – but also in terms of research positioning. We would recommend as a minimum drawing on approaches such as Responsible Research and Innovation or RRI (*Stilgoe et al.,* 2013). Still rarely employed in digital agriculture, RRI is based on the following principles: anticipation (what will happen if...positive/negative impact), reflexivity (what does digital responsibility mean, what limits are there to our hypotheses/choices/knowledge, etc.), inclusion (with who and for who, what values) and responsiveness (how to adjust development trajectories in response to changing circumstances). It draws upon transdisciplinary research. Developing technology for digital agriculture within an RRI framework would help to meet

83. https://whatisresilience.org/wp-content/uploads/2016/04/Applying_resilience_thinking_FR_aktiv.pdf

84. **Responsibility:** fairness, inclusivity, frugality (environmental impact), moving towards a much-needed diversification of cultures, practices and products in a context of reduced inputs, ensuring take-up by a wide-range of stakeholders. **Relevance:** meeting actual needs, delivering effective, acceptable solutions which preserve diversity and freedom. **Sharing:** where users are able to make use of their expertise and local data, give their opinion on outputs (assuming these are clear and well-communicated, with uncertainty estimated), and act on the parameters of tools while remaining within a plausible framework.

the challenges identified while factoring in the global context and considerations on the need to integrate a systemic vision and issues such as frugality, security and resilience.

Definition

The concept of RRI (Responsible Research and Innovation), introduced in the 2010s (*Owen et al.*, 2012; *Pellé et Reber,* 2015; *Stilgoe et al.*, 2013) is characterised by four key aspects, "anticipation, reflexivity, inclusion and responsiveness", all of which must be implemented throughout the research and innovation process (*Stilgoe et al.,* 2013). Research into RRI in agriculture remains limited and does not deal specifically with digital agriculture. However, since the end of the 2010s, *Klerkx and Rose* (2020) have noted a growing interest in RRI within agriculture 4.0 (*Bronson,* 2019; *Eastwood et al.,* 2019; *Rose and Chilvers,* 2018)