Digital routes to sustainability in agriculture

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DIGITAL ROUTES TO SUSTAIN-ABILITY IN AGRICULTURE

Digital technologies offer a broad spectrum of applications in all areas of activity, including agriculture. Digital is an established friend to farming and the food chain. However, as the pace of its expansion increases, so do questions over the types of farming we need and the nature of the digital support they will require. This dossier showcases INRAE's work to devise digital systems that are truly useful and sustainable in the field.

The information technology required for the production and use of the vast quantities of data involved in genomics and mass phenotyping for the selection of varieties and breeds, is not discussed in this dossier. We nevertheless recognise its direct and powerful impact on the choices and activities of farmers. Equally, the numerous public databases available on agriculture, food and the environment and their uses are not discussed here.

DIGITAL: A FORCE FOR FARMING

Sensors on farm machinery, imaging services, decision support systems (DSS) and robots, discussion platforms and social media tools have populated everyday farming life, while Information technology also shapes the food value chain right through to the customer. Despite their familiarity, the key features of this new digital landscape warrant a closer look. **The case of France.**

Farmers are producers who must contend with the hazards of climate change and the living world, but they are also managers and traders, and their success has always relied on tools. Beyond the development of farm machinery and the inseparable bond between farmers and their tractors, the systematic introduction of chemicals in the last century helped farmers to increase production. It has freed them from some of the more onerous farmwork. From the 1980s, digital technology arrived on French farms, with bioinformatics and new tools for the selection of varieties and breeds and the development of robots for tasks such as milking. In the past decade, though, these technologies have visibly changed what farming looks like. Sensors act as extra eyes and ears for farmers, improving our understanding of agroecosystems. The knowledge they provide, once processed, has led to the development of programmes to aid on-farm decision making (DSS, decision support systems). Directing the correct quantities of water, fertilisers or phytosanitary products to an exact location and at the right moment calls for great precision. Robots and automated systems are now available to perform these tasks. Digital systems and tools not only improve productivity, they also reduce the environmental impacts of farming systems. Enhanced by artificial intelligence, they are currently widely used in precision agriculture to improve economic performance and achieve sustainable intensification.

IN FRANCE

70%
of new milking parlors have milking systems

10%
overall equipment rate, i.e. approximately 10,000 robots

Robots that milk, hoe, weed, sow and spray

Initially developed for use in livestock buildings, agricultural robots can perform a variety of tasks (milking, feeding, cleaning out stalls). The first to appear on farms, in 1992, were the milking systems that have now become a standard feature in 70% of new milking parlors; now bringing the rate of global equipment of milking parlors to 10% (approximatively 10,000 robots).

Currently, the major challenge for robotics in agriculture is the use of robots out in the fields. Despite the strides made in the development of robotics in industrial settings, the adaptability and navigational sophistication needed to negotiate conditions in the field can indeed be difficult to develop. It is no easy task to coax these “indoor robots ” to function on uneven and dusty ground, threatened by increasingly unpredictable climate conditions. Back in 2014, INRAE (then Irstea) exhibited a "Follow-Me" robot from its Baudet-Rob project at the SIMA (International Exhibition of Solutions and Technologies for Efficient and Sustainable Agriculture, simaonline.com). This uses Lidar to follow the farmer in the fields, enabling vegetable growers or fruit pickers to harvest a crop without having to carry it. Since then, a further project funded by the ANR (the French agency funding scientific research), the Adap2E project[1], has shown even greater ambition. A research prototype is being developed. It can perform different robotic tasks: mapping a field, treating crops, weeding, sowing and spraying. This robot can interpret the data it captures, meaning that it can adapt its actions to the condition of the crop it is observing, and can make adjustments in the task it has been programmed to perform. It can identify priority zones for treatment and is able to act in real time. It is currently being trialled for the spraying of phytosanitary products in vineyards.

The leading global manufacturer of agricultural robots, the French company Naïo, is now democratising access to its products with a price list that starts at €25,000 and the offer of rental schemes. Oz, Orio, Ted and Jo can perform tasks unsupervised. Depending on the model, they hoe, weed, plough, drill or carry payloads. Their purchase by cooperatives is further expanding access and we have reached the point where the investment is worth it because of the savings on labour costs[2]. In France, in 2021, several hundreds of robots[3] were in use, mainly in fruit and vegetable production and in vineyards. Of these, 60% are used in organic farming.

60 %
of outdoor robots are used in organic farming

Upping data quantities to refine model qualities

The systems involved in agriculture are highly complex and there is still much to learn about their various components (plants, animals, microorganisms) and the processes associated with them (hydrological flows, nutrient transformation). We have also seen an explosion in farm sizes since the 2nd World War. The need to monitor increasingly large tracts of agricultural land and manage large herds places increasing demands on time for an ever-diminishing population of farmers, time that they don't have to spare. Fortunately, a constellation of different sensors is now available to help the busy farmer. These can be static, installed in camera traps, connected objects and weather stations, fixed to farm machinery or attached to animals, humans or implements, or they can operate as movement detectors or GPS devices, transmitting data flows that are stored and processed using computer calculations or algorithms. Once processed, these data become a form of knowledge that can help to improve our understanding of the systems they monitor. Sensors make the invisible visible, transmitting ever greater detail. They provide the data for models of plant growth or animal behaviours, for example, breathing life into programmes that can not only detect and predict, but also recommend courses of action. The earliest DSS, tools that use modelling to support decision making began to appear in the 1980s.

Providing a valuable service for farm management, digital tools can detect water stress or certain diseases, or can assess carbon or nitrogen concentrations in the soil. They can advise farmers on cropping plans, treatments, weeding, or where to target irrigation. Some of the programmes created by INRAE serve as reference systems, for example those dealing with pests, or Optirrig, an irrigation management programme. Many other programmes have also been developed by Agricultural Technology Institutes to supply the needs of farmers.

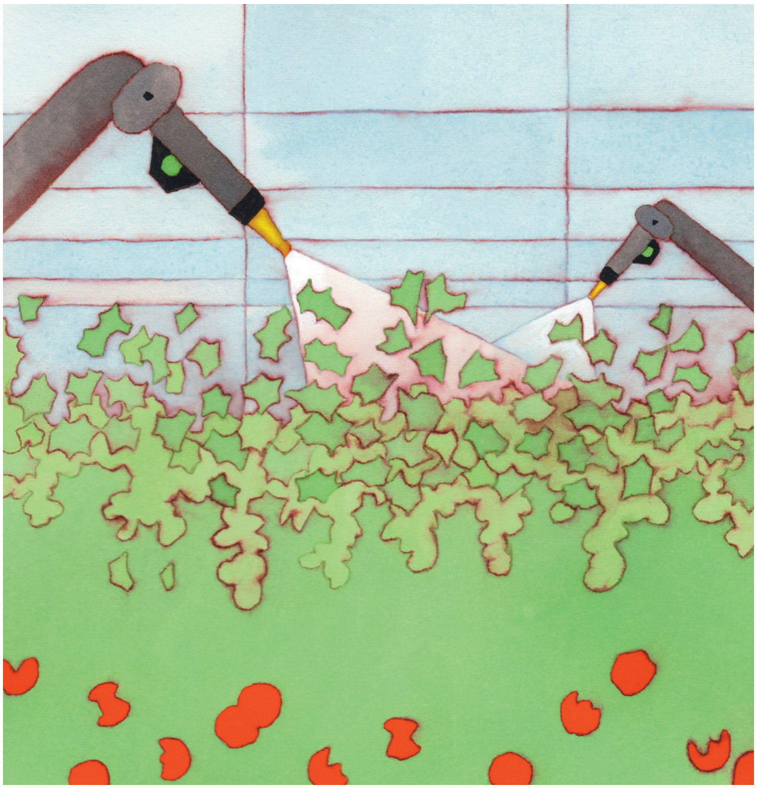
More recently, a new generation of decision support systems is making use of remote sensing, via satellites, GPS or the internet, to add even greater detail to the data provided. Drone images are now also available to replace or supplement the data from satellite images. →

With digital technology, the invisible becomes visible, more and more precisely.

1. Adap2E (Adaptive Autonomous Production Platform for the Environment) is an ANR Young Researchers project run by the TSCF research unit with the help of the ITAP joint research unit.

2. bit.ly/3Sedx54

3. bit.ly/3TsTwc7



Hiphen, a start-up that provides plant phenotyping, was incubated by the EMMAH joint research unit at INRAE's Provence-Alpes-Côte-d'Azur centre. It uses a variety of digital technologies to generate crop imaging, working with networked sensors, drones and satellites whose data can be accessed via a smartphone. These tools can offer unrivalled efficiencies. For tests on wheat, for example, the analysis of images captured from the experimental plots has superseded the painstaking tasks of tallying ears of wheat and taking careful measurements to calculate leaf areas.This work was previously carried out by hand.

Modelling, too, has to change if it is to accommodate the multi-objective nature of farming. What is more, its designers must tread delicately, seeking to aid decision making without necessarily replacing the decisionmaker, supplying the user with information for various purposes: diagnosis, prediction or alerts. To its key role in DSS can be added the help it provides in collective decision making and training.

The AI powerhouse

With the advent of Big Data, new processing technologies have been developed. Artificial intelligence (AI) now allows us to produce original knowledge from vast quantities of data. These data, harvested in sufficient quantities to encompass a given range of possibilities, are cleaned and processed to predict values and generate classifications, or simply to establish patterns. Deep Learning and Machine Learning technologies are used to process complex images, satellite images, or temporal series (for example, the continuous or repeated measurements of a given parameter over a long period). Data mining techniques are used to extract information from internet data. For example, the Padi-web platform[4], created by the European MOOD project and developed at the TETIS joint research unit, uses data mining techniques on materials posted on the internet and social networks (Facebook, Twitter) for the early detection of the emergence of animal diseases.

A key goal for researchers is also to ensure that this new knowledge is both accessible and usable, and they do so through their work on vocabularies and the semantic web in particular.

These technologies make it possible to tailor data collection to suit a particular user or purpose, even when they operate on a large scale.

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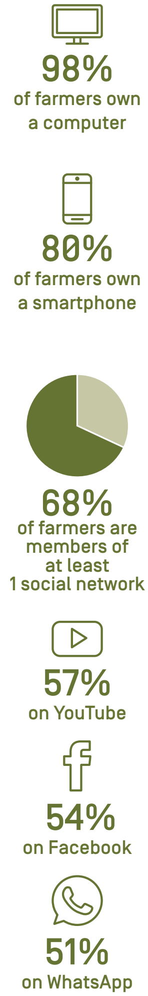
Connecting people

Exchanges between producers, processors, distributors and consumers throughout the food supply sector now occur at a faster pace and, increasingly, in virtual form. Connectivity and information systems permeate the industry's activities, including logistics.

Farmers in France are big technology fans and internet users. In 2022, 98% of farmers own a computer, and 80% have a smartphone[5]. They go online at least once a day to access information, mostly on the weather but also on new practices and technologies or to check the markets. Experienced users of social networking sites, YouTube, Facebook and WhatsApp in particular, farmers are members of multiple communities, using the latter for individual exchanges of information or to add data to shared information systems (on the weather or parasite levels, for example). Notably, 31% say that they have superfast connections. Some of them reach out beyond their professional interest groups to share their lives on Twitter and other networks, explaining their work on the farm and the challenges they face to a wider audience and offering a portrait of their profession that is both unvarnished and positive.

In a sector that expanded rapidly with lockdown, food distribution platforms operate at very different scales. While they may be owned by national distributors such as Grand Frais, a new and rapidly expanding player, initiatives at a more local level, driven by both individuals and groups, have also brought consumers and producers closer together. La Ruche qui dit Oui, for example, a network of local distribution hubs for neighbouring producers and customers, has now taken on all the trappings of a start-up, having very quickly grown its operations and sales figures, while numerous "fresh and local" initiatives have sprung up, driven by local communities who have been encouraged by the Egalim 2 Act (see page 71) to participate in the national move towards local food. Having observed the growth of these platforms during successive lockdowns, the ObSAT Observatory[6], run by the Alimentation Locale (local food) joint technological network (RMT)[7], nevertheless notes that many of them have more recently seen a downturn in profits, often brought about by hastily devised business plans that have not been thought through.



Source: Agrinautes study, 2022. bit.ly/3gajWkt

In today's world, there is a place for digital technology on all types of farm, whether conventional, organic, large or small, although it has historically been the larger intensive agricultural players who have benefited most. Reaching beyond agricultural practices and individual performance, digital makes new data available to value chains and brings greater ease of connection. In doing so, it is shifting the sector's dynamics of power and the patterns within the food value chain, offering a way to close the social gap in access to information. ●

4. https://agritrop.cirad.fr/594604/

5. bit.ly/3gajWkt

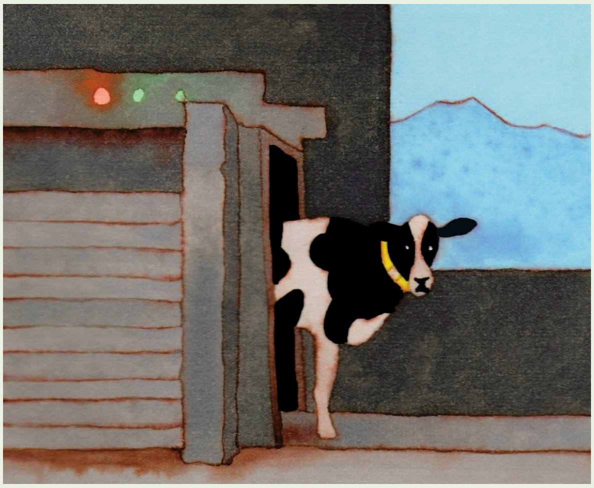
6. The Alimentation Locale joint technological network (RMT), which INRAE co-organises, created ObSAT, the observatory for local food systems, working with the Brittany CIVAMs, a federation of centres set up to promote and valorise farming and the countryside.

7. https://www.rmt-alimentation-locale.org

APPLICATION SHOWCASE

Livestock farming
Prevention is better than cure

Since the early years of the millennium, the monitoring of individual animals has meant that farmers can now tell at an early stage if their animals have health or behavioural problems or have come into season. Nathalie Mitton, a researcher at Inria and co-author of the white paper *Agriculture and Digital Technology* [1] offers us one example: *"One of our doctoral students founded a start-up that manufactures collars to monitor the health of cows. Usual behaviours (oestrus, calving) and unusual behaviours (limping, problem behaviours) as defined by farmers are incorporated as parameters in the tool. The data is transmitted by the sensors and analysed by artificial intelligence (AI). If there is a problem, an alarm is triggered, so that farmers don't have to keep going back to their animals to check their health. It's a step forward, both for animal welfare and for the farmers, who no longer have to perform so many painstaking and mentally-demanding tasks."* Similarly, machine learning and an indoor tracking system for individual dairy cows were used by INRAE doctoral student Nicolas Wagner to develop a health detection method in his thesis[2]. His method enables the detection of 90 to 100% of anomalies caused by health problems, often as much as 2 days before the first clinical symptoms can be detected by the farmer.



Pollination and biodiversity
Follow the bees

It is essential for beekeepers to track their bees to ensure good production levels and the availability of forage materials, but more frequent visits to the hive generate higher costs and each visit acts as a stressor for the insects. Based on research carried out by INRAE (Beelive project), the BeeGuard company has, since 2016, been selling systems to monitor hives and pollinator behaviours.

By installing sensors on the hives and elsewhere, beekeepers can monitor the good functioning of the hive without disturbing it, checking indicators for temperature, humidity and return rates to the hive. Information on the bees' comings and goings allows the beekeeper to keep an eye on resource levels in the surrounding area and to be alerted to any unanticipated rise in the mortality rate. Thus equipped, hives can act as early-warning systems for the quality of the environment.

1. It has been produced by teams from Inria and INRAE to set out their vision of the digital technology that should be developed for agroecology, see page 93.

2. Thesis title : Detecting changes to the pattern of animal activities across the day linked to pre-pathological states, stress, or a reproductive event, 2020, www.theses.fr/2020CLFAC032

3. National institutional hub for the shared provision of satellite imaging.

4. B2B agrifood platform which provides data on products from the farming sector.

5. Platform that collects data on processed food products for consumer apps.

6. Yuka is a mobile app that scans the information in a product's bar code to identify products that are bad for the consumer's health. It alerts users to high levels of of additives, salt, fat, or sugar in food products, and to potentially dangerous contents (endocrine disruptors, carcinogens, allergens) in cosmetics.

Crops
Detecting mildew with drones

The early detection of diseases and the exact location of infected plants help to optimise crop treatment and, above all, to reduce the use of phytopharmaceutical products. At farm scale, disease recognition and water stress programmes have been developed, such as that developed by Bordeaux company Chouette to detect the first signs of mildew on vine leaves using facial recognition principles. The drone carrying the camera is connected to GPS, providing vineyard owners with a map showing the exact location of the infected plants. Wine growers can then act early, targeting just the infected zone. Not only will this system allow them to reduce the spread of disease by taking early action, by facilitating the highly-targeted application of treatments, it will also reduce their use of phytopharmaceutical products.

A new method using IA to enable the detection of 90 to 100% of anomalies on cows caused by health problems.

Land management
Satellites to help environmental planning

The DINAMIS[3] platform brings together public and private partners from research and industry, including the French national centres and institutes

for space studies (CNES), scientific research (CNRS), development research (IRD) and agricultural research for international development (Cirad), along with the French version of the Ordnance Survey (IGN), Airbus and, of course, INRAE to provide access to a range of commercial images produced from optical data with very high spatial resolution, and a link to free high-resolution visual data and radar, using images from the Pléiades constellation and SPOT 6-7.
Images from Sentinel 2 will soon also be available. With an image resolution of up to 500 mm, the data allows the monitoring of agricultural fields (buildings, type of use, stage of crop growth, diseased zones), forested areas (species, felling, damage from disease) and bodies of surface water. These data are highly useful for development policies or local spatial planning, and for environmental monitoring and management.

Traceability
Databases for labelling

Farming and food production now generate large quantities of production data (origins, expiry dates, ingredients, time spent on pasture) that only digital technology is capable of processing, analysing and reproducing. Data is transmitted at all points along the production line to the end user, facilitating each production stage and, ultimately, feeding the databases of scoring systems such as Nutriscore or Eco-score, high-end quality-control systems such as the AOC/AOP and IGP systems, or labels such as the AB organic label in France.
In France, two platforms host the national databases. HubAlim[4] tracks data on agricultural products, while Num'Alim[5] collects information on industrially-processed food products, adding in corporate social responsibility data for each producer.
Apps such as YUKA[6] use Num'Alim's reference database (Univers'alim) as their source, the latter covering more than 250,000 food products sold in France. The data is displayed on packaging or can be accessed via on-line food sales sites.

Digital technology in farming

By improving production, tracking products, and cutting down on labor-intensive tasks, digital technology is now a fact of farming life.

❶ **Satellites** enable data transmission and help monitor individual land parcels, providing information on land use, yields, and crop development.

❷ **Collars fitted with transmitters** allow cows to move freely between the cowshed, the milking parlor, and the fields. They transmit information on the behavior of both individuals and the herd.

❸ **Robots** not only provide automated milking but also **analyze the milk** itself. Information on protein content, density, or the presence of antibiotics or parasites goes directly to the farmer via a server.

❹ Data on milk production levels, veterinary visits, herd numbers, and forage supplies help **farmers to manage their farms.**

❺ **Weather stations** measure air humidity, temperature, and wind strength. These factors determine the growth of meadows and crops.

❻ Guided by leaf colour, robots identify whether a vine is diseased and apply targeted spraying.

❼ Robots follow pickers during harvesting for fruit and vegetables, relieving them of their loads.

❽ Drones equipped with cameras or thermal sensors overfly fields and transmit data on the condition of soils and crops.

❾ The data transmitted to farmers via mobile phone satellite networks or short-wave radio (where there is no mobile phone coverage), allow them to monitor yields and soil moisture levels and warn them of bad weather.

❿ Networked grain silos provide tailored remote alerts for humidity and temperature levels, warning farmers when mold might appear in the grain and cutting waste by 10%.

⓫ Networked traps in orchards allow pests identification and alert farmers of their presence. They also send the data to the National epidemic monitoring service.

⓬ Data on the origin, mode of production, and processing of food ensures that food products can be traced from the producer right through to the consumer, regardless of the sales route (farm gate, local groups supporting small farmers (AMAP), shops), using labelling and applications such as Yuka.

CLOSER CONNECTIONS FOR STRONG LOCAL RESILIENCE

Digital has changed how we communicate, introducing new players, reconfiguring networks and transforming the shape of the economic landscape. In the agrifood sector in France, it has strengthened the role of the consumer and allowed new value chains to emerge that serve the community.
Analysis.

Even in France, where food is officially a national heritage asset, consumers have been seduced by the advantages of ready meals for some decades now. Processed foods have taken over from fresh ingredients, pumping the latter with preservatives and additives. The market has been industrialised and globalised, distancing producers and consumers. In a highly urbanised country such as France, the relationship between people, food and agriculture has undergone a profound change. And, as one crisis succeeds another and poor practices in the agrifood industry are exposed, a degree of distrust has crept into the relationship.
Meanwhile, the ongoing environmental debate has revealed quite how far agriculture is both perpetrator and victim of environmental pollution and degradation. Fortunately, though, farming can also help to remedy the situation. In the current cultural space, where tensions and doubts over production practices abound, the spread of digital in farming is reconfiguring the relationships between actors by taking out the middlemen and strengthening direct relationships between consumers and farmers. It is also introducing tools to restore confidence and ensure transparency in what is becoming a shared management of the environment.

Closer links in new value chains

The prevalence of online orders and deliveries via the websites of major distributors, or direct sales platforms for local producers, such as la Ruche qui dit Oui and Locavor in France, means that online hubs now form part of our daily lives. According to Isabelle Piot-Lepetit, Scientific Director at #DigitAg, *"Value chains are changing as the result of digital, shaped by all those involved, from field to fork. The disruption stems from the fact that our chains are turning into multi-directional networks. A farmer can simultaneously supply supermarkets, specialist shops or private customers. Platforms allow users to cut out the middle man, to the benefit of both consumers and producers."* Digital can thus offer genuine opportunities to farmers to find and create a loyal client base that knows about their farming methods. At the other end of what is often a shorter chain, it helps consumers to make choices on the basis of their greater knowledge of production methods. Responding to strong public demand, traceability for human and animal foodstuffs has been man-

datory in France since 2002. Shop shelves are packed with engaging stories on food sources, contents and methods of production, and consumers are dazzled by an array of certification labels, some might say to the point of confusion. While it does the job of raising consumer confidence levels, traceability also gives power to the newly-informed consumer. When consumers make choices concerning free-range and organic farming methods, local suppliers, environmental footprints or fair payment to farmers, they influence the supply system. *"The chain is now being reversed, with consumers driving the process. For example, the C'est qui le patron? (who's the boss?) initiative makes sure that all its products are created, selected and tested by the consumers within the group. The consumer is increasingly becoming an actor in this new value chain"*, explains Isabelle Piot-Lepetit.
Interestingly, in a study on local food platforms, the French Observatory for Local Food Systems (ObSAT) recently found that, *"of the hundred platforms in the study, those that were inclusive of farmers, providing information on their farming practices and giving them a voice, proved to be more resilient when consumer footfall dropped after lockdown was over"*.

An instrument for local food systems

Digital technologies are also useful in helping the various agrifood sectors to organise themselves within each agricultural area and to build links between areas, starting with on-farm practices, where the focus has moved beyond the confines of the individual field or parcel. A well-connected farming population is able to improve its coordination and keep its risks low. For example, the sowing dates for sunflowers can be synchronised, enabling farmers to mitigate the damage caused by corvids that eat the seed.
In France, local food projects (PATs) have been introduced to make agriculture and food in the regions a more local affair altogether, providing support to new farmers, short supply chains and the use of local products in canteens. Brought in by the 2014 French Future of Farming Act, these PATs are co-created by groups of local actors (municipalities, agricultural or agrifood businesses, artisans, members of the public, etc.) always with digital support.
"Since the Egalim 2 Act, localism has taken off. Indeed, for local authority canteens, 50% of products must now be sustainable [1] *and 20% must be organic. Continuity of supply is a major issue for local authorities and the quantities involved are enormous. In the Occitanie region, for example, a total of 40 million school meals must be supplied and managed each year. There are two possible ways to deal with this demand – either the system can use large mixed farms, or smaller fruit and vegetable production units can be combined, although for the second to work, you need a production and logistics plan and the whole network has to be managed. This is what Bonduelle does to supply its factories, placing farmers under contract. A #DigitAg thesis is currently looking at the planning and optimisation of fruit and vegetable crop rotations for today's market at farm scale, and this could pave the way for upscaling"*, explains Véronique Bellon-Maurel, Director of #DigitAg.
The greater Montpellier area (Montpellier Méditerranée Métropole intercommunal structure) has taken steps to encourage agroecology. Certified as a French market of national interest (MIN), the Mercadis platform connects professional buyers and producers. It encourages short supply chains and environmentally-friendly production and →

FUTURE

What sort of food future do we want?

A study[2] on future trends in food distribution, led by INRAE and Grenoble INP, has examined possible scenarios for the development of food markets in the next twenty years. The study looked at scenarios defined by four different ways for society to approach the market. In the first, "Individualism", the consumer's personal desires rule the market, giving the upper hand to the Big Five web giants (GAFAM). In the second, "Committed Engagement", the management of common goods and the fair payment of farmers become a focus for consumers, whose views are expressed via on-line platforms. These issues also shape major public policies in this scenario. The third, "Communities", leads to an archipelago of contrasting and incompatible food supply models. Last, a "Low Cost", scenario leads to reductions in product quality and in returns for farmers following a price war between platforms. Bernard Ruffieux, who led the study, concludes: *"E-commerce and local logistics are here to stay. But the way they shape the future has yet to be decided. Although the big platforms like Amazon and established operators are currently in the process of revising their economic models, consumers and public policy makers will also get a say in the matter"*.

ISSUE

Keeping food and data safe: trust, traceability and transparency

From the monitoring of goods to their eventual recall, the traceability of food products is a matter of public health. Guarantees must be provided for the quality of the data used in the process, but data security is just as important. In France, information on food products' provenance, expiry dates, ingredients and, for meat and dairy products, how much time animals have spent on pasture, is greatly appreciated by consumers. Only digital technology has the capacity to process, analyse and reproduce all these data. They are transmitted at all stages of production right through to the consumer and beyond, feeding into the databases of scoring systems such as Nutriscore or Eco-score, and of quality control systems such as the AOC and IGP certifications of origin, or labels like the French AB organic label. Digital can also track the consumer, analysing responses to the different types of product information.But how can we have confidence in the reliability of these systems, given their reliance on a vast pool of aggregated data trawled from an even vaster ocean of sources? Jérôme François, Director of the Num'Alim agrifood platform, explains the process: *"Currently, the error rates for data supplied by the industry lie between 30 and 50%. Although most of the errors simply involve a missing decimal point or a mix-up between kilocalories and kilojoules, on occasion, more serious errors arise, for instance in cases where the information on allergens is incorrect. Here, by putting the users of their websites or apps at risk, businesses are playing with fire. That's why our SCIC (public interest cooperative company), where agrifood businesses, consumer associations and public authorities work alongside each other, is supplying tools to our members so they can check their data with our partner Consotrust and can clean it up using machine learning, ironing out errors at an early stage."*

Because of the substantial contribution made by human error to the inaccuracies in food data, researchers need to develop data acquisition technologies with less human involvement. For example, as part of the interdisciplinary work at #DigitAg, the Convergence Institute for digital agriculture[3], an interdisciplinary postdoctoral researcher (INRAE-University of Montpellier) is exploring the possibility of linking sensors to RFID labels so that, in addition to tracking a product, they could also monitor the rate at which it deteriorates[4]. Data quality is a must, but the reliability and security of data transfers and flows is just as important, especially where food safety is concerned. For a number of years now, the Blockchain tool has been in the news. Originally created to ensure the safety of cryptocurrency transfers, it is well-suited to deal with the challenges of supply chains involving many actors in multiple sectors, both old and new, all with very different needs. A blockchain database is shared by all its users, with the data organised into blocks. For a block to be added to the chain, a complex validation algorithm is applied that calls for various forms of consensus from its users. Once validated, the block is added to the chain and can no longer be changed, preventing users from modifying data unilaterally. The drawback of blockchain as a security solution for information systems is its high energy consumption in systems that invite a large number of users.

promotes the return to local agricultural and food products, with a focus on an "organic and local market floor". More than this, it is working to reduce food insecurity and has made it easier for providers of food aid to access fresh local produce by enrolling the MIN in the Centrale de Règlement des Titres, the French food voucher scheme. The platform's logistical data fIows are streamlined by digital technology. Similarly, as part of the "BoCal, Bon et Local" initiative, a local website (bocal.montpelliers3m.fr), posts listings of short supply chains for consumers. These practical applications of the local authority's agroecological and sustainable food policies are co-produced with societies, farmers, the scientific community and the consumers of Montpellier.

To construct a project, participants need access to both information and know-how. How do you conduct a competitive analysis? What supply chains should be developed in an area? The answers are provided by the "Alimentation Locale" joint technology network (RMT), which promotes local food, and, through ObSAT, its Observatory for Local Food Systems. It supplies producers, municipalities and other facilitators with reliable figures on the economics of production, transformation and distribution logistics for short supply chains, helping them to put together local food projects and strengthen their business plans. Its database is open (data that are freely available for use by all), participative (in partnership with the French Chambers of Agriculture and the consumer group UFC Que Choisir), and aggregated (using different data sources).

Shared management and public policy

Digital technologies can also play a role in monitoring systems and strengthening the effectiveness of public-sector initiatives.

In response to repeated public health emergencies, the French government set up three platforms in 2018 to monitor the spread of infectious diseases (dealing respectively with animal health, plant health and the food chain), co-managed by INRAE, DGAL and the ANSES. Their purpose is to collect data to optimise the public health monitoring system. Collecting and sharing data from farmers and industry can speed up the detection of emerging diseases or the presence of pests, parasites or pollutants, quickly pinpointing their locations and enabling the direct management of an outbreak at its point of origin. Meanwhile, the Padi-web platform uses data collected on the internet to offer the same service for animal diseases (MOOD project, *see page 68*).

Water, soil and the air we breathe are common goods. The decline in their quality over the past decades has led in France to the introduction of public policies for their improvement or restoration. Digital's vast and varied information-gathering powers and the opportunities it provides to share and exchange information and analysis have opened up a collective space in which the tools and information are now available to assess a given situation, define shared goals and establish joint strategies. Digital tools thus make shared management possible at local scale, building consensus and creating local action plans to conserve goods that benefit whole communities. They allow measures to be taken beyond the confines of fields and farms and a comprehensive strategic vision to be developed for a local area that improves the management of agricultural impacts. The conditions are thereby created for common goods to occupy a different social space.

Remote sensing also has a place in the implementation of Europe-wide and national policies. In line with the European Green Deal[5], which has allowed the European Union to prioritise ecological and health issues, the next Common Agricultural Policy will link some of its funding to good farming practices and the reduction of environmental impacts. The rules for eco-schemes will thus make grants conditional on the presence of hedgerows or buffer strips on a minimum of 10% of a farmer's land. There must, however, be a way to check whether farmers have indeed planted the hedgerows they declare in their submissions. The satellite offer from the DINAMIS consortium (see page 11) constitutes a first step towards such monitoring, giving greater force to the policies in place.

By bringing producers and consumers closer together, digital allows greater transparency in the sector's responses to society's renewed interest in natural products and in environmentally-friendly practices. In making local systems easier to manage, it places greater emphasis on shared and public action. But to what end? ●

1. Sustainable products: products that fairly reward the producer and are environmentally friendly.

2. Foresight study "Quatre scénarios pour éclairer la distribution alimentaire du futur", published in February 2022 and led by Bernard Ruffieux, Professor at the Grenoble and Louis-Georges Soler National Heritage Institute (INP) and Assistant Director of Science in Food and Bioeconomics at INRAE.

3. www.hdigitag.fr

4. The sensor is a biopolymer that reacts to the gases (CO2 and ethanol) given off by food as it deteriorates. It is attached to the internal surface of the packaging, just under the RFID label stuck on the outside. As the food product decomposes, the gases given off alter the electrolytes in the biopolymer, and the RFID reacts. This research is being conducted in the Electronics and Systems Institute (MRU 5214) and in the Agropolymer Engineering and Emerging Technologies laboratory (INRAE-University of Montpellier).

5. bit.ly/3MDhcbw

ON TRACK FOR AGROECOLOGY

Agroecology offers a framework for adaptation and transition that is well-recognised within the scientific community, not least by INRAE. It has also received the endorsement of the High-Level Panel of experts (HLPE)[1] of the CFS, the Committee on World Food Security, who consider it to provide a viable way forward. France and its European neighbours have made agroecological transition a priority, so what can be done to turn digital technology into a lever and accelerator for the transformation that is needed?

Solutions.

Climate change, soil impoverishment and biodiversity loss are producing a growing crisis of identity for the agricultural sector. To compound these pressures, we have seen a rise in the global human population and food demand, a fall in the numbers of available agricultural workers and, in Western countries, increasingly strong public demand for environmentally friendly, healthy and affordable production methods. The two most recent crises for Europe – COVID19 and war in Ukraine – have demonstrated our resilience, but have also exposed the vulnerabilities in our agriculture, reminding us that the issue of food security is still very much on the agenda. Agroecology is particularly well placed to adjust to these many challenges by putting ecosystems at the heart of production models, reasserting the local nature of food and recalibrating the value chain to give greater recognition to producers. The question is, can digital accelerate this transition? Despite attempts to construct an oppositional narrative for agriculture and digital, the two in fact operate as different dimensions of a complex system and INRAE has set itself the task of studying and encouraging the synergies between them, aiming to produce healthy and sustainable farming and food systems in which farmers retain their autonomy of decision and action. Digital has indeed been shown to be a lever for agroecological transition, with the potential to support and accelerate the adoption of this model. But we have to look at how this will work in practice.

1. Report of the High-Level Panel of Experts of the Committee on World Food Security – July 2019. bit.ly/3CIF88J

2. Food security, as defined by the Committee for World Food Security, exists when *"all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life"*. This definition was agreed at the Rome summit of 1996, and is to be found in the World Food Summit Plan of Action.

Combining agronomy and ecology

Inevitably, we are landing on the issue of sustainability. According to the United Nations, food sustainability depends above all on food security[2], that is, on the provision of adequate, healthy and nutritious food for all. The United Nations also extends its definition to include practices that are culturally acceptable, financially equitable and accessible to all and, importantly, it also includes the need to reduce the toll taken on the environment. To reduce the harm done to the environment and to cut down on losses and waste, we must re-think agricultural systems, like food systems, in a global and cross-cutting way. All the links in the chain must be integrated, from the enterprises and industries that support agricultural production (seed production, fertilisers, etc.), to logistics and distribution once products have left the agrifood processing lines. Two agricul-

© Christophe Maître /INRAE

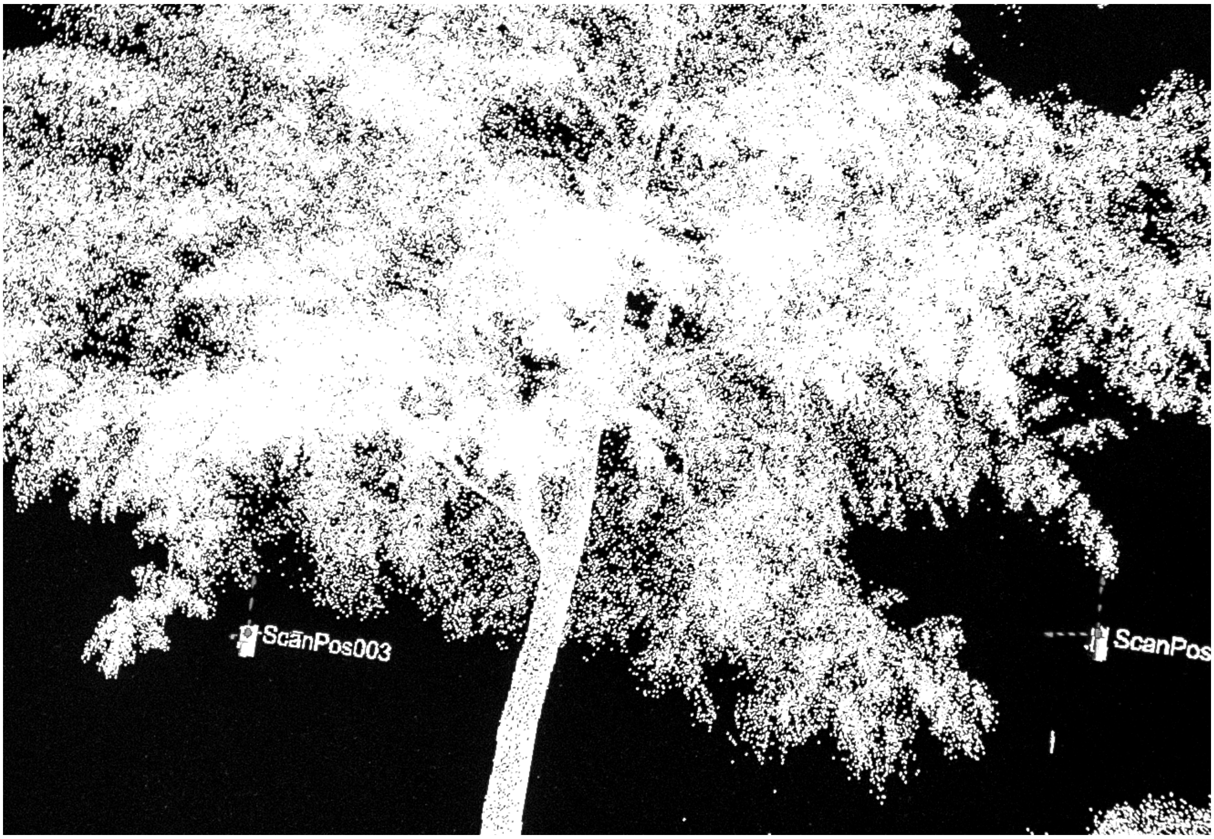
↑ Measuring climatic parameters, including access to sunlight, in an agroforestry field associating barley, wild oats and walnut trees.

tural models have been recommended by the HLPE: sustainable intensification and agroecology. The second, which is a break away from the conventional agricultural practices of developed countries, has been adopted by INRAE, pursuing a model that is supported by both the European Union and France.

So what is Agroecology? As its name suggests, this model combines the principles of agronomy and ecology. It sets out to improve the way that ecosystems function, enhancing their self-regulatory capacity while alleviating the pressures placed on them by human activity. It reduces the use of synthetic inputs (pesticides, fertilisers, antibiotics) and is built around the principles of ecology and functional biodiversity, displaying sobriety and respect for the cycle of natural inputs (water, organic matter, nutrients). It thus acts as a brake on the pollution of soils and watercourses, conserves resources and encourages natural regeneration. It generates benefits for animal welfare and promotes a better living for farmers (revenues, independence, the continuation of family farming, decent jobs, etc.).

According to Xavier Reboud, appointed to lead the Agriculture and Digital project by INRAE's scientific directorate on Agriculture, *"Agriculture is going to change, whatever we do. That doesn't mean that we can't make use of digital technology to accelerate that change. Developing agroecology on a large scale is no easy task. Its ecosystems are more complex than those of traditional agriculture. They need careful management, adjusting to variations in both the immediate conditions and the wider environment. And, sometimes, we just don't have the knowledge. We need to learn more on how to manage intercropping and get to know our soils better, to explore how microclimates work and discover more about the vast number of microorganisms that can either help or hinder farmers. And that is simply not possible without the help of digital tools.*

One issue that research is going to have to address in the medium term is the possible use of digital twin technology on farms to support the agroecological transition. If we were to use this technology on farms, it would involve the creation of digital 'twins', exact virtual replicas of particular physical features such as fields, animals or machines, whose creation is made possible by the use of data from sensors and cameras on the ground. They could help to optimise water use, guide the distribution of seed and the targeted application of fertilisers, reduce pesticide use, or track a herd's state of health." →



↑
Assessing tree growth in agroforestry using Lidar technology.

Improving ecosystem management by expanding our knowledge

Ecosystems function in a highly complex manner. We are only just beginning to explore their processes and functions – the ways organisms interact, the effects of biodiversity, the ability of certain species to resist, recover and adapt when confronted with disease, parasites or climate hazards, and the composition and capacities of the soil. We need to know far more than we do at present about biodiversity, habitats and how they function, if we are to reproduce their benefits to agriculture or even attempt to guide their evolution in response to climate change. Farming practices such as intercropping, crop rotation, the use of service crops and the diversification of varieties and breeds are all agroecological levers that are directly inspired by biodiversity. The many operations required to monitor them closely can be mastered and managed with the help of digital systems.

The use of sensors to collect large-scale data on the landscape and behaviours, the massive data used in genomics and the development of vast computer-processing and storage capacity have created the opportunity to understand and model the behaviours of species, crops and agrosystems. While applying different constraints or different technical approaches. At the same time, apps for farming advice and planning make it easier for farmers to manage complex cropping systems and to combine several different performance criteria such as yield, quality and environmental impact.

A meadow, with the diversity of species it contains, offers a smaller-scale example of a complex system. Grazing their herds on pasture is advantageous to livestock farmers in terms of both their place in the local economy (giving them greater autonomy within the system) and the health and productivity of their animals. For these gains to be achieved, though, it is critical to be able choose a seed mix that will produce the characteristics farmers want. Co-created by the MAGELLAN team from INRAE's Occitanie-Toulouse AGIR joint research unit with the help of 300 livestock farmers and 16 agricultural advisers, the CAPFLOR app offers advice to farmers on seed mixtures (containing between 6 and 14 species or varieties). It enablesthem to choose mixes that are not only suited to the soil types and climate conditions of their chosen fields, but also fit with their particular farm management practices.

19%
of GHGs in France come from agriculture, of which:

48 % from livestock farming

40 % from arable crops

12 % from motors (engines, machines)

Looking beyond the field boundary

Digital technology can also help to identify flows of materials, allowing existing systems to be modelled and new circular economic models to be generated. For example, the Organix marketplace set up by Suez allows organic-waste producers and the managers of anaerobic digesters to work together to optimise waste supplies and flows. The Maelab startup, incubated by the Agronomy and Environment laboratory (INRAE-University of Lorraine), helps local people to create and evaluate scenarios for transformation at the field, farm and local-area scales. An associated research project, currently being developed as part of the wider FairCarboN Priority Research Programme and Infrastructure (PEPR) launched in 2022, involves the creation of a multi-agent modelling platform. It will be able to assess carbon dynamics at local scales. Ultimately, this project will make it possible to assess carbon flows, proposing scenarios for change with a 2030-2050 horizon and focusing in particular on industrial practices and spatial planning.

Contributing to ecosystem services

Reducing air, water and soil pollution by the adaptive use of organic fertilisers, managing soils and planting cover crops to limit greenhouse gas emissions (GHGs) or, again, restoring biodiversity through hedge planting and the creation of permanent meadows, are all considered to be ecosystem services. Véronique Bellon-Maurel, Director of #DigitAg, tells us more about how digital technology can help: *"Just as digital enables us to create individually-tailored medical services, it can also be used to monitor agricultural and ecological systems. The forthcoming version of the European Common Agricultural Policy calls for a more detailed assessment of the impacts of farm production and for the more sober management of resources (a 20% reduction in mineral nitrogen inputs, for example, under the Green Deal). Member States are expected to transition to systems that make it easy to generate large quantities of data on carbon capture, soil nitrogen levels and the state of biodiversity."*
In France, of the human activities responsible for the emission of GHGs, agriculture is ranked equal second with manufacturing (contributing 19% of the total)[3]. The chief culprits are livestock farming, which can lay claim to 48% of total agricultural emissions (mostly via methane, CH_4), and cereal crops, which contribute 40% (mostly nitrous oxide, N_2O). Since 1990, though, agricultural emissions have been falling at a steady rate (9%). One of the various emission reduction schemes to reduce the contribution of agriculture, the 4 per 1,000 initiative launched by INRAE, sets out to achieve a 0.4% world-wide increase in carbon sequestration across all types of agricultural soils (arable, forests, meadows), matching the annual increase in global CO_2 emissions generated by human activities. It plans to do so by creating and maintaining permanent grasslands and by changing agricultural practices in grain-growing areas. Meanwhile, policies such as the European Green Deal and France's national low-carbon strategy seek to encourage environmentally-friendly practices, including carbon sequestration. To be certain that they are effective, we need indicators we can trust. The European NIVA (New IACS Vision in Action) programme, to which INRAE is a contributor, is working on methods to calculate three Common Agricultural Policy indicators: carbon sequestration, nitrate removal and biodiversity. The approach combines data from many sources, including the French RPG (part of the wider CAP land-parcel identification system, recording details provided by farmers such as parcel plans, crops produced and activities), the SENTINEL satellites, open-source data such as weather data, and the data provided directly by farmers themselves. These disparate data have to be processed by dedicated software so they can be linked and analysed together at the correct scale.

New-found freedom for farmers

Microchips that automatically detect unusual

Agroecology is well placed to adjust to the many challenges of food security by putting ecosystems at the heart of production models.

→

3. CITEPA activity report 2021; bit.ly/3MGw8FV

EXPERIMEN-TATION

The robotics revolution

Robots, like models, have to evolve to meet new needs and they must be able to adapt to the variations they will encounter in crop development, farmed animals or environments. This is particularly true in the case of selective hoeing and weeding. These techniques that fell into disuse with the advent of phytosanitary products, have re-emerged as possible solutions decades later, now that the drawbacks of synthetic chemicals have belatedly been recognised. The ROSE Challenge, an experimental research programme funded jointly by the French Ecophyto programme and the ANR, has pitted four teams of public researchers and equipment providers against each other in a quest for mechanical and technological alternatives to herbicides. The projects cover the whole chain, providing integrated robotic solutions from the initial identification of weeds on crop rows through to their selective elimination.

The adaptive capabilities of robotic tools can decide the success or failure of the sort of high-precision performance that is needed to differentiate between highly complex crops and to carry out targeted and specific actions. At larger scales, the manual execution of such tasks becomes a practical impossibility, creating demand for a new generation of autonomous tools. Here, robotic design is moving beyond the use of single machines that operate individually to groups of robots that can act in concert. Farmers select the number of robots they need for a particular task and assign them different roles depending on the nature and context of the work to be carried out. These new modular agricultural systems are lighter-weight, causing less soil compaction, and are able to cooperate with each other. There is no reason why such systems should not be shared by a group of farmers. This sort of radically new vision will be one of the legacies of the Adap2E project[1]. INRAE has also teamed up with SabiAgri, the agricultural equipment manufacturer, to work on human-robot dialogue. The Tiara[2] laboratory is conducting research on the decision-making capabilities of artificial intelligence and the on-line reconfiguration of robotic behaviours. This work has been scaled up to national level, where Inria, the CEA and INRAE are coordinating the NinSar project, working with the French robotic community to develop the smaller and more manoeuvrable mobile manipulators that are needed as part of agroecological crop management[3].

← The Ted vineyard robot spans both sides of the vines for precision weeding to reduce competition for water.

1. See note 1 page 67.

2. Tiara (Toward intelligent adaptable robots for agriculture) is a collaborative research programme funded by the ANR as part of the LabCom 2019 programme, bringing together the Romea team from the TSCF research unit and the SabiAgri company. Https://www6.inrae.fr/tiara

3. Funded under the Agroecology and Digital PEPR and supported by the Sadea acceleration strategy.

© Christophe Maitre / INRAE

↑
In Brittany, the Institute for Genetics, Environment and Plant Protection is testing sensors for detecting mildew on potatoes.

behaviours in cows allow farmers to reduce the time they spend monitoring a herd, while they can cut down on drudgery by using automated systems to deliver food to feeding troughs, or robots to carry out other tasks. Such digital developments free up farmers to work on their action priorities and gain greater strategic control over their businesses which, in turn, brings them greater autonomy. The new proximity with consumers of all kinds made possible by such technologies allows farmers to tailor their production methods to their markets and gain greater control over their income levels. By making visible the ways that farmers contribute to landscape biodiversity and the enhancement of common goods, and by helping them to strengthen these contributions, digital technology provides a means for farmers to take pride in the actions they take for the wider benefit of society.

Avoiding waste

Losses and waste absorb 30% of the world's agricultural production. In cereal crops, grain loss during storage can represent up to 10% of total volume and is mostly caused by the development of mould under damp conditions. The SISAM project[4], run by the PANAM France SAS with support from LAAS-CNRS, is currently working on a system to monitor the status of stored seed and grain and on the remote control of silo atmospheres (in terms of temperature, humidity, CO_2 and pressure levels). This not only saves on seed, it also allows farmers to avoid the application of post-harvest treatments and optimise their energy consumption. In towns and cities, too, apps such as TooGoodToGo enable individuals to buy goods that are reaching their sell-by dates, contributing to waste reduction and the local circulation of foodstuffs.

Conclusion

To function properly, agroecological approaches to sustainability require systemic engagement across an entire local area. Calling for a wider strategic vision, they also improve community resilience. With the support of digital technologies, it becomes possible for the agroecological model to be applied on a large scale. That is not to say, though, that there are no pitfalls along the way. ●

4. The SISAM project is an intelligent seed storage system under a modified atmosphere; bit.ly/3TcN2OH

ACCELERATING TRANSITION, BUT NOT AT ANY COST

Information technology offers unparalleled and renewed opportunities for understanding, action and communication and, as such, can be a formidable lever to accelerate agroecological transition and sustainable food. However, as we move down this route of technological acceleration and change, we need to be alert to certain risks. **Overview.**

Following the arrival of Fintech, Medtech and Foodtech, Agtech[1] has now hit the markets. Attracting a hefty 51.7 billion dollars of global investments in 2021[2], the digital farming industry has seen the creation of thousands of startups across the world, including some 400 in France. With an eye to its development potential, investors and entrepreneurs have now turned digital agriculture into a priority market. Its development is surging in response to a variety of needs, despite certain constraints imposed by a sometimes poor fit between the practices and knowledge accrued by the tech industry and the workings of agriculture. Véronique Bellon-Maurel describes the work being done: *"The development of a form of digital agriculture adapted to agroecology is now underway. A whole catalogue of smart benefits, including new ways to acquire and process data, automated tasks, internet connectivity and on-line exchanges, is providing us with the opportunity to develop a comprehensive set of solutions that can help the transition towards sustainable agriculture and food systems that respect the needs of both humans and animals. We do nevertheless still have to make sure we fully understand the risks, so we don't end up going down the wrong path."*

1. The use of technology in agriculture, horticulture and pisciculture (software, automation, data analysis) to improve the yields, efficiency and viability of the farming sector.

2. url.inrae.fr/3FyZFQk

3. Agrinautes study 2022, bit.ly/3gajWkt

Accessibility and the co-creation of tools

Information technology enables major gains to be achieved in production quality, environmental co-benefits and reduced costs (fewer fertilisers), with the potential to benefit large numbers of people. But we still have to make sure that the intended beneficiaries, in this case farmers, are in fact able to access and enjoy the promised rewards.

Out in a farmer's fields, or in the livestock sheds, sensors tend to function individually often without access to mains power. Ingenious solutions can be needed to help them transmit their data. WiFi is out of the equation because it uses too much energy, and the coverage provided by cellphone networks (3G, 4G and 5G) is still incomplete in agricultural areas. Although in France the 3G network has recently been greatly expanded and now provides a service to 95%[3] of farmers, 5% still have no connectivity and often only the farm office can pick up a signal. Last, even when they have coverage, 5% of farmers still have to cope with low speeds. *"We need to set up spontaneous networks that can communicate from one sensor to* *another, or that can sometimes operate as part of hybrid networks, interacting with passing drones or tractors"*, says Nathalie Mitton. *"The idea is for the system to be sufficiently agile to seize on every possible communication route, even using community radio frequencies."* Establishing full network coverage in rural areas thus still needs to be encouraged.

Digital tools can make a positive contribution to a farm's viability, but they can only do so if farmers and the agri-food sector are prepared to use them. A DSS, for example, if it offers too many warnings, or is too complicated to use, may well be abandoned. INRAE's researchers, especially the members of the #DigitAg team, are working to identify the obstacles and drivers associated with take-up, seeking to establish whether the data are relevant and clearly presented, and whether interfaces are ergonomic and easy to use. Other than these technical and practical user-focused issues, there is also an ethical concern over the purposes to which users may put their new-found knowledge. Here, the process of open innovation can help in the search for answers, allowing all stakeholders to be included from the outset.

Florence Amardeilh, co-founder of Elzeard, looks back on the development of her planning software for fruit and vegetable farms: *"When I went out to visit farmers, I realised that the fruit and vegetable growers were still working with pencil and paper or using Excel spreadsheets. As I didn't want to simply impose a tool on them, we started by learning the business and we spent time with them on the ground. It took two years of conversations before we wrote even a single line of code."* Accessibility is, of course, also about costs, or rather about the cost/benefit ratio for professionals who are seasoned borrowers when they are confident that a capital investment will deliver what they need. Margins are all the more critical because a farm's viability relates to its size. Xavier Reboud recalls the experience of AirInnov, a startup that offered to provide farmers with aerial images of their fields. *"It seemed as though the drone would be a real help in improving the processing of in-field data because it allowed better monitoring of the crops, but the company went into liquidation. With an average annual margin of just 70€ per hectare, some of the farmers stopped using the service because it cost too much."* →

INNOVATION AND ACCESSIBILITY

A travelling apps laboratory

The French Agro Institute has created a travelling laboratory on wheels, co-funded by the AgroTIC Chair and Occitanum.

The mission of this AgroTIC Mobilab is to raise awareness among farmers of ways to apply technology in agriculture. Simon Moinard, who runs the mobile lab, tells us more: *"We go out to visit farmers and let them see the range of different sensors for themselves, we explain how they work and what their limitations are. Often, they realise that they have not been using them properly and that, as a result, returns have been poor. These discussions serve a dual purpose: we come away with information on the needs and practices of the farmers so we can develop new sensors that are more relevant, and they become more proficient in their use of the new technologies. They can then enter into a more constructive dialogue with service providers. Although some of them may find digital a daunting prospect at first, they quickly realise that, ultimately, it is quite simple and can enable them to protect their harvests and improve their environmental footprint."*

Good data governance and protection of the data supplier

A single piece of data has no value. Combined with other data, though, it can become extremely useful. Compared with other sectors, the data collected for agricultural purposes often comes from a very wide range of sources. This introduces question marks over quality control and interoperability, both preconditions for any system to work properly.

In its 2019 report, "Cost of not having FAIR research data", the European Commission reported an annual cost to Europe of 10.2 billion euros[4] from poor data management in research, measured in time spent, cost of storage, licence costs, research retraction, double funding, lack of interdisciplinarity and loss of potential growth. It stressed that, contrary to popular wisdom, open data and its sharing can be beneficial, even to data holders. Indeed, a recent analysis[5] of scientific publications has shown that citation rates are higher for publications with linked data because of their greater accessibility. The Commission, like the French State, is working to increase open data, speaking out for the principle of FAIR data (Findable, Accessible, Interoperable, Reusable). In July 2021, the French government asked INRAE to set up and manage the Recherche Data Gouv platform[6]. Since July 2022, the platform has offered a multidisciplinary storage facility for all researchers who seek a secure space to upload their data.

Isabelle Piot-Lepetit, has observed and argued for the need for transparent stewardship in the collection of data from individuals: *"In a thesis on common goods at #DigitAg, one of our doctoral students attempted to set up an open seed platform for farmers. The farmers refused to cooperate, preferring to stick to closed data systems for clearly defined on-farm purposes with identified returns. To develop open systems and pool information, there has to be trust in the stewardship of the data. Data-management rules, in particular, need to be put in place so that participants don't feel exploited and retain the sense that they still have agency within the system."*

Issues can also often arise over the particular vocabulary used by those working digital technology. Research teams such as the working group of the AgriSemantic Research Data Alliance (RDA) are seeking to create a "shared language" that would facilitate the exchange and sharing of agricultural data. To achieve their goal, the researchers are studying the different vocabularies in use and the semantic links between them[7].

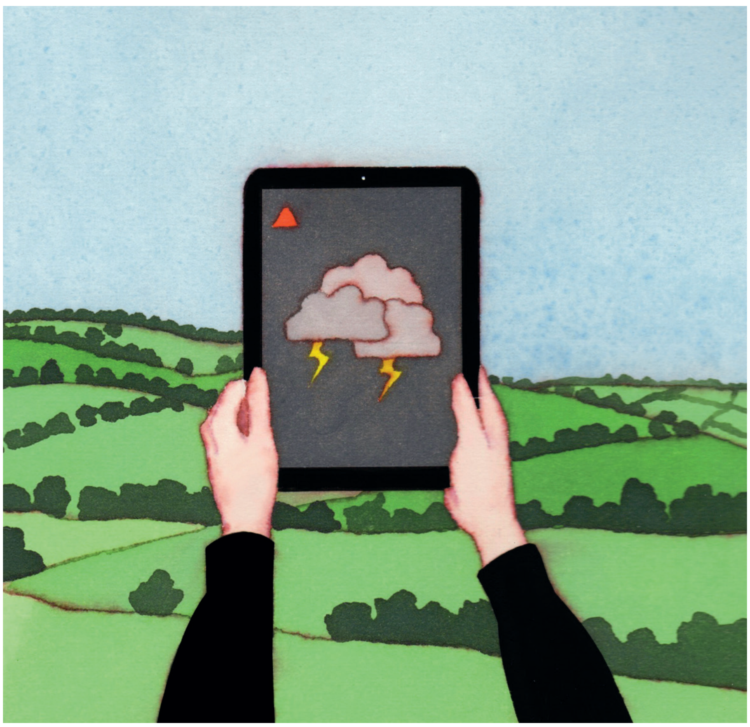
Beyond the issues of quality surrounding the collection and storage of data, we need to be able to collate data derived from different sources and of different kinds. For this, shared standards need to be defined. INRAE is a member of the Agro EDI Europe Association[8], which works to facilitate the exchange of electronic data between stakeholders in the agricultural world. Although the standards that are already in operation in the supply chain (for invoices, orders, etc.) now ensure the success of 99% of transactions, many other standards still remain to be defined, in particular those that relate to data on the individual parcels of land owned by farmers. *"A standard is a bit like the grammatical structure of a sentence. For each purpose, we create a sentence structure, add elements and document the data. For the 'invoices' standard, for example, we start with international norms and we then add in the details that are needed for the agricultural sector. At the same time, we also create reference systems that assign the same binary code to each word*

4. bit.ly/3ArQ7mE

5. Colavizza G. et al., 2020. bit.ly/3T8ZAH6

6. recherche.data.gouv.fr/en

7. Aubin S. et al., 2017.



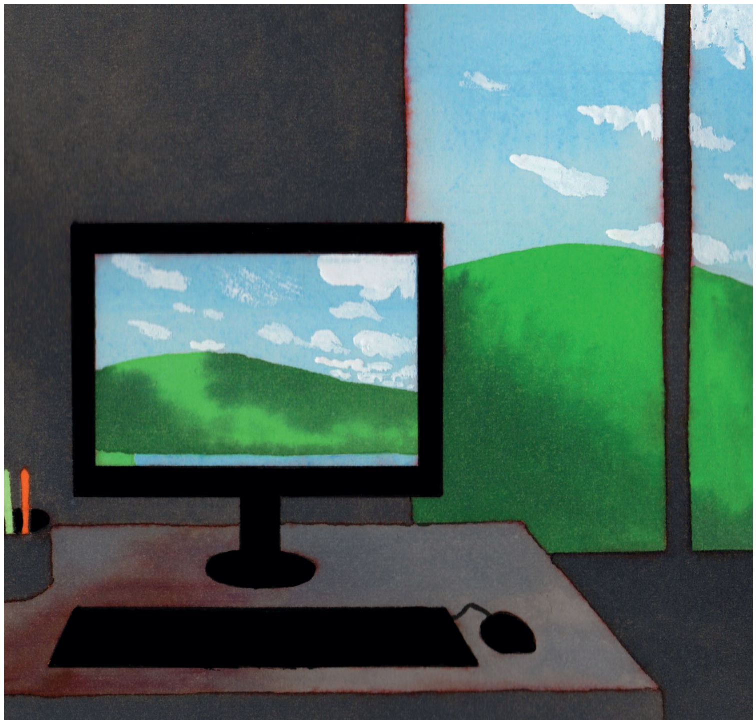
in our sentence. You could say that we are the editors of a common dictionary for the sector", explains Marie Buerret, head of the projects and communication section at Agro EDI Europe.

The need for digital to support individualised and human forms of management

"We wanted to find out how the next generation viewed digital technology in farming", Xavier Reboud tells us. *"So the Relance Agronomique GIS (scientific interest group on agronomic revival) launched a bande dessinée competition in engineering schools and agricultural colleges which they called 'Tomorrow's @griculture'. The 57 entries it generated in 2018 expressed, among other things, the worry that excessive use of digital tools would interfere with the relationships established by humans, not just with animals but with the soil itself. Concerns were expressed that digital systems could lead to excessive standardisation, or even some sort of alienation, that would be detrimental to individualised and human forms of management."*

The sort of scenario they envisage might go as follows, taking the example of a pig farm. Because it is hard to tell just by looking at an animal whether it has a fever, a pig farmer might install infrared sensors to monitor the animals, making it possible to check a pig's temperature in real time, and even to receive an alert when it gets too high. In this instance, digital technology is clearly providing a useful service. But the system can also offer a further service, automatically releasing a dose of medication into the animal's feeding trough, having identified the animal by its number. Rather than alerting the farmer, who would then look for the cause of the fever and treat the animal, the system automatically takes over the treatment of the individual animal. This replacement of farmers by machines can be perceived as being a retrograde step – by delegating their expertise to machines, farmers are downgraded to the status of mere technicians who work under the direction of the machines to achieve the smooth functioning of the wider system. Rather than being "empowered" because they have been provided with information that was initially hard to access, farmers find that their expertise has instead been diminished by technology. Sociologists call this de-skilling.

A form of digital in agriculture that is familiar to many is the use of precision farming apps. These allow users to follow decision-making pathways that have been developed using modelled data. The user's actions are mostly directed towards specific locations or individuals that "require treatment" according to a simple economic rationale. Véronique Bellon-Maurel believes that we need to move on from this paradigm, as she explains: *"We shouldn't just use these technologies to control non-conformities within the system that are defined by their impact on economic performance. Modern digital products are quite different from the older precision-farming devices; they are both easier to use and they look beyond the limits of the field. Our goal is to build a form of IT that will support the wider processes of agroecology and can accommodate the diversity and independence of farmers."*



8. The Agro EDI Europe Association (EDI = Electronic Data Interchange) was formed in 1992 by La Coopération Agricole, l'Union InVivo and the Association Nationale de Révision. The work of this cross-sector group is directed towards the creation of norms and standardisation for messages and exchanges to ensure that systems in the agricultural and food sectors are interoperable.

9. bit.ly/3Twa96C

Counting the costs to the environment

Information technology is estimated to have consumed around 12%[9] of France's total electricity output in 2019 according to the country's General Council for the Economy, Industry, Energy and Technologies. The question of environmental impact is as important for digital agriculture as it is elsewhere and must be addressed. The →

white paper, *Agriculture and Digital Technology*[10], co-authored by Inria and INRAE, accordingly emphasises the need to *"reduce energy expenditure, the consumption of other resources (whether they are renewable or not) and the pollution caused by the use of these technologies."* It goes on to explain: *"The development of digital solutions must thus be considered in terms of costs: equipment (e.g., parts used, size, number, particularly for sensors and robots); data produced (e.g., nature, number, storage); the power needed to run the software. So that the goal is always to save natural resources (e.g. water, minerals) and energy."*
According to Nathalie Mitton, *"We are currently not in a position to evaluate these consolidated overall costs in terms of energy, materials and pollution. For example, the in-field telemetry systems that measure the moisture content of the soil and target parcels for irrigation achieve considerable water savings. But how much water is needed to extract the precious metals and rare earth elements required to produce these systems? And the recycling of the sensors also uses water and electricity. In the end, you have to wonder whether we have truly achieved environmental net gain when you look at the whole supply chain."*
The use of digital tools in agriculture calls for sobriety. Life Cycle Analysis (LCA) methods developed by INRAE's ELSA hub in Montpellier, combined with data from the MEANS platform, make it possible to establish the "whole life" environmental costs of manufacturing a product (from the materials used to the energy that is consumed for supply-chain logistics, through to its ultimate destruction/recycling). INRAE and #DigitAg are jointly studying the environmental costs of the use of digital technology in the agrifood sector from a sociological and economic perspective. The project's principal lines of investigation include the effects of restricting sensor numbers, the choice of systems that use the least energy, the use of manufacturing equipment with long lifespans, and support for High-Low Tech. MIT's High-Low Tech principle offers solutions that integrate high tech elements (electronic modules, computation) with low tech structures. It uses simple, undemanding technologies that are freely accessible and easy to repair, drawing on common methods that are locally available, and it incorporates recycling. The development of High-Low Tech often takes place collectively by end-users in FabLabs.

10. url.inrae.fr/3voKdBb (see page 28 too).

11. INRAE thesis (defended July 2022), which set out to "show how digitalisation interacts with the French system of innovation in agriculture, including its paradigms and the ecologising trajectories of agriculture".

Cooperatives and Chambers of Agriculture also have a contribution to make, especially through the work they do to ensure that the innovations offered by information technology companies meet the specified needs of their members. They are prepared to suggest different directions for development to AgTech businesses. With an eye to their own bottom lines, they might be tempted to propose options that are certainly attractive, but are expensive, of little utility, and harmful to the environment. The need for such interventions is all the greater because, as we know from the doctoral work of Éléonore Schnebelin[11], while it is indeed true that some AgriTech professionals strive to take the environmental impacts of developing and using their digital solutions into account, others pay them little heed.
As mindsets turn towards sobriety, blockchain is having to reconsider its energy costs, which are all the greater because the network is open to the public. Studies reported on EcoInfo, a CNRS site, estimate that the global electrical consumption of blockchain in 2019 was comparable to that of countries such as Austria, Belgium or Denmark. Work to reduce consumption levels is currently underway, as is flagged by the announcement in September 2022 by the Enthereum project (which brings together both providers and users of bitcoin) of its intention to produce a far more frugal blockchain.

Conclusion

In recognition of these major concerns and to enable information technology to offer positive benefits for agroecology, a set of four principles has been established by the teams at Inria and INRAE to guide their research and development of the relevant technologies and practices. These are: the inclusion of stakeholders at all stages of the innovation process; the anticipation of risks; responsiveness to external changes; and self-reflection by companies on their actions. These principles allow benefits and practical applications to be maximised, while controlling the risks inherent to any innovation. What steps, then, are research and innovation communities in France taking to apply them in their work? ●

THE CHALLENGES OF EXPANSION

Agriculture has been swept along by the tide of digital acceleration. Together, the expansion of big data, the powers of artificial intelligence and the interests of investors are now embedding digital technologies in farming practice on a wider scale than ever. What can be done to ensure that sustainable agricultural and food systems emerge as winners in this process?

Taking action.

Technological developments that have already been tried and tested in other sectors have expanded the opportunities available to agriculture. Our commitment to agroecology as the future for farming has led INRAE to partner with our sister institute for digital research, Inria[1], to ensure that the research priorities of both institutes support the transition from conventional agricultural practices. But something more than the right technical advances will be needed if we are to meet this challenge that encompasses organisational, economic, social and even political transformation. An interdisciplinary approach is required so that the technological solutions we devise can also be subjected to the scrutiny of experts in the human and social sciences. There must be collaboration at every stage of the innovation cycle, creating the process of repeated reinvention that will be necessary for our societies to adapt to continued environmental changes. With government encouragement, researchers, developers and socio-economic actors in France are responding by changing their working practices, engaging with future users of their products and procedures to generate co-constructed and adaptable solutions. Because they are jointly conceived, such solutions are better tailored to the needs of users, who then find it easier to embrace them. It only remains to disseminate such new knowledge and practices to others, being careful to deliver training in a form suited to all generations and farming communities.

1. Inria: French National Research Institute in Digital Sciences and Technology.

Getting the most out of digital for farming

It is no small task to integrate the agroecological and digital transitions. INRAE and Inria have chosen to meet this challenge by strengthening their collaborative activities. As partners on major programmes such as the Agroecology and Digital PEPR (priority research programme and infrastructure) and #DigitAg, the two institutes have together already co-authored more than 400 scientific publications and numerous software programmes and applications. The popular Pl@ntNet application, which has enabled some 20 million users to identify plants using photographs from their smartphones, is just one of their successes. In June 2022, a new four-year framework agreement set the seal on this shared ambition. It emphasises the necessity of increasing collaboration →

TOGETHER

Building on experimentation on farms

INRAE and the #DigitAg Institute are the French representatives on a team of researchers from France and 8 other countries (Argentina, Australia, Canada, China, Malaysia, Morocco, the United Kingdom and the United States) that has identified six governing principles for this "new generation" of experimentation, referred to as On-Farm Experimentation (OFE)[1] by the research teams involved.

These are:

→ REAL SYSTEMS
Experiments are conducted on farm and are embedded in farm management.

→ FARMER CENTRIC
Experiments are driven by the farmer's questions and are performed collaboratively involving, as a minimum, both farmer and scientists.

→ EVIDENCE DRIVEN
Experiments are based on the analysis of farm-specific data, which may be facilitated (though not dictated) by digital technologies.

→ SPECIALIST ENABLED
Experiments draw on the contributions of external experts, making it possible for new tools to be introduced and varied viewpoints to be considered.

→ CO-LEARNING
Experiments are built around ongoing discussion between the participants who, in designing and carrying out the experiments jointly, share their visions and experiences, learning from each other and further developing ideas together.

→ SCALABLE
Experiments create knowledge that is valuable locally for individuals, and that is also intended to stimulate broader insights.

The OFE movement includes more than 30,000 farms across the world. Among its participants in France are the 3,000 farms of the DEPHY farm network (created as part of the French Ecophyto Plan), whose members are reducing their pesticide use, and a number of livestock farms whose sustainable systems are monitored by Agricultural Technology Institutes and Chambers of Agriculture. In practice, OFE initiatives take the form of a step-by-step process in which farmers and scientists together define the matters to be addressed, setting up experiments that are tailored to the particular circumstances of a farm.

1. ofe2021.com/

on digital biology, networked buildings, animal welfare, labour-saving measures, robotics, sensors, the optimisation of networks to access data, and decision-making tools. Importantly, it asserts the need to provide farmers freedom of choice over their use of the digital tools on offer, and the importance of the participatory development of tools that provide genuine support to farmers.

It can sometimes be an immense task to dream up tools able to take account of the full complexity of the systems they are designed to help, and the development of digital twin technology can certainly be described in these terms. Digital twins are extremely detailed digital representations that allow predictions to be made concerning the evolution of a system and that enable users to manage the predicted changes. They have the potential to facilitate and accelerate experimentation by providing a digital replica that resembles the system it is based on as closely as possible. This would allow precious time to be saved in the development process. It willmake it possible to test out innovative practices or systems in different configurations and to predict the conditions governing the creation and effectiveness of such innovations, from the conception stage onwards. Because of the speed of the machine-learning processes involved, the results exceed anything

Digital technology is helping to usher in a new era of collaboration between farmers and researchers at all stages of the development process, sharing the benefits of experimentation, evaluation and the capitalisation of knowledge.

that could be produced in a human lifespan. We have not yet determined how digital twins could be developed for agricultural activities, which involve many actors and must adapt to the changes introduced by climate and other hazards. We must also assess their potential for on-farm use as a support for agroecological transition. These are not inconsiderable challenges.

Innovating with participative sciences and partnerships

Participatory science invites all members of civil society to participate in research and to co-construct innovative projects. Apps that allow data to be collected from multiple sources have made it possible for crowdsourcing to increase the potential of research. The GERoNIMO project, for example, collects data from the pork and poultry industries to supplement the information generated by research. Its purpose is to provide farmers with new knowledge and tools that will encourage them to be innovative in their selection of breeds, looking for traits that help animals to cope well with local conditions, while taking environmental issues into account.

For the past decade, the entire French wine industry has been at work on the LACCAVE project, which seeks to share information on the consequences of climate change with the industry and to devise and access different adaptation strategies via modelling. The whole sector's participation in data provision for this modelling has meant that shared solutions could emerge at both local and national levels (for example the introduction of new grape varieties and novel pruning and grafting practices). The project culminated in the presentation to the French Minister of Agriculture and Food, in August 2021, of a route map for the sector that set out its strategy for adaptation to climate change.

The move from conventional agriculture to agroecology is, however, not without its risks and many farmers consider these to be too great to attempt it. What levers could be found to facilitate transition on a wider scale?

Enriching research with test data provided by farmers

As an essential part of the research process, testing has been conducted on experimental farms for centuries. INRAE acts as the scientific lead for many farm networks who are prepared to try out innovative practices with novel tools. Now, digital technology is helping to usher in a new era of collaboration between farmers and researchers at all stages of the development process, sharing the benefits of experimentation, evaluation and the capitalisation of knowledge.

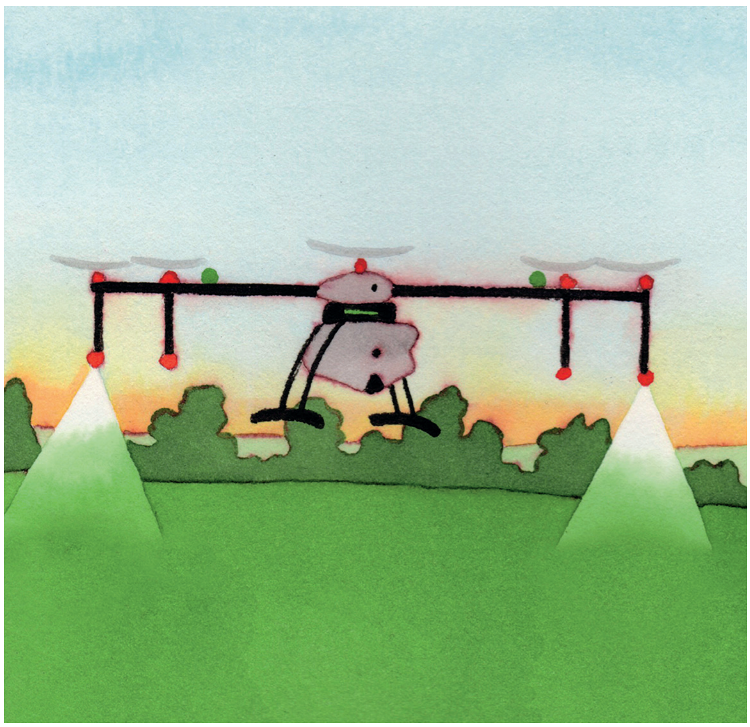
An excellent example of collaborative experimentation in digital farming can be found in Digifermes®[2], digital farm projects that are mainly run by Agricultural Technology Institutes and Chambers of Agriculture. Each participating farm is supported by a RDI partner that conducts objective and rigorous assessments of the new technologies. Open to digital businesses, start-ups, agricultural groups and businesses, and to all parties who want to help the development of agriculture, "digifarms" are intended to promote a form of digital agriculture that satisfies the needs of farmers. They carry out two types of activity: the assessment under real-world conditions of new technologies and prototypes, and the co-creation and co-construction with end users of digital innovations. →

AGRICULTURAL EQUIPMENT MARKET

8 billion euros in 2021

18 billion euros in 2025

2. digifermes.com



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↑ Sharing experience on a tomato crop.

The sharing of testing and data: a necessary step

The farmers collect data as they go about their daily activities, which is then used by the researchers to build models and create scenarios to measure the impacts of jointly-agreed targeted actions. The added value is considerable, but it is not an easy matter to establish these working relationships. OFE (see inset p. 28) calls for a strong element of trust between those involved, particularly with regard to the protection and equitable sharing of data that may well be sensitive and have potential economic value. In 2021, OFE2021, the first international conference on OFE initiatives, was organised in France, providing a forum for 170 participants from 36 countries to debate these issues. Delegates asserted the need to raise the profile of OFE at public institutional level, highlighting to policy makers the advantages that OFE has to offer for the agroecological transition.

In 2019, the French government instituted its Territoires d'Innovation system. Its local innovation projects are funded by the PIA3 Investments for the Future programme and encourage open innovation at local scale as a means to generate sustainable development models. The area-specific innovation project that INRAE coordinates with partners in the Occitanie Region brings together businesses, start-ups, local councils, chambers of agriculture, competitivity hubs and other players in the world of development, with a focus on farmers and consumers. The goal is to develop innovative digital projects that respond to the particular needs of the participants. Such as, investigating the use of bees as indicators for biodiversity in urban landscapes, finding ways to digitise a survey tool for agroecological infrastructures that currently uses impractical printed forms for its outdoor work, or looking for alternatives to glyphosate to clear the ground in apple orchards. In their search for answers, the Occitanum partners observe existing practices, send out calls for expressions of interest, encourage dialogue between participants, and support experimentation to identify the best digital options. These options are then evaluated to measure their environmental impacts and check that they have a healthy cost-benefit ratio. Attention is also given to their social implications. The partners verify that both the experiments and solutions meet the three key criteria for upscaling – that they should be documented, repeatable and transferable.

Capitalising on knowledge through training

Once knowledge has been successfully co-produced, information on an innovation must still be transmitted to stakeholders in the sector. Education plays an essential role in this. As part of the "Enseigner à produire autrement" (teaching for a new model of production) initiative, launched in 2014, French students working for the agricultural CAP, Bac Pro and BTS qualifications are now taught about of the challenges of the agroecological transition. As proof of its commitment, the French government's route map for the development of digital technology in agriculture, published last February, places "digital training in teaching and agricultural consultancy" at the top of the list of 7 workstreams. An early flagship in this field has been the AgroTIC specialism available to agricultural engineering students at Bordeaux Sciences Agro and the Institut Agro Montpellier, which has been providing teaching on digital technology for 25 years. At the Centrale Toulouse Institut-Ensat (previously Toulouse INP-Ensat), a training course specifically designed to provide engineers with dual skills in digital and agroecology is under development. Last, most second-year Masters students at AgroParisTech can now choose a module that will take them "from agronomy to agroecology (AAE)". These four institutes, like most other French public higher-education establishments and research bodies that are overseen by the Ministry of Agriculture, including INRAE, are members of the Agreenium Alliance. #DigitAg, the Convergence Institute run by INRAE, has forged educational links between its 500 researchers and many actors in research and teaching, including the University of Montpellier, with a hundred or so theses currently being supervised. Meanwhile, Chambers of Agriculture along with training and technical institutes are making digital training courses available to farmers.

A general call for action from government

For an issue as important as food sustainability, the whole of society should be encouraged to act. The ambition to protect this common good has led to a shift in the interface between the public and private spheres, with the emergence of new interactions and dynamics.

→

WELFARE INNOVATION

An open-air lab

A majority of the French public has expressed its support for improved farming conditions and practices, attending to the welfare of farm animals from birth to slaughter. To turn this vision into a reality, the LIT Ouesterel livestock innovation laboratory was created in western France. Co-founded by INRAE, Terrena and Triskalia, it builds links between researchers and stakeholders (farmers, the food production industry, consumer groups, members of the public, etc.).

They collaborate in the co-construction, testing and scientific assessment of innovations designed to improve animal welfare. For example, the WAIT4 project, to be launched in January 2023, will spend 5 years testing a suite of automated data-acquisition devices for animals and the farm environment. The project's purpose is to develop indicators that would enable the welfare of an animal to be assessed throughout its lifespan. Looking in particular at the welfare implications of innovative farming practices, changes in animal feeds, and adaptation to climate change. As part of this project, LIT Ouesterel will pursue an open and participatory science policy, enabling results to be sent to all interested parties.

It will also canvas the latter for advice, critiques and suggestions to shape the direction of the research.

The involvement of all partners, in particular that of the general public, plays an essential part in ensuring that the responses brought forward will satisfy public interests and expectations in terms of animal welfare.

Technology

A white paper for the future

Declaring a shared mission to "get the most out of digital technology to contribute to the transition to sustainable agriculture and food systems", INRAE and Inria have set out their research priorities in a white paper. They are:

- **→ providing digital tools for collective management at a regional level;**
- **→ helping individual farmers to manage their technical journey;**
- **→ transforming relationships between stakeholders within sectors;**
- **→ creating and sharing data and knowledge.**

url.inrae.fr/3voKdBb

FRANCE 2030

Forging an alliance between agriculture and digital

The research and infrastructure projects supported by the Agriculture and Digital PEPR will follow four priority pathways:

→ 1. BUILD a socio-ecosystem that encourages responsible research and innovation;

→ 2. CHARACTERISE available genetic resources to assess their potential use in agroecology;

→ 3. DESIGN the next generations of agricultural equipment;

→ and 4. DEVELOP digital tools and methods for the analysis of agricultural data, the production of agricultural equipment, and decision making.

Its primary aim is thus, through the production of knowledge, to strengthen the range of tools that produce and capitalize on digital data. Its projects could first, for example, seek more rapid and efficient ways to characterise genetic resources in animals and plants, or provide data to model and assess the impact of agroecological practices.

They could then co-produce, with stakeholders from the sector, new generations of digital agricultural equipment to simplify certain agricultural tasks [robotic tools, decision-making software] and to improve animal health and welfare [networked buildings, sensors, etc.].

Last, they could measure the impact of these digital innovations on both the environment and farmers, while studying the contribution that can be made by public policy to such changes in practice and the support it can provide for the farmers who implement them.

Transition calls for the development of major infrastructure and demands substantial investment. Within the agroecological model, with its focus on local management, the power of communities is growing.

Having used its Territoires d'Innovation programme to provide initial impetus to projects in this area, in 2021 the French government pledged a further billion euros of funding for FoodTech and AgTech start-ups[3]. Its declared ambition was to take France from eighth to third place on the global competitivity scoreboard, propelled by the boost this injection of funds would provide to France's recognised expert activities across the entire food supply network. With global investment in FoodTech and AgTech almost doubling in 2021[4] and an eye to its ranking, the French government made 200 million euros of support for start-ups immediately available in 2021, with the rest of the promised support being provided through the France 2030 Investment Framework in particular. The allocation of 2 billion euros to Objective 6 of the Framework, *"to achieve a healthy, sustainable and traceable food supply"*, is intended to encourage the emergence of food champions, to strengthen the development of innovative markets in the food sector and to accelerate the transition to come. Under the plan, new public-private research and innovation structures have been put in place, including PEPRs (priority research programmes and infrastructure) and Major Challenges. Two such programmes, co-led by INRAE, specifically address issues relating to agriculture.

Committed to agroecology and digital technology, France is aiming for third place on the podium for investments in its start-ups.

↑ This farmer can automate hoeing using sensors installed on his tractor.

A research programme to foster sobriety and increase the attractiveness of agriculture

With a budget of 65 million euros over 8 years, the Agriculture and Digital PEPR, which is jointly led by INRAE and Inria, aims to federate research from all disciplines at the interface between digital technology and agroecology, and to bring together the relevant socio-economic partners. Its purpose is to direct the development of digital technologies towards products that can support agroecology. To achieve this, it seeks to identify the specific developments that are needed, and to analyse their impacts. Looking at ways to encourage sobriety on the one hand, and to refresh the attractiveness of the agricultural sector on the other.

The Great Robotics Challenge

Having achieved a global first with milking robots in 1992, France has lost ground internationally in the development of agricultural equipment. The country has every intention of regaining a firm foothold in a market that was worth 8 billion euros in 2021[5] and, it is estimated, will be worth 18 million euros in 2025. One contribution to its campaign to win back the markets is the Great Robotics Challenge, which received approval in July 2022 and will run in tandem with the Agroecology and Digital PEPR. Jointly managed by the RobAgri Association and INRAE, it will form a network of researchers, industrialists, competitivity hubs and agricultural federations to shape promising and emerging national work on robotic solutions for agroecology and to accelerate their expansion and development. The network will introduce new practices, develop new technologies, create benchmarked tools and facilitate their use. The Challenge will be based at the Montoldre AgroTechnoPôle in the Allier. It will provide a collective space for multiple stakeholders to learn to debate the issues, work around stubborn obstacles through the use of experimentation, and build a shared vision of the new face of French agriculture. ●

3. bit.ly/3EMAmK3
4. bit.ly/3FaVbP6
5. Source FIRA 2021.