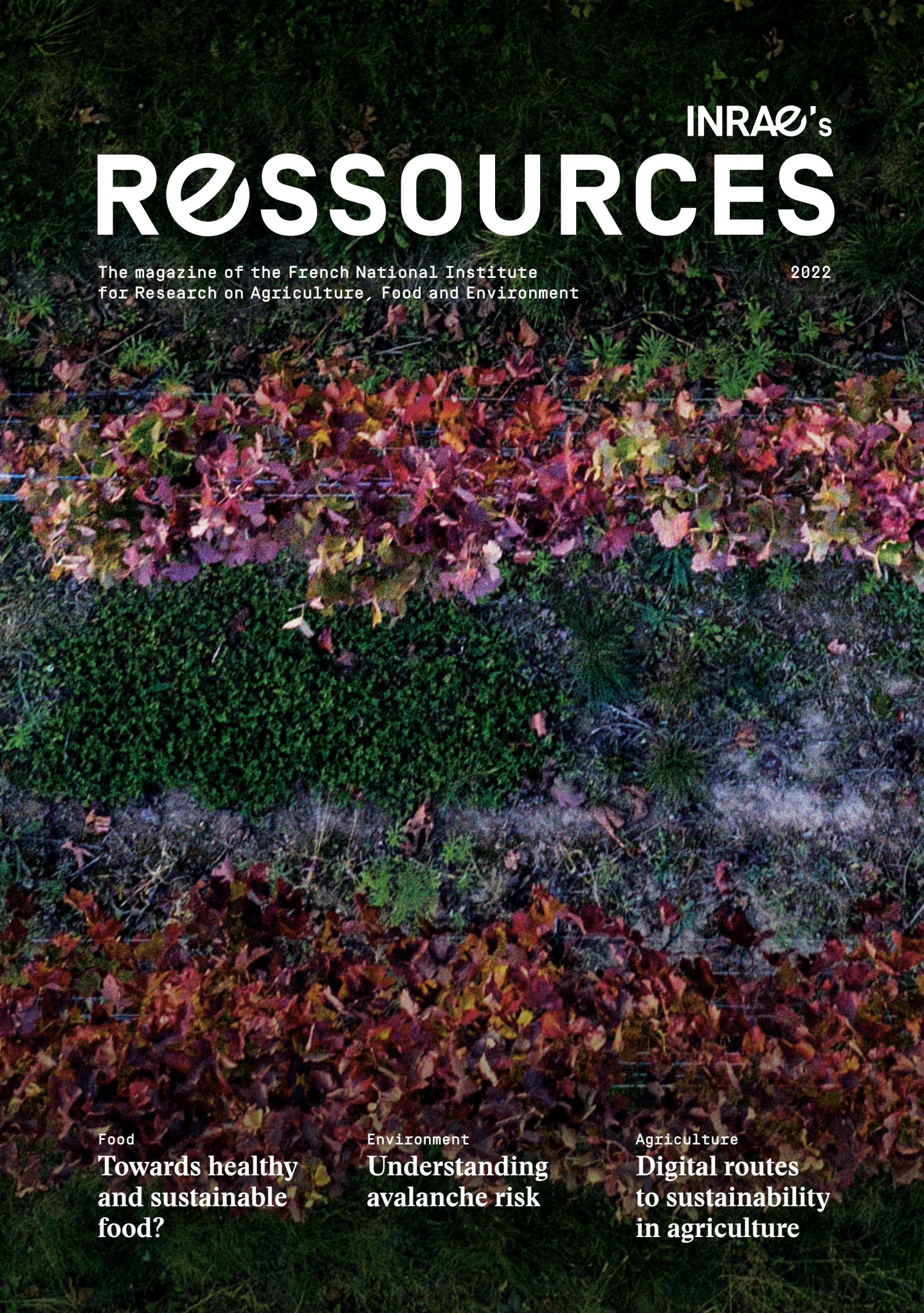
# INRAE's Ressources 2022

Inrae Direction de La Communication, Philippe Mauguin, Aliette Maillard, Christine Young, Teresa Bridgeman, Alessandra Riva



INRAE's

# RESSOURCES

The magazine of the French National Institute for Research on Agriculture, Food and Environment

2022

Food

## Towards healthy and sustainable food?

Environment

## Understanding avalanche risk

Agriculture

## Digital routes to sustainability in agriculture

A checkerboard of vines

**With more than 300 grape varieties and hybrids, the genetic diversity of the Colmar ampelographic collection contributes to ResDur programmes for creating disease-resistant varieties. Thus, 9 new varieties – 80% less pesticide dependent and still promising high quality wine – are ready to hit the market.**

INRAE Grand Est-Colmar centre


↑
A soil bank
**Inaugurated in 2013 in Ardon, the European Conservatory for Soil Samples (CEES) houses 30,000 soil samples which represent the diversity of urban, agricultural, forest and other soils. The InfoSol Unit uses these 65 tons of soil to monitor soil quality.**
INRAE Val de Loire Centre

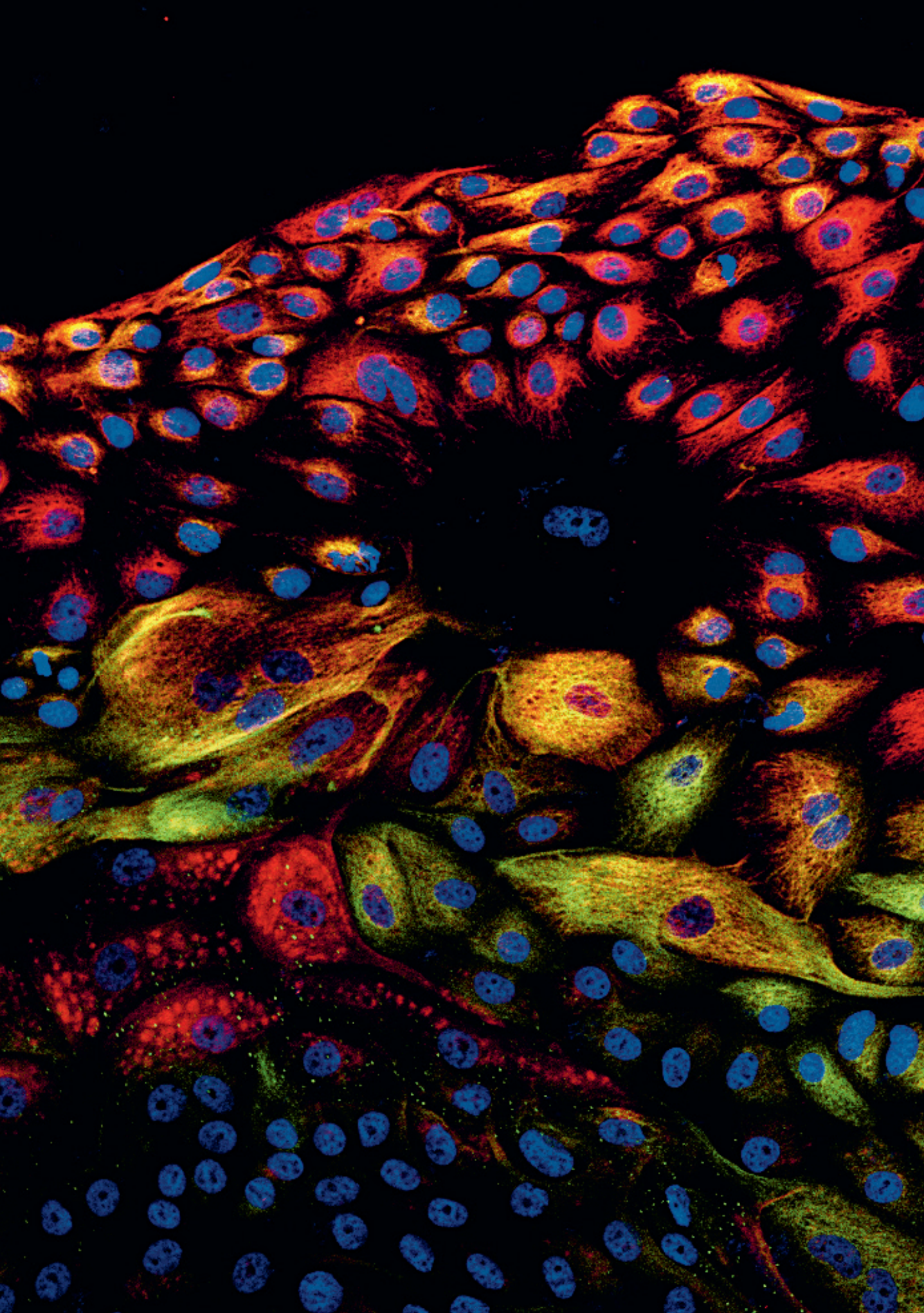
↑
Climate-resilient grass
**In Lusignan, Siclex is a facility that simulates extreme climates in real conditions and tests how sown grasslands adapt to the effects of climate change: water shortages, increased temperatures, and in the longer term high $CO_2$ content. After a year of operation, this facility has already provided recommendations to farmers on grassland management and has identified the most resilient seeds.**

Multidisciplinary Research Unit on Grasslands and Forage Crops, INRAE Nouvelle-Aquitaine-Poitiers Centre

↑
The study of taste
**Distribution of samples during a tasting session by a panel of volunteers at the Centre for Taste and Feeding Behaviour (CSGA) of Dijon.** INRAE Burgundy-Franche-Comté Centre



↗
Cells in colour
**Ovine tanycytes in culture. These cells are involved in brain plasticity and nerve cell renewa in adults.** Reproductive Physiology and Behavior Unit, INRAE Val de Loire Centre



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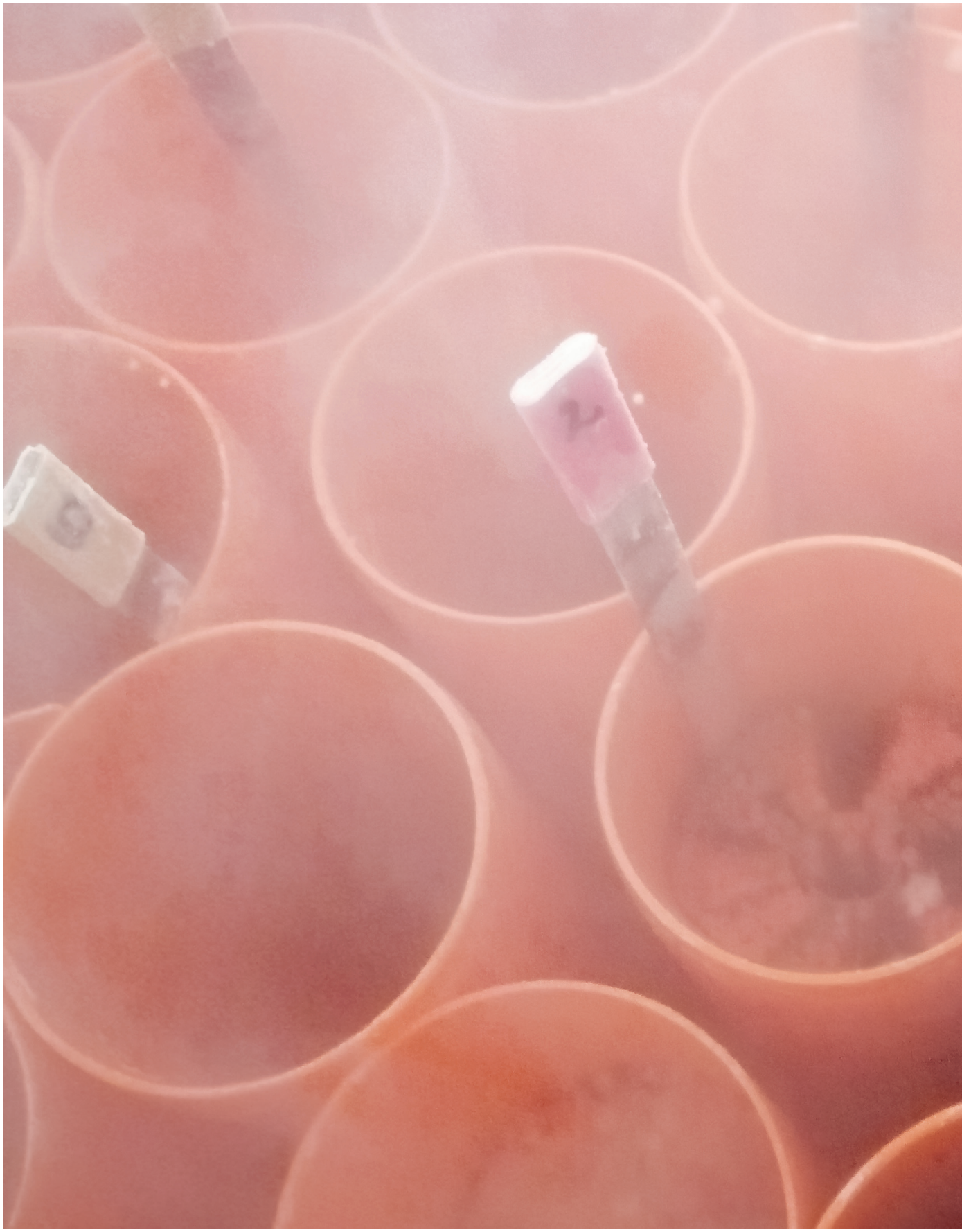
Extreme event
**On November 2nd, 2014, 150 mm of rain fell in 24 hours on vineyards in the foothills in the Languedoc region, France. A third during the last hour alone [Mediterranean Observatory of Rural Environment and Water in Roujan]. This rain event, which caused major runoff and soil erosion, is studied to model the interactions between water resources and agricultural activities at the watershed scale.**

Soil-Agrosystem-Hydrosystem Interaction Laboratory, INRAE Occitanie-Montpellier Centre



↑
Frozen DNA
**The cryoconservation of spermatozoids of domestic birds makes it possible to evaluate their fertility and to conserve this heritage of endangered species. It is the basis of numerous biodiversity conservation programmes carried out by the Biological Resource Center for Research on Domestic Animals (CRB Anim).** Reproductive Physiology and Behavior Unit, INRAE Val de Loire Centre

→ [next page]
Guadeloupe: increasing food autonomy with mixed crop-livestock farming
**Intercropping (bananas-peppers, cucumbers-sweet potatoes...), sugarcane leaf mulch, and repellent plants for pest control. The AgroEcoDiv project has been developing agroecological practices in mixed crop-livestock farming in collaboration with farmers since 2015. Their results will enable local farmers to adapt crop and livestock production to economic and environmental constraints.**
Animal Production Research Unit, INRAE French West Indies – French Guiana Centre.

## MASTHEAD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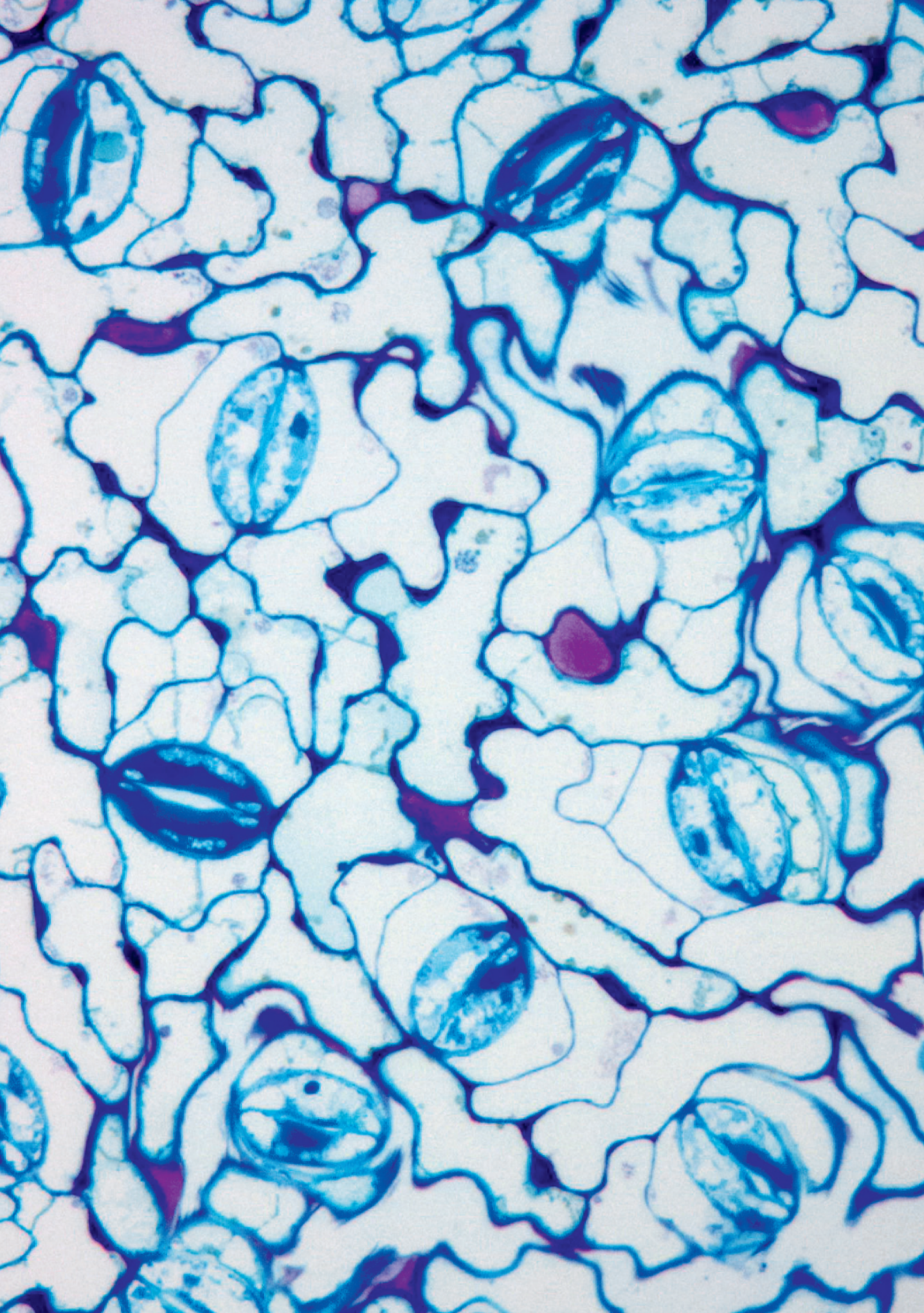

# Making transitions happen

**by Philippe Mauguin, CEO of INRAE**

2022 saw the multiplication of crises, geopolitical conflicts, the ongoing Covid-19 pandemic, climate change and associated risks, highlighting the fragility of essential resources such as water and energy, putting at risk global food security.

Now, more than ever, we need more science to make the right transitions, in the face of overlapping challenges. As a public research institute on agriculture, food and environment, INRAE is well positioned to respond to these challenges. Our core research activity provides knowledge and scientific solutions, with a transdisciplinary approach. As a finalized research institute, we are dedicated to transferring our research to you, involving all stakeholders. We work with policy makers at local, national, European and international levels, at every step of the policy lifecycle, to design public policies supporting these transitions. We are also involved with the private sector, to develop innovations stemming from our research and impact society. INRAE's *Ressources* Magazine presents the results of our approach, conducted at the French, European and international levels, as a useful tool for all actors involved in making the necessary transitions happen. In our thematic dossier we offer you the opportunity to dive into a society issue, get informed on the scientific and technical knowledge stemming from our research, ready to be used by society and get an analysis of their concrete applications and the social and economic transitions that must shape public policies. With INRAE's *Ressources* dossiers, we offer you the opportunity to explore a new topic each month online. In this first paperback edition, the best of 2021 and 2022, you will discover three dossiers analyzing the transitions to digital agriculture and healthy and sustainable food, as well as an overview of our international scientific and technical expertise on snow avalanches. Additionally, you will find access to all our previous dossiers in this special edition. We hope to challenge you to renew your analysis, and to inspire you to join us and respond collectively to the global issues that we are facing.

←
On the surface
**Stomatae on the inner surface of a poplar leaf. Observation by epifluorescence microscopy.** Methylene blue- Azure II dye.
BIOFORA Unit,INRA Val de Loire Centre

# TOWARDS HEALTHY AND SUSTAINABLE FOOD ?

The world's population is growing and with it the need for agricultural and food resources, as well as the impact on the environment. To meet these challenges, research is taking action and developing concrete solutions with its partners, in particular to facilitate the adoption of diets that are both healthy and sustainable.


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# SUSTAINABLE & HEALTHY EATING, THE BASICS

Healthy for humans and sustainable for the planet: the equation for our diets is a hard one to solve. However, the foundations for building this new paradigm are beginning to emerge.
**An analysis of western customs and practices.**

If we only ate fatty and sweet products whose production is low in greenhouse gas (GHG) emissions, our diet would have a low impact on the environment, but a deleterious one on our health. If we were to cut out soft drinks, cured meat products and crisps and eat mainly fruit, vegetables, dairy products and fish, our diet would be healthy, but socially difficult to accept by a large part of the population. And if there were a diet that was at once healthy, more environmentally friendly and acceptable, it would still have to be economically accessible to all.

### Sustainability, beyond environmental issues

According to the Food and Agriculture Organisation of the United Nations (FAO), the sustainability of a diet is based on several criteria: it must have a low impact on the environment; it must contribute to the food and nutritional security of the population; it must be culturally acceptable, economically equitable and accessible.
However, the cultural, economic, social and agricultural situations are so diverse around the world that it is impossible to define "the" diet that could be adopted by the whole world population. There is thus a variety of conceivable and desirable developments in our diets. As far as France is concerned, the State relies on the nutritional recommendations issued by the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) in order to establish the National Nutrition and Health Programme (PNNS), which supports public policies aimed at improving the nutritional and health situation of the population. The main points of this plan are: to reduce our consumption of sugary products and drinks, cold cuts and meats (except poultry); to control the consumption of highly processed foods; to consume fish from sustainable stocks; to emphasise local and seasonal foods; to increase our consumption of plant products of good nutritional quality such as whole grains, legumes, fruit and vegetables...

These recommendations allow us to move towards a healthier diet, but do they allow us to have a lesser impact on the environment? To answer this question, INRAE researchers have studied the diets of the French.

**The environmental impact of diets**

Studies (INCA 3 2014-2015, ANSES collective expertise 2017 and CREDOC 2013) on the French population show that the 20% of people with the best diet from a nutritional point of view consume less meat, cured meat products, sweetened and alcoholic drinks, and more plant products than the average. By doing so, their diet emits 18% less GHGs and is therefore more environmentally friendly.

To go further, the researchers used modelling to design a diet that meets the nutritional recommendations and further reduces GHG emissions. With a greater reduction in animal products, an increase in plant products and a decrease in the consumption of hot beverages (like coffee and tea), the researchers found a diet that emits 30% less GHGs than the current average diet. These two diets, the observed and the modelled, cost less than the current diet (€6.20 and €6.40 per day per person, instead of €6.70) but are still unaffordable for part of the population – bearing in mind that the average French budget stands at between €5 and €6 per day per person, and around €3.50 for the lowest income households. Moreover, the question of their social and cultural acceptance remains, particularly for the reduction in meat consumption.

**What place for meat?**

Meat consumption is very uneven around the world (an African consumes 6 to 10 times less meat than a Westerner, and an Asian 2 times less), but it is projected to increase by 60% by 2050, due to the combined increase in the world's population and the purchasing power of fast-growing countries. While animal products provide all the amino acids we need and are the main source of vitamin B12, iron and zinc essential during pregnancy and growth, excessive consumption of meat, particularly red meat, can have adverse health consequences. Its saturated and monounsaturated fatty acids can lead to cardiovascular disease. Recent studies conducted at the TOXALIM Research Centre in Food Toxicology have shown the link between excessive consumption of red meat or cured meat products and colon cancer. Moreover, livestock farming, particularly ruminant farming, is responsible for a portion of GHG emissions. Indeed, at the global level, direct and indirect GHG emissions from livestock farming are estimated at 14.5% [1] of total emissions linked to human activities, the equivalent of 7.1 gigatons of $CO_2$ each year. In addition, animal welfare, a growing concern in society, calls into question certain production practices in industrial livestock farms. But while it is undeniable that a reduction in meat consumption is in the interest of the environment, livestock farming also has its virtues.

↘

**250 kcal**
Desired reduction in daily calorie intake

**30%**
Potential for GHG emission reductions with the adoption of less meaty and more plant-based diets

**+60%**
Estimated increase in global meat consumption by 2050

**500 g**
Recommended meat consumption (excluding poultry) per week per person

1. Direct and indirect emissions related to food production, energy consumption, enteric fermentation, etc. Source FAO: www.fao.org/3/i6345e/i6345e.pdf

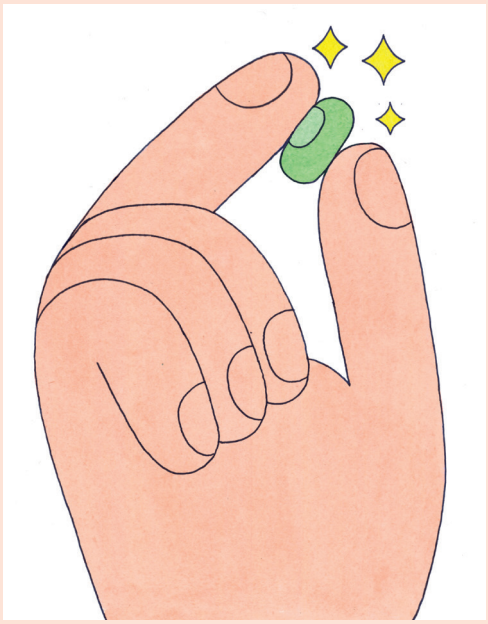
**Preserving livestock farming**

Livestock farming allows the use of uncultivable agricultural land as temporary or permanent grasslands (more than 5 years without cultivation) which play a major role in storing carbon in the soil. Animals also enable the valorisation of co- and by-products of the plant sector that cannot be consumed directly by humans, or provide organic fertilisation of the land. Furthermore, if everyone adopted a diet based solely on plant products, the increase in demand for these products would proportionally increase the need for cultivated land and probably the quantity of pesticides used. The recommendations of the World Health Organisation (WHO) therefore call for a rebalancing of intakes between animal and plant products. In France, this would mean changing our ratio of animal and plant protein consumption from 65/35 to 50/50 on average.

**Sustainable eating means thinking food systems**

Consumption should not be thought of separately from agricultural production. A sustainable diet starts with environmentally friendly production. →

**Rebalancing animal and plant proteins intakes in western diets is key.**



SOLUTION

# Promising legumes

**At present, legumes are good candidates for solving the complex equation of a healthy and sustainable diet: lentils, broad beans and dry beans for human consumption; peas, horse beans, clover and alfalfa for animal feed. Both good for our health and the environment, they are an essential link in the transition to sustainable diets.**

As a source of protein (20 to 40% depending on the species, compared with 10 to 13% in wheat, for example), legumes allow us to cut down on our consumption of meat and reduce the need to import soya for animal feed. In addition, legumes have agronomic and even climatic advantages. Integrated into crop rotations, they can act as a nitrate trap and fix nitrogen for the following crop. They help to break the cycle of diseases, pests and weeds, and thus to use less pesticides on a crop rotation scale.

Despite these many advantages, legumes account for only 4% of the utilised agricultural area in France and the consumption of dried pulses (such as lentils, beans, broad beans and chickpeas) has dropped to a quarter over the past 20 years to reach very low levels in France (2 kg per person per year in 2020 according to Agreste). How can this disenchantment be explained? As far as consumption is concerned, one can blame the time they can take to cook, the digestive disorders they may cause or an exacerbated taste of the "green note" type. They are also victims of prejudice: studies show that dried pulses are associated with a vegetarian diet and are not perceived as a source of protein but rather as an accompaniment to meat. On the production side, their high sensitivity to climatic stresses, such as frost or drought, and their low resistance to biological pests lead to uncertain yields. Neglected for years, the value-added chains are today relatively unstructured. Logistics are complex and costly for small volumes. These productions are thus seen as economically unattractive in the absence of public aid.

Weaknesses that researchers are trying to overcome, from production to processing and consumption. They are, for example, developing new pea and horse bean varieties that are more resistant to drought, frost and disease, as well as new legume-based products *(see article on page 25)*. This objective is directly supported by the French government with the "plant protein plan" launched in 2020, which aims to double the agricultural area used for crops rich in plant proteins (like soya, peas, dried pulses, alfalfa and feed legumes) over a 10-year period, to reach 8% of the utilised agricultural area at national level.

**20-40%**
Proportion of protein in legumes

**8%**
Target of French agricultural area devoted to legumes in 2030, compared to 4% in 2020

**2 kg**
Consumption of dried pulses per person per year in France in 2020

**100%**
of the amino acid intake provided by a legume/cereal combination

*"It's a virtuous circle, producing better allows us to eat better, and eating better allows us to stimulate demand for better production"*, says Sophie Nicklaus, an INRAE specialist in eating behaviour at the Centre for Taste and Feeding Behavior (CSGA) in Dijon. Today, our food systems (including agricultural practices, manufacturing processes in the agrifood industry, transport methods and distance travelled by products) have an impact on our environment, such as water and soil pollution, GHG emissions, deforestation and loss of biodiversity, as well as on our health, since a polluted environment and unsustainable environmental practices will increase our exposure to various contaminants.

**... and adopting more agroecological practices**

On the fields, it is a matter of developing more environmentally friendly models. Agroecology is a good example. The principle: agricultural practices (like biocontrol, winter cover crops, intercropping and permanent grasslands) that rely on the functionalities offered by ecosystems with the aim of reducing GHG emissions, limiting the use of synthetic inputs and preserving natural resources. Organic farming, characterised by the absence of synthetic inputs and antibiotics, is also a good way of greening agricultural practices with the added bonus of beneficial impacts on health. Recent research based on the Bio NutriNet study, which followed 69,000 people over 7 years, showed a 25% reduction in the risk of cancer (all types) in regular consumers of organically produced food, compared to those who consumed it less frequently. Research is ongoing in order to explain these results. For Emmanuelle Kesse-Guyot, an INRAE epidemiologist with the Nutritional Epidemiology Research Unit (UMR EREN), several leads need to be explored: *"potentially higher levels of certain micronutrients (antioxidants, carotenoids, polyphenols, vitamin C or more beneficial fatty acid profiles) in organic food, or the presence of synthetic pesticide residues, more frequently and in higher doses, in conventionally farmed food compared with organic food."*

At this stage, these are only hypotheses, as researchers are still assessing the potential relationship between the consumption of organic products and health, as well as the links between pesticides and metabolic diseases (such as diabetes, obesity and hypertension) or cancer. What is certain, however, is that at the individual level, those who consume large amounts of organic products have adopted a diet that emits far less GHGs as they tend to have a more plant-based diet than other consumers. However, converting all agricultural land to organic agriculture would also have its limits: with lower yields, feeding the planet with organic agriculture raises the question of the availability of more arable land.

**Adapting western diets: eat less, locally and seasonally?**

While studies show that reducing the consumption of animal products has the greatest potential to reduce GHGs, complementary actions can also contribute. Eat less? The studies cited above indicate that Western diets should be reduced by 250 kcal to 3,000 kcal per day per person, including waste (i.e. 1,850 to 2,000 kcal actually consumed). Halving consumer food waste would reduce GHG emissions by about 5% on a global scale.

As for the very popular "eat local", it is not necessarily synonymous with sustainability. Indeed, although transport by air does increase the carbon impact of a food item, it represents only 1% of the fruit and vegetable import tonnage, and has therefore a limited overall impact. *"If we have to point the finger at a problem with food transport, we should look at the distance between the place of purchase and the home, which can account for up to 40% of a food's carbon impact"*, says Nicole Darmon, an epidemiologist at the Montpellier Interdisciplinary Center on Sustainable Agri-food Systems (social and nutritional sciences) (MoISA). Thus, going to →

**Food systems are responsible for almost one third of global greenhouse gas emissions.**

# Cutting consumer food waste in half would reduce global GHG emissions by 5%.

pick up strawberries from a "local" producer by car is not necessarily more sustainable than eating an imported product. Eat seasonally? Again, it all depends on what you are looking at. For Emmanuelle Kesse-Guyot, the most important thing is to produce in season in order to limit the use of heated greenhouses, but there is nothing to stop you from eating in winter a tomato coulis produced in summer!

**Food accessible to all**

Does eating healthy and sustainable food have a cost for the French consumer? For Nicole Darmon, the impact would appear to be small. On the one hand, reducing meat purchases tends to bring down costs, especially as it represents the largest item in the food budget of the French. On the other hand, eating more fruit and vegetables can increase costs, even with the less expensive legumes. But Nicole Darmon warns: *"it is very difficult to have a healthy and sustainable diet below €3.50 to €4 per day per person"*.

Furthermore, when people are constrained by their budget, they tend to choose foods that provide cheap calories, such as refined cereal products and fatty and sweet products. These products –typically crisps and biscuits– are poor in essential nutrients and are often loaded with sugars or salt, which, when consumed in excess, make them harmful to our health. On the other hand, they are convenient, comforting and have the advantage of being wasted less...

Eating more sustainably undoubtedly implies that our diets should become more plant-based. But beware, reducing the share of animal products will only serve the sustainability and quality of our diets if it is to the benefit of a wide variety of plant-based products of good nutritional quality while at the same time bringing about conceivable changes for the consumer in terms of habits and budget. Even though eating more sustainably seems to be within the reach of Western countries such as France, it requires a strong political will to make transitions at all levels: production, processing and consumption. ●

**40%**

Share the carbon impact of a purchase/home journey for food can reach

**3.50 to 4 €**

Minimum budget per day and per person for a healthy and sustainable diet

# ARE FRENCH CONSUMERS READY?

There is a consensus on the need to move towards more sustainable agricultural and food systems. But this transition can only be achieved if the consumer, at the end of the chain, changes his behaviour and habits. How can this be achieved? **Decoding the case of France.**

Social representations, accessibility, psychological factors and collective dynamics: the act of eating is more than the ingestion of food. Our eating behaviour is both linked to our sociocultural environment and subjected to psychological and physiological mechanisms.

### Taste and conviviality at the heart of our behaviour

While food serves a vital need, it is also a source of gustatory and social pleasure when meals are shared at the table. This notion of pleasure is essential and plays a driving force in our choices: *"pleasure is linked to the food itself, to the social context and to the representations associated with the food"*, explains Sophie Nicklaus, an INRAE specialist in the study of eating behaviour at the Centre for Taste and Feeding Behavior (CSGA) in Dijon. A pleasure that can be taught from a very young age. INRAE is thus working with Santé publique France (the government agency for public health) on the dietary practices of parents to promote appropriate eating habits in children. This early food education is particularly important because the foundations of eating behaviour are laid during the first years of life, and the prevention of chronic diseases linked to food, such as obesity, is all the more effective the earlier it is implemented. Recent studies have shown that eating habits can be established as early as... during pregnancy! A study carried out on minipigs (an animal model close to humans in terms of physiology) has shown that a maternal diet during pregnancy and lactation, respecting a normal caloric intake but too rich in fat and sugar, has negative impacts on the lipid balance, the metabolic activity of the intestinal microbiota and leads to the production of neurons in an area involved in learning and memory in piglets. Thus, piglets fed this diet in utero were more motivated by fatty and sweet food rewards.

### Learning to enjoy

Making our eating behaviour evolve also requires repeated exposure to a food. A new, unknown food is a priori rejected. By repeating the exposure to this food and doing so in a familiar and friendly context, the chances of being accepted will increase: *"This is for example the case of coffee, which is very bitter, but to which we are exposed* →

NUTRINET-SANTÉ

## The transition monitored on a daily basis

Impact of prices on consumption, organic or conventional products, environmental impacts, economic trade-offs linked to purchases... Since 2009, the NutriNet-Santé project has been studying the relationship between health and food, and in particular the sustainability of food according to individual lifestyles. This cohort is based on the monitoring of volunteers, who are regularly questioned via online questionnaires about their lifestyle, consumption, health and environment. *"With more than 100,000 participants, the cohort allows us to obtain detailed behavioural analyses"*, explains Emmanuelle Kesse-Guyot, research director at INRAE. And indeed, all types of profiles are represented: the employed and unemployed, students, retirees, vegetarians, flexitarians, vegans and so forth. Emmanuelle Kesse-Guyot concludes: *"The people we are following have agreed to it, they are volunteers with a particular profile and they are more inclined to follow a balanced, sustainable and healthy diet... But we must see this cohort as a living lab! If these people are capable of approaching a healthy and sustainable diet, it means that the dietary transition is possible."*

OBSERVATION

## Less cooking for more leisure time

Social progress and the resulting lifestyles have greatly changed our eating habits since the second half of the 20th century. Fabrice Etilé, an INRAE economist at the Paris School of Economics (PSE) has studied the evolution of time spent cooking, together with Marie Plessz, an INRAE sociologist at the Centre Maurice Halbwachs (CMH). *"We observe on average a decrease in cooking time between 1985 and 2010, going from 68 down to 55 minutes per day. 60% of the observed reduction is linked to the integration of women into the labour market."* Marie Plessz notes that the "meal norm", consisting of three meals a day, at fixed times, and allowing the household to gather around the same table, has been maintained in France, unlike the United States. *"The culinary culture of these two countries is known throughout the world. Even though it is very different, it is based on the idea that women are responsible for the food the family eats. We are still far from gender equality in this field: the decrease in the amount of time spent cooking by women has not been offset by an increase in the amount of time spent by men... It is a significant workload, unpaid and still largely invisible"*, says the sociologist. The decrease in the amount of time spent cooking, combined with the increase in income and education levels and the expansion of the agri-food industry, has favoured the development of ready-to-eat products at the expense of cooking from scratch. These ready-to-eat products *"meet one of society's demands: to have more free time"*, says Fabrice Etilé.

TIME SPENT COOKING PER DAY

68 MIN
in 1985

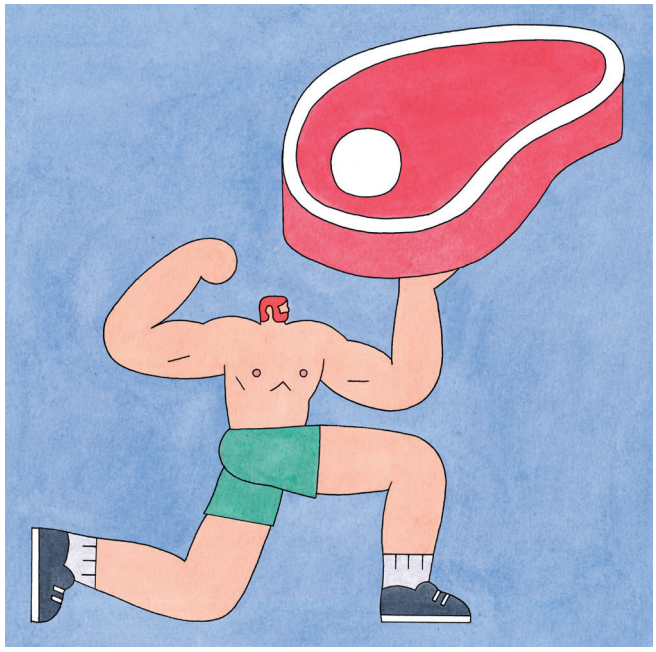
55 MIN
in 2010

*regularly, at work during the coffee break, in the family circle. We are exposed to it in a positive context, which leads us to try this food again despite a taste that is not always appreciated at first"*, explains Sandrine Monnery-Patris, a researcher in cognitive psychology at the CSGA. Thus, offering plant-based protein dishes in the canteen could help children appreciate these products, but only if it is in a positive environment. A major challenge is to raise awareness and train canteen staff regarding the context and environment of the meals, especially with regard to novel foods.

### Overcoming social representations

The strength of social representations and our cultures guide our diets. As a result, the adoption of nutritional recommendations comes up against numerous psychological biases. For example, replacing meat, still very much present on Western menus, seems difficult for the consumer. Sandrine Monnery-Patris' work explains this, showing that animal protein is associated with strength and virility, whereas plant protein is associated with lightness and femininity. In addition, meat is seen as the main element when we have to prepare a dish, whereas plant proteins (cereals, dried pulses) are seen as sides. In her opinion, these results explain why it is difficult for the consumer to replace a food that is synonymous with strength and at the centre of the dish with a food that is more associated with lightness and considered peripheral. Among the beliefs that have a life of their own, we can mention the issue of the practicality of dried pulses. For the people interviewed

**Plant-based protein dishes in the canteen could help children appreciate these products, but only in a positive environment.**



as part of the researcher's work, one obstacle to the consumption of these foods is their supposedly long preparation time, whereas in reality, there are now a good number of dishes based on legumes or cereals that do not require any additional preparation time. Another image to be challenged is that dried pulses are food for vegetarians or vegans...

To overcome these prejudices, the researcher points out that information and communication are effective means. It is a question of communicating on taste and proposing attractive and easy-to-make recipes.

### Commitment as a driver for change?

Some consumers are committed to changing their diet, such as vegetarians or vegans. Benjamin Allès, an epidemiologist at the EREN research unit, explains that *"among the motivations of people turning to a diet that limits or eliminates animal products, the most frequently reported are animal welfare, the environment and sometimes health"*. The observations of the NutriNet-Santé study also indicate that nowadays the majority of people who exclude all or part of animal products from their diet belong to high socio-professional categories. →

This shows that the level of education and the ability to learn and integrate new benchmarks are important factors for change. However, the probability of adopting a vegan diet is rising among participants with a lower socio-economic level, suggesting a broadening of these categories of people. Furthermore, Stéphan Marette, an INRAE economist in the Paris-Saclay Applied Economics unit, points out that *"even though consumers may be aware that for their health and that of the environment it is better to change their diet, and may be interested in the approach, this does not mean that they will respect these recommendations. In particular, they face limitations in terms of budgetary capacity, attentiveness when shopping and/or memorising complex information which often prevent them from turning to more virtuous foods."*

**Cost, a barrier to change?**

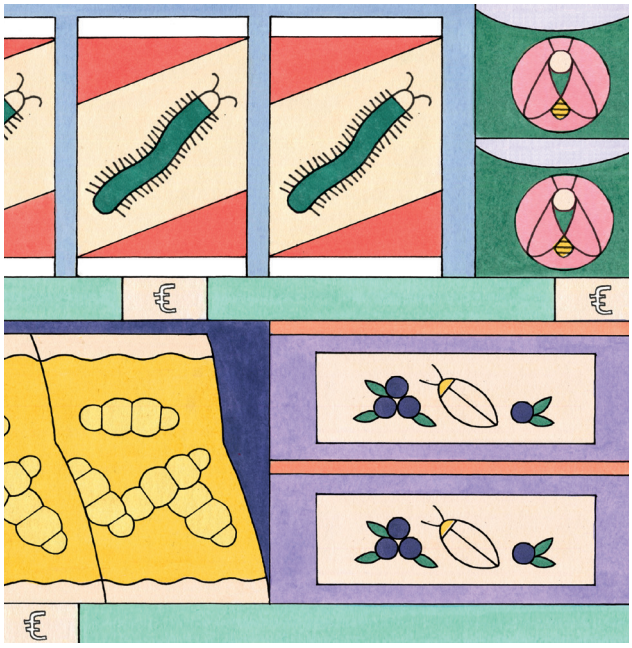
Obviously, especially for those with small budgets. The average food budget observed among disadvantaged households is around €3.50 to €4 per day per person. According to Nicole Darmon, below this budget, *"it is very difficult, if not impossible, to have a diet that meets all the nutritional recommendations"*. These results were obtained by observing the purchases made by these households, but also through modelling. When a nutritionally good diet is modelled for the lowest possible price, the minimum is €3.85 per person per day for an adult. As for the average French food budget, it is €5 to €6 per day (excluding alcoholic beverages). In contrast, in Western countries, the shift to a more sustainable diet will result in a small decrease in the cost as a result of reduced meat consumption.

Because of all these obstacles, the researchers at INRAE insist on the importance of small steps to achieve the objectives set. As Stéphan Marette points out, it is gradual changes that will facilitate the change of habits such as *"original recipes, more pleasant meals in the canteen... In short, tricks that make it possible to incorporate modest but realistic changes"*. And that, on a large scale, will bring about transitions. ●

FORESIGHT

## Insects on the plate, is it possible?

**Meat, eggs, fish, dairy products, dried pulses and cereals are the main sources of protein consumed in Western countries.**
**To successfully feed the world's growing population, other sources of protein are being explored, such as insects. Currently, about 2 billion people, mainly in Africa, Latin America and Asia, consume about 2,000 different species of insects worldwide.**
**However, in Western countries, insects are not yet part of our menus because their consumption raises questions: health issues, as the European Food Safety Authority (EFSA) only issued a positive opinion in January 2021; and cultural issues, as the consumption of insects still comes up against social representations. In France, a few start-ups have embarked on insect production, but for Benjamin Allès, an epidemiologist at the EREN unit, *"the most likely scenario is that insects will be consumed in the form of meal, or indirectly via the feed of farm animals, mainly for fish and chicken."***



In order to facilitate the transition to healthy and sustainable diets, researchers are experimenting with new, more attractive plant-based foods. To this end, legumes are making their way into the development of new product recipes. **An update on tomorrow's foods.**

# LEGUMES, STARS OF THE LABS

Mitigating climate change, reducing the need for synthetic fertilisers, maintaining water and soil quality... In addition to contributing to healthy food systems, legumes seem to be able to meet society's new requirements, particularly in the face of environmental challenges. In the context of research on human nutrition, scientists are particularly interested in pulses, including soya, peas and lentils... After being shunned for a long time because they suffered from a poor image – difficult to digest, long to cook,...– these legumes are now back in the limelight. They are a source of protein, vitamins, fibre and minerals, have a low glycaemic index, limit the risk of cardiovascular disease and promote a feeling of satiety. Eaten with cereals, they provide all the amino acids we need and are a source of protein that can reduce our consumption of meat and our dependence on imported soya...

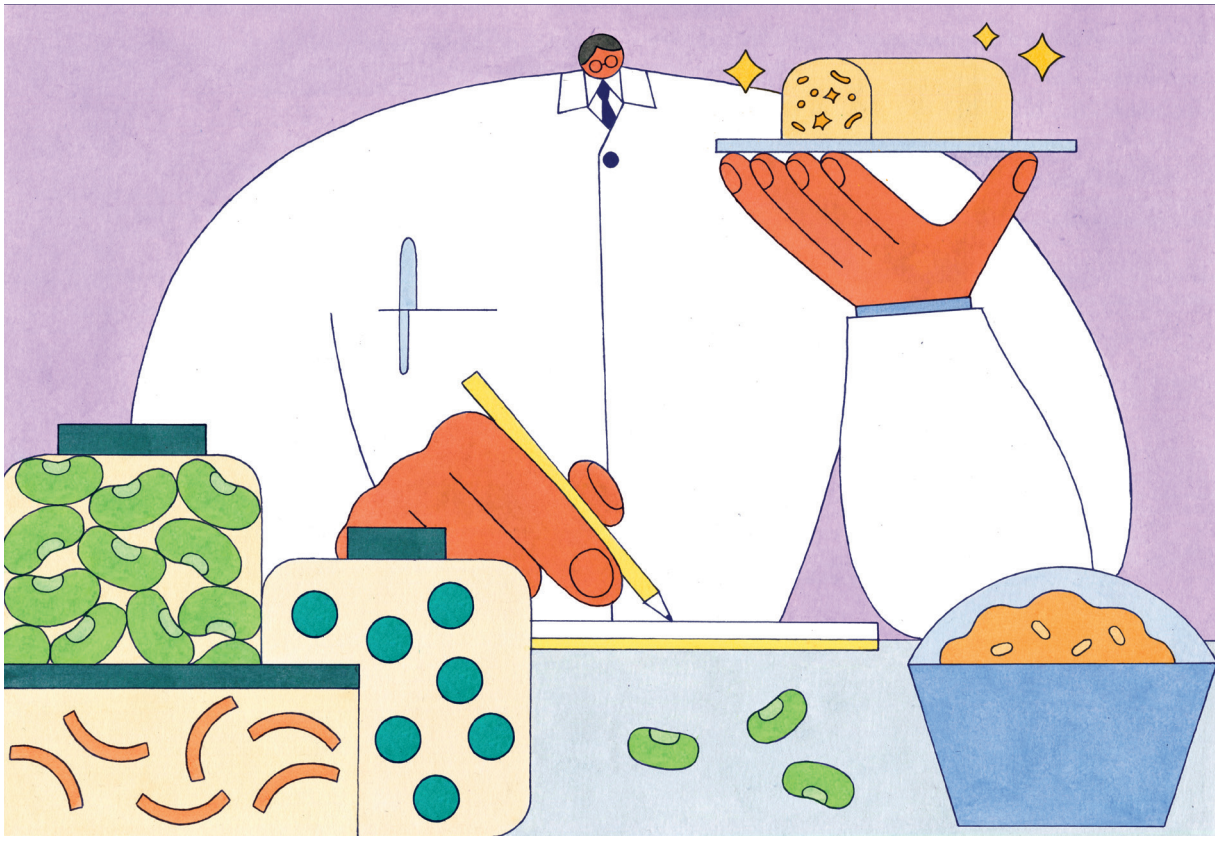
However, there is a downside: since the 1990s, French legume production and acreage have collapsed. The lack of outlets coupled with the problems of production and processing of legumes means that the sector is finding it difficult to structure itself. In the absence of public aid, these crops have been considered economically unattractive until now. At the end of 2020 and in an effort to help the sector, the government set up a new €100 million "plant protein plan", whose objectives include increasing the area under legume production by 40% in three years and supporting research and development in this sector. INRAE scientists are actively involved in this field and are working to facilitate the return of legumes to the consumer's plate, in particular by including them in recipes for products commonly consumed by the population.

**€100 million**
Budget of the "plant protein plan"

**+40%**
Target increase of area under legume production by 2024

### For dairy products

INRAE is developing new manufacturing processes for foods such as dairy products. Stéphan Marette, an INRAE economist in the Paris-Saclay Applied Economics unit, is working on ways to combine and balance the plant and animal based parts of our diet: *"Even if we can note an increase in vegetarian or vegan diets, for the time being, 95% of consumers prefer animal derived products... Mixing cow's milk and plant proteins provides a way of initiating the dietary transition while limiting changes in eating habits, and preserving the hedonic aspect linked* →



*to the consumption of milk"*, he explains. This is how a *"vegetarian milk product"* saw the light of day on the researchers' bench and is the subject of several patents with different compositions of up to 50% milk and 50% pea flour, the maximum level to still contain enough lactic ferments and to ensure that the taste is not too modified for the consumer. *"In our studies, the most popular products are for now those containing 25% peas and 75% milk."* Stéphan Marette emphasises that the industry has yet to be created, along with increased production in the field.

> **"Mixing milk and plant proteins provides a way of initiating the dietary transition."**
>
> Stéphan Marette, INRAE economist

**For the softness of cakes**

For its part, the SayFood joint research unit is working on obtaining a soft cake made from legume and cereal flours as this combination leads to a protein profile that is more balanced in terms of essential amino acids compared to cakes made exclusively with wheat flour. The FlexiProcess project has led to the development of a soft cake containing pea flour.

Camille Michon, former head of the unit (now director of Human Resources at INRAE), explains that this product was chosen because *"it is a product of mass consumption, which can impact the whole sector if the integration of the legume in the recipe is accepted by consumers"*. How do you find the right mix of wheat and pea flours to ensure the softness of the cakes and the honeycomb structure of the crumb? A multi-criteria and multi-constraint model was designed, taking into account, among other things, the proportion of pea flour in the cake, the particle size of the wheat and pea flours, the speed and duration of the mixing of the fat phase as well as the baking temperature. The idea behind it? Demonstrate that it is possible to equip oneself with tools to help steer the process and better

# A genuine breeding ground for innovation, legumes meet nutritional and environmental needs.

control the quality of the finished products by correcting the effects of a raw material that is not fully standardised.

**For the diet of the elderly**

Here again, legumes are a solution to prevent potential problems of undernutrition in the elderly. In order to diversify the food offer adapted to the over-65s, it is necessary to understand the impact of changes in oral status. One of the objectives of the AlimaSSenS project is to understand the mechanisms of food breakdown and food bolus formation in the elderly. Most of the time, their oral physiology is altered and their protein needs are increased.

To meet these needs, INRAE researchers took examples of cereal-based foods with a honeycomb structure: brioche and sponge cake, and enriched them with legume proteins. Following studies using imaging and rheology (the study of the deformation and flow of matter under the effect of a stress), it was found that the latter only have a slight impact on breakdown and the enjoyment of eating. These results will enable the design of cereal foods enriched with proteins from legumes.

**For a new pasta recipe**

Owing to its taste, ease of preparation and reasonable price, pasta is one of the foods that is widely appreciated by all categories of consumers. Traditionally made from durum wheat semolina in France, pasta has a specific structure consisting of a protein network surrounding starch granules, which is responsible for its low glycaemic index and organoleptic qualities. However, it is low in certain amino acids essential to our health, such as lysine, and its consumption can lead to metabolic disorders in people who are intolerant to gluten... In order to supplement the gluten-free offer, INRAE is developing pasta made from a mixture of wheat semolina and legumes, thus providing essential amino acids, and which will soon be available on the shelves of supermarkets and specialist shops. The culinary, sensory and nutritional qualities are comparable to those of pasta made from 100% wheat or gluten-free cereal-based pasta. And what is more, the process retains the classic pasta-making steps, requiring no additional equipment!

A genuine breeding ground for innovation, legumes meet nutritional and environmental needs: research is thus actively pursuing the creation of a new food offer and the promotion of these plant proteins. But supply is not enough: public action will have to support it and help structure the sector to facilitate its adoption by consumers. ●

# ACCELERATING THE TRANSITIONS

Combining nutritional quality and sustainability in our diets seems possible and accessible. So what can be done to accelerate everyone's transition to a healthy and sustainable diet? Taxation, awareness-raising, education... the levers for public policy action are numerous. **An overview.**

Acting on prices. This leverage seems to be essential for public policies in the face of consumers for whom price is a major criterion.

### Taxes and their effects

The first strategy is to tax products that are less healthy because, according to economists, a taxation policy can bring about a change in consumer choices at little cost. This is the principle behind the "soda tax" introduced in France in 2012, then revised in 2018, whose objective is to encourage a reduction in the consumption of sugary drinks. Adopted in some 40 countries, this tax seems to be playing its role, particularly in the countries that are most fond of soda, such as the United States and the United Kingdom, where consumption of these drinks has fallen.

Economists at INRAE have shown that these taxes could have a significant impact on purchases, but this varies depending on the type and level of tax. For example, the UK tax, which is proportional to the sugar content of the product, led to a significant decrease in the purchase of these drinks, whereas the French tax, which was introduced in 2012 and was independent of the sugar content, led to little change in consumption. France therefore adopted the same taxation system as the UK in 2018. In addition to questioning purchasing decisions, these taxes reinforce the messages about the health consequences of excessive consumption of soft drinks. The introduction of this type of tax may also have the effect of encouraging manufacturers to reduce the sugar content of their products.

This leads to more ideas. What if products that have a negative impact on the environment were also taxed? Cécile Bonnet, an INRAE economist at the Toulouse School of Economics (TSE), has studied the effect that the introduction of a carbon tax on meat could have: the research shows that a tax indexed to the $CO_2$ emissions from meat production would lead to an increase in prices and therefore a decrease in the consumption of products with a greater impact in terms of GHG emissions. However, taxing products means passing on the costs to consumers, with greater economic consequences for the poorest households. A complementary strategy could therefore be to subsidise healthy products. A study shows that

in France, subsidising fruit and vegetables by 20% would increase their consumption by 8 to 10%.

### Healthy food for all

Access to healthy and sustainable food for all seems to be the crux of the problem, especially as the poorest households are the biggest consumers of products of lower nutritional quality. Nicole Darmon, an epidemiologist at the MoISA unit in Montpellier, demonstrates as part of the Opticourse project that healthy and sustainable eating is possible, even on a small budget. A field trial, in partnership with two supermarkets, showed that affixing an "Eating great" logo can guide customers towards inexpensive and nutritious food choices and influence purchases. At the same time, researchers and facilitators organised fun group workshops focusing on taste, nutrition and price, offering tips on how to improve the nutritional quality of purchases without breaking the bank, while still indulging in taste. In the same vein, the Dijon metropolitan area *(see article on page 33)* is considering experimenting with food vouchers to help the most disadvantaged people buy fruit, vegetables and legumes.

### Informing and raising awareness for better guidance

Informing and raising awareness are the key words in public policies to guide consumers towards a more sustainable diet. To this end, the French state relies on the National Nutrition and Health Programme (PNNS). Launched in 2001, this is a public health plan aimed at improving eating habits and thus the health of the population. It is deployed through various actions, including the introduction in 2017 of a display system called Nutri-Score, in order to enable consumers to make informed choices between products in the same category. Developed by researchers from various organisations including INRAE, this score is determined by a calculation that classifies the nutritional data of foods per 100g of product into five categories, from A to E (green to red). Researchers have shown that the Nutri-Score can improve the nutritional quality of purchases by 4% and that the easier the label is to understand, the more effective it is! However, to be even more effective, all brands should adopt it, which is still far from being the case. As European regulations currently prohibit the imposition of this labelling on brands, only a fraction of them have committed to implementing it. A study by the Food Quality Observatory (Oqali, located at the INRAE centre in Ivry-sur-Seine) shows that the market share of products with Nutri-Score varies from 10 to 50% depending on the food sector.

As the Nutri-Score makes it possible to guide purchases towards products that are good for health, one might wonder about a possible display of the environmental impact of products. This is a desire of the public authorities who, in the context of the law on the fight against food waste and the circular economy, have launched an 18-month experiment to define an environmental display for food products by the end of 2021. There are many systems in various formats (score, label and so on) that take into account a wide range of indicators, often including the carbon footprint. In this context, INRAE scientists are studying which system would be the most effective in guiding consumers. The results of the Lab2Green project show that environmental labelling, regardless of its format, has a significant effect on the environmental quality of consumers' purchases. Moreover, the traffic light approach is more effective than a quantitative model (such as displaying the amount of $CO_2$ emitted). It remains to be seen what the impact would be of placing an environmental label alongside the Nutri-Score label, and what choices consumers would make in the case of antagonistic displays. In parallel with these studies, ADEME and INRAE have developed the Agribalyse database, which provides information →

**5 LINES OF ACTION**

Tax unhealthy products

Subsidise healthy foods

Inform

Raise awareness

Develop the supply of healthy products

**Taxes and subsidies must take into account issues of social and economic inequality.**

PUBLIC POLICIES

## Territorial food projects

Territorial food projects (PATs) were created as part of the National Food Programme (PNA) in 2016. The aim? To put the territories into action around food. Local authorities, farmers, associations, consumers and, more generally, all those concerned with food, are working together to relocalise our food.
Brigitte Nougarèdes, a sociologist at the Innovation joint research unit at INRAE in Montpellier, is taking a close look at the Pays Cœur d'Hérault project, winner of the PNA call for projects in 2019, and subsequently the TETRAA project (AgroParisTech, Fondation de France) which brings together 77 municipalities.
She highlights the areas of improvement needed to succeed in this "reconnection":
→ facilitate access to agricultural land and buildings to diversify agricultural production;
→ support agricultural models that can contribute to the agro-ecological and food transition;
→ and improve or build coordination between production, processing and marketing, in order to structure sustainable local food chains.
At the same time, new forms of food aid must be devised to ensure access to quality food for all.

VALUE CHAIN

## When animals are fed well, humans feel better

The Bleu-Blanc-Cœur association was created in 2000 with the support of INRAE and the idea that if animals are better fed and do better, humans could also benefit from it in terms of their own health. The ambition? To develop a value chain "from field to fork" with the founding principle of better feeding animals to improve the nutritional quality of the products they yield. The aim is to diversify and balance animal feed by including more plants, legumes and forgotten seeds that are rich in nutritional value (flax, lupine, peas, grass) and to respect animal welfare.
Today, 7,000 farmers are involved in this sector, which has millions of consumers.

EXPERTISE

## A 360° policy in Overseas France

Overseas departments and regions are among the most exposed to diet-related chronic diseases. The prevalence of obesity, diabetes and hypertension is high, which can be explained by both particularly high social inequalities and eating habits marked by a high consumption of sugary drinks and a low consumption of fruit, vegetables and dairy products.
In 2020, a collective scientific expertise led by the French National Research Institute for Sustainable Development (IRD), for which Caroline Méjean (research director at INRAE) chaired the panel of experts, formulated 24 recommendations for action in order to implement the National Nutrition and Health Programme in the French overseas departments. These include encouraging the installation of equipment and the development of urban facilities to enable physical activity, the reformulation of products (such as the reduction of added sugar, sodium and saturated fatty acids), the introduction of vouchers and workshops to raise awareness on nutrition, the promotion of allotments to improve access to quality products, and the strengthening of local health care services.

on the environmental impact of a product, from agricultural production to its purchase or preparation by the consumer. This database could be used as a basis for the display system that will be adopted.

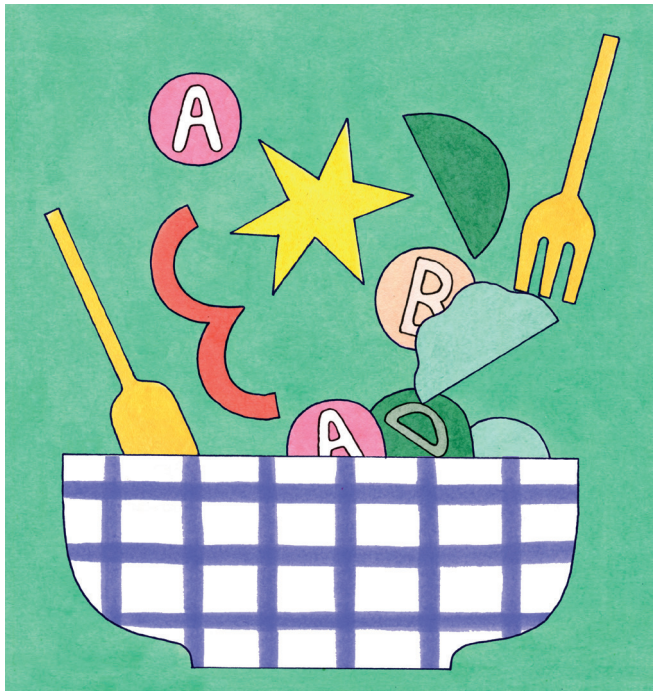
### The issue of awareness-raising messages

It is also within the framework of the PNNS that awareness-raising messages are developed: "Eat at least 5 fruits and vegetables a day", "For your health, avoid eating too much fat, too much sugar, too much salt"... We have all heard these messages, but do they actually contribute to changing our eating habits? According to Vincent Requillart, an INRAE economist at TSE, these information campaigns generally have a positive effect on consumption, but their impact remains relatively modest.

Campaigns such as "5 fruits and vegetables a day" can temporarily increase the average consumption of fruits and vegetables by 5%. In the long term, they can thus contribute to changing social norms regarding food. However, it should not be overlooked that these norms may appear contradictory to the dietary practices of certain populations. As Faustine Régnier, an INRAE food sociologist from the Social Sciences and Food unit (ALISS, Ivry-sur-Seine), points out, *"for people from low-income backgrounds, food is an area of freedom, sometimes the only one, where they feel they can make a choice, express their tastes, and thus compensate somewhat for other daily constraints, which therefore limits the impact of awareness campaigns".*

### For step-by-step changes

For Nicole Darmon, this implies working on a complementary approach in order to make step-by-step changes possible. For example, gradually introducing dried pulses into one's diet or preferring whole grains, and thus moving towards a more sustainable diet without upsetting one's habits. It is also a question of supporting transitions through actions that are close to the population: cooking workshops, community gardens, collective workshops to guide purchases. What about food-related mobile applications to support people in these steps? An estimated 30% of the population has already downloaded one. Once



again, however, it is the people on the lowest incomes who use them the least: technical barriers linked to poorly performing equipment are compounded by financial and time constraints, little knowledge of digital technologies and, in migration situations, a poor command of spoken and even more so written French.

### Educate first

The adults of tomorrow are the children of today. Raising children's awareness of sustainable food from the youngest age is a real challenge. One lever for action to reach a maximum number of children, whatever their social background: schools and school catering. In France, there is no shortage of initiatives: the "Fruit for recess" operation, the creation of school vegetable gardens, educational workshops and the like. But above all, the meals served in the canteen are governed by regulations and recommendations pertaining to their nutritional quality. And since 2019, following the EGalim law, canteens must offer a vegetarian menu at least once a week. This sends out a strong signal, even though it is still →

**Since 2019, French canteens must offer a vegetarian menu at least once a week.**

too early to measure the effects of this public policy scientifically. The school and school catering sector are also a major lever abroad. In Kenya, the schools and colleges permaculture programme –SCOPE Kenya– educates and prepares young schoolchildren and non-schoolchildren in twelve counties to understand nutritional value and food consumption for improved health, and to participate in agricultural production through school permaculture gardens. In Brazil, interventions in public primary schools teach children about healthy diets, a topic included in the curriculum. At the same time, school canteen cooks are also trained on the subject.

### Acting on products

The last card to be played in order to accelerate dietary transitions: act on the supply side. While research is working on the development of new products *(see page 25)*, it is also taking an interest in the development of new, healthier formulations, with less salt, sugar or fat in particular. This is the case, for example, with cold cuts. Although one option may be to simply reduce their salt and saturated fat content, the loss of sensory quality quickly puts a limit on it. A more promising option would seem to be the substitution of sodium chloride (salt) with potassium chloride, and of animal fats with vegetable oils containing unsaturated fatty acids, which are healthier. The results: researchers developed a dry sausage with a 30% reduction in salt and 60% reduction in saturated fatty acids without degrading the sensory quality. Public policies draw on a whole range of regulations or taxes that aim to encourage or require companies to change their products towards healthier formulations. In order to monitor changes in the nutritional composition of foods, INRAE and ANSES created the Food Quality Observatory (Oqali) in 2018, which allows reporting on the efforts made by the industry.


**NUTRI-SCORE**

In France, 500 companies have adopted the Nutri-Score display, representing 50% of the food market share.

Of all the products rated, 31.7% are classified A, 9.6% are classified E. For some fatty products such as vegetable oils (like olive and hazelnut), the best possible score is C. 94% of the French are in favour of the Nutri-Score. 1 French out of 2 declares having changed at least one purchasing habit thanks to Nutri-Score.

Source : www.oqali.fr

### Steering production

And since our diets begin in the fields, public authorities are also endeavouring to steer production towards a rebalancing of animal/plant proteins. The French Ministry of Agriculture and Food thus initiated a 10-year national "plant protein" strategy in 2020. It aims to double the cultivated area of protein-rich plant species such as soya, peas, dried pulses, alfalfa and fodder legumes by 2030, in order to both rebalance diets and increase the protein autonomy of livestock animals. At the same time, this plan promotes the structuring of a local product offer for dried pulses.

There are therefore many levers to guide and accompany consumers towards healthier and more sustainable diets. If none of them seems strictly speaking more effective than another, the solution is probably to combine them and to rely on the complementarity between national and territorial policies, voluntary commitment of companies and changes in the behaviour of consumer-citizens. ●

# Research put to the test

Sophie Nicklaus, an INRAE specialist in the study of eating behaviour at the Centre for Taste and Feeding Behavior (CSGA) in Dijon, is the scientific director of the "Dijon, Sustainable Food 2030" project led by the Dijon metropolitan area.
**Interview.**

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**The Territories of Innovation (TI), a new model for research, development and innovation encouraged by the government via the French Investments for the Future programme in 2019, aim to accelerate transitions through greater cooperation between players as close as possible to the territories and their expectations. Deeply committed to social and food issues, the metropolis of Dijon has brought on board more than 30 partners, including INRAE, in its "Dijon, Sustainable Food 2030" project. Sophie Nicklaus explains to us how this new type of project works and the perspectives it opens up.**

**What are the objectives of the "Dijon, Sustainable Food 2030" project?**
This project targets both ends of the food chain: producing better and eating better. We see this as a virtuous circle, not as a straight line with a beginning and an end. Eating better stimulates more virtuous production practices, and producing better allows us to eat better! We analyse the quality of the soil and ascertain that it is possible to produce in an agroecological way, in particular by growing legume crops which, in addition to having nutritional qualities, enrich the soil with nitrogen and make it possible to limit the use of fertilisers and phytosanitary products. We are developing new processes with the industry in an effort to develop high quality value chains with local roots. We are also coordinating communities of citizens to identify their needs and expectations in terms of sustainable food.

**Can you give us some examples of actions carried out within the framework of the TI?**
Dijon Métropole wants to develop a local legume industry. At present, it is difficult for farmers to find a viable economic model on certain plots while meeting environmental constraints on water quality or reducing the use of nitrogen fertilisers and pesticides. We therefore study the quality of soils to identify those most suitable for the agroecological production of legumes and we support farmers in adopting more environmentally friendly practices. We also share with them our knowledge on these plants, as the Agroecology Joint Research Unit in Dijon holds Europe's largest collection of genetic resources on pulses. Another action consists of establishing a territorial label –for the moment called "Dijon Agroecology"– to certify the quality of the products. These are slightly more expensive, but they allow better social recognition and better remuneration for producers. It is then a question of ensuring outlets for these products at a fair price. The city has therefore committed itself to a purchasing policy through the collective catering it provides. For more than two years, even before the implementation of the EGalim law, children have been offered a weekly menu at the canteen in which the proteins are exclusively plant-based and, where possible, local. With 8,000 meals served every day in the canteen, the city's purchasing power is one of the most effective levers of transition. Moreover, through the adoption of less carbon-impacting eating habits in out-of-home catering, the city also aims to influence the consumption →

habits of citizens for their evening or weekend meals, by changing their habits and their perception of the products. In addition, in order to ensure access "for all", the city is financially committed through the social pricing of school meals: families pay for the canteen according to their income and, for a meal costing €12.90, those on low incomes only pay €0.50. This is decisive, especially as for some children this will be the only good, proper meal they have in the day.

**How does research work on this expected change?**

At the CSGA, we study the determinants of eating behaviour over the life course, using an approach that combines nutrition, sensory evaluation and psychology. We draw on observations or interventional experiments, both in the laboratory and in the population. For example, we are working on children's eating behaviour: how is it rooted in the educational and family environment? How is it modified? We know that certain cognitive elements (information, for example) play an important role in changing children's behaviour, but not only that: pleasure is an essential lever for getting them to adopt healthy behaviour. Obviously, the more healthy foods are enjoyed, the more they are consumed. The TI project allows us to study in real life the factors that would favour the acceptability of vegetarian menus by children and, in particular, the appreciation of legumes and vegetables. With more stringent requirements than set out in the EGalim law, particularly concerning the environmental impact of products and the nutritional quality of meals, we are observing children's behaviour and their responses to the various levers of action used, such as information, experimentation, repetition and sensory education. This allows us to develop decision-making tools for Dijon Métropole. We also offer training modules for professionals. Indeed, "cooking with plants" currently accounts for only 20% of the training hours for collective catering cooks, compared to 80% for "cooking with animal products". It is important to reverse these proportions in order to help cooks adopt more plant-based cooking practices. We are studying the practices and needs of the professions in order to understand the best ways to make them evolve. We are relying on local partners for this aspect with the Trades and Qualification Campus "Food, taste, tourism" and the engineering school AgroSup Dijon. Other INRAE studies are part of these reflections. In Dijon, Clermont-Ferrand and Versailles, for example, teams are developing new processing methods that integrate legumes into the preparation of everyday products to promote their consumption *(see p. 25)*.

**Is the local scale relevant to meet the food issues?**

The territorial dynamic is decisive because exchanges and meetings between stakeholders are facilitated. Long-term relationships can develop on a basis of great trust, strengthening the project. Moreover, the emotional dimension, which connects citizens and decision-makers to their territory, encourages their involvement and the development of local food supply chains. The local scale makes it possible to tackle the subject and find possible solutions, but it is obviously not enough to meet the needs of the population in terms of quantity and diversity of agricultural production. Moving towards the borders of the department, or even the region, is a natural step. The aim is not to be self-sufficient in food, but to encourage a dynamic towards greater sustainability.

**How does research fit into this project, what are the mutual contributions?**

The project's piloting structure meets every two weeks with the socio-economic and academic partners in order to examine the different initiatives, such as the implementation of the "Dijon Agroecology" label for quality products, in which we have been very involved. Meetings in the field complete this arrangement. For my part, I am in direct and regular contact with the city's director of catering. On the one hand, research provides scientific results and expertise in agroecology, decision support, in the fields of food, nutrition, eating habits, economics and sociology. We have the capacity to develop innovations that are technical, methodological, scientific as well as organisational, with a wide variety of methods,

"With 8,000 meals served every day, the canteen is one of the most effective levers of transition."

including participatory science approaches that are crucial if citizens are to become involved in their food. On the other hand, the strong partnership with Dijon Métropole offers us a unique testing ground where we can observe in "real life" the new systems devised in the laboratory. It is these experiments carried out on the scale of the territory which, when capitalised on in terms of knowledge, can be transposed to a larger scale in order to achieve the expected transitions. This is truly fascinating work because the city has a logic of action and multiplies the levers. I very much like the idea of leaving the laboratories and seeing what our skills can do for the city! Our work will have tangible benefits for everyone, which is very rewarding. ●

ENGAGEMENT

## Dijon makes food a nutritional, health, agricultural and social issue

**Food security is one of Dijon Métropole's key public policy issues. With the guiding notion that what we eat transforms the territory in which we live, Dijon has the ambition to achieve a profound transformation of its agri-food system, both on the production and consumption side, in order to build sustainability.**

**With little industry, the city has long been committed to projects in the fields of agriculture and the environment, with, for example, the implementation of an urban plan that preserves agricultural land. Based on the principle recalled by Philippe Lemanceau, former INRAE research director and vice-president of the Metropolis in charge of the food transition, that *"the agro-ecological transition can only be achieved if market and demand coincide"*, the food transition has become a priority issue for Dijon with the "Dijon, Sustainable Food 2030" project.**

**Economic players (like Dijon Céréales, Seb, Orange and Vitagora), social players (such as solidarity grocery stores and food banks) and academic players, including INRAE, quickly rallied around the initiative. Designated in the first wave of French Investments for the Future 3 as Territories of Innovation in 2019, the project has a budget of €46 million, including more than €26 million from private funds, to experiment together and develop prototypes that can be transposed to other territories.**

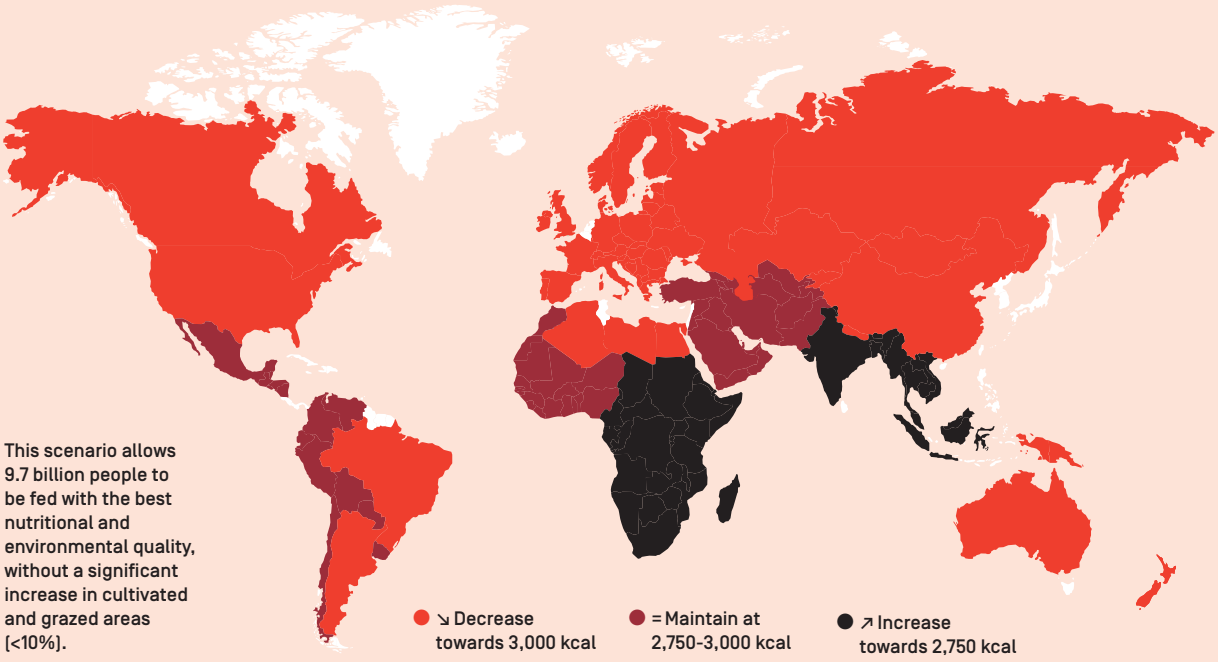
**As Philippe Lemanceau points out, *"the aim is to show that the food transition involving the agroecological transition is possible, and that it is beneficial not only for the environment, but also for the local economy and social cohesion, particularly between farmers and citizens, between urban and rural areas. This social component is very important: healthy and sustainable diets must be accessible to all."***

**It's a virtuous circle: produce better to eat better, and eat better to produce better.**

# "HEALTHY DIETS"
# A SCENARIO TO FEED THE WORLD IN 2050

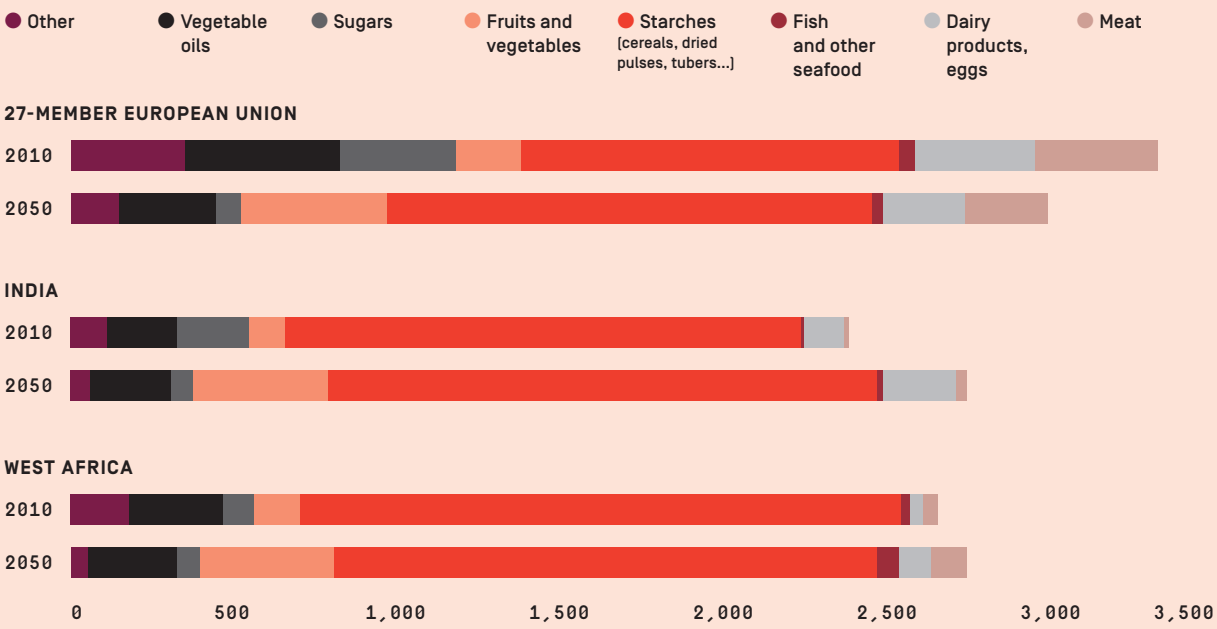
based on the *Agrimonde-Terra* study

## REBALANCING ALL DIETS TO 2,750-3,000 KCAL PER DAY/PERSON (including waste)




This scenario allows 9.7 billion people to be fed with the best nutritional and environmental quality, without a significant increase in cultivated and grazed areas (<10%).

## EVOLUTION OF THE DIET IN 3 REGIONS OF THE WORLD (in kcal/day/pers.)



# HOW TO FEED THE PLANET IN 2050?

Under-nutrition, over-nutrition, ecological issues... How can we meet the challenge of feeding 9.7 billion people in 2050? A collective challenge with regional solutions, with a consensus on the need to think in an integrated manner.

## The issues.

On 13 July 2020, the UN warned in its annual SOFI[1] report that "since 2014, the number of hungry people worldwide has been slowly rising", thus seeing the achievement of the second Sustainable Development Goal (SDG), "Zero Hunger", move further away. In 2021, the same report highlighted the worsening of the trend by the COVID-19[2] pandemic, which increased the number of people suffering from hunger in the world (moderate or severe energy insufficiency) from 650 million in 2019 to 768 million in 2020. In addition to these populations facing problems of undernutrition, there are now also 2 billion people with an unbalanced diet, characterised by an excessive consumption of calories and certain nutrients (like salt, sugar and fats). This consumption encourages overweight and obesity, and increases the risk of various metabolic diseases (such as hypertension, diabetes and certain cancers).

Even though these figures may be frightening, given that demographic forecasts predict a population of 9.7 billion on the planet in 2050, research has been actively engaged for many years in order to gain knowledge in the face of a challenge that goes far beyond the mere question of the quantities to be produced, and to examine, alongside geopolitical strategies, agricultural and food systems as a whole. A challenge for which solutions must be developed over time and by mobilising numerous levers for action.

### The three pillars

In order to identify the paths to be explored, researchers are conducting foresight studies based on current data and trends. After considering the issue of food security exclusively from a production perspective in the early 2000s, advocating an increase in productivity without taking into account its impact on the environment or the quality and diversity of food, the studies quickly integrated the issues of losses and waste, as well as of the necessary changes to be implemented in food consumption. Gradually, the combination of agroecology, the reduction of losses and waste and the adoption of more balanced diets, combining more products of plant origin and fewer meat products (at least in developed countries), has emerged as a way of solving the food equation without leading to a damaging increase in the amount of land used. →

### Agrimonde-Terra: an integrated and systemic approach for 2050

The intertwining of issues highlights the need to think about the transition of food systems in an integrated manner, encompassing the role of land use and including environmental and health issues. With this in mind, CIRAD and INRAE presented in 2016 the results of a joint study on "land use and food security in 2050". The aim of the Agrimonde-Terra[3] foresight study was to identify the levers likely to improve food security and nutrition on a global scale by 2050. It is part of the research priority on global food security explored by the INRAE-CIRAD interdisciplinary research programme "GloFoodS" *(see page 42)*. Using both a quantitative and qualitative approach, based on current data and trends and combining possible evolutions of a wide range of factors (such as climate change, diets, urban-rural relations, agricultural structures, crop and animal production systems and public policies), the results have identified five possible scenarios.

In order to develop them, the Agrimonde-Terra foresight first analysed the long-term dynamics of food security, focusing on land use: access and agronomic potential, intensity and distribution between the different uses and services provided by the land. Secondly, quantitative hypotheses were formulated, taking into account the evolution of the global context in its technical, economic and social dimensions. These dimensions include climate change and its mitigation, demographic transitions and urbanisation, international trade, the evolution of diets, and technical progress in agriculture and livestock farming. To examine these hypotheses, simulations were carried out by integrating elements of the global context, in particular the climate projections of the Intergovernmental Panel on Climate Change (IPCC).

**A scenario based on "healthy diets" could reduce over- and under nutrition and associated chronic diseases.**

1. SOFI report produced annually by the UN and its agencies (FAO, WHO, WFP, Unicef, IFAD) – The State of Food Security and Nutrition in the World – 2020. url.inrae.fr/3yfS0PT

2. The SOFI report estimated that between 80 and 130 million more people would suffer from hunger in 2020 as a result of the COVID-19 crisis.

3. Agrimonde-Terra. http://bit.ly/3GxzzNv

### The different scenarios

Five scenarios were thus proposed: three based on current competing trends observed in most regions of the world ("Metropolisation", "Regionalisation" and "Households") and two corresponding to disruptive shifts in the relationship between land use and food security ("Healthy diets" and "Communities"). The Agrimonde-Terra foresight study concludes that most scenarios will not be able to ensure global food security in a sustainable way in 2050, due to an increase in deforestation for agricultural purposes, with some scenarios having ambivalent outcomes.

"Metropolisation" would contribute most to the increase in the prevalence of overweight and obesity. The "Communities" scenario, based on the development of small communities and the management of common agricultural goods, would imply a reduction in food availability at global and regional level.

In contrast, the "Regionalisation" scenario, with the networking of medium-sized cities and rural areas and the emergence of regional food systems based on family farming and traditional diets, would lead to ambiguous outcomes in terms of global food security.

The "Household" scenario, in which family farms and cooperatives would be major actors in land use, would lead to a decrease in undernutrition but with ambivalent effects on overnutrition.

### The positive prospects of the "Healthy diets" scenario

The "Healthy diets" scenario would best reduce the prevalence of over- and under-nutrition and associated chronic diseases. It proposes diets that combine a variety of products: fish, meat, milk, cereals, fruits, vegetables and legumes, with their micronutrients and fibre preserved. →

# THE PROJECTIONS FOR 2050
## Agricultural land

**Conducted by INRAE[1], the study "European Agriculture in 2050"[2] proposes projections for 2050 of the various components of the world's agricultural and food system, dividing it into 21 regions, 8 of which are in Europe.**

**The need for cultivated land**
If current diets are maintained in developed regions and the nutritional transition continues in emerging or developing regions, the need for cultivated land in the world would vary from +223 to –11 million hectares, in addition to the 1.5 billion hectare cultivated in 2010. It would be considerable in Sub-Saharan Africa and India. A hypothesis of disruption towards "healthy" diets (as defined by the WHO) would ease the pressure somewhat, but not as much as might be expected: the need would change on a global scale from +194 to –51 million hectares compared to 2010.

In Europe, as in other developed regions, such a change would lead to a reduction in total caloric intake and consumption of animal products, allowing for a decrease in cultivated areas ranging from –14 to –30 million hectares.

**Potential surpluses in Europe**
The "surplus land" that could appear in several regions of Europe, particularly in Central and Eastern Europe, would be too small for its agricultural use to contribute to food security in other regions of the world.
It could, however, be an opportunity to reduce our dependence on soybean imports by developing oilseed crops, or to move towards less input-intensive cropping systems that require more land. Depending on the yield and diet hypotheses selected, between 4 and 44 million tons of soybean meal could thus be produced on this "surplus land", making it possible, in the best-case scenario, to avoid imports altogether, while still leaving 9 million hectares "available" for other uses or for yield reductions.

The results of this study, carried out for the Pluriagri[3] association, and in particular the uncertainties that it integrates or points out, are available to stakeholders in order to help them develop the (re)orientation of their policies, including in the context of the European Green Deal, which aims at a transition towards a more sustainable agriculture.

1. Directorate for Expertise, Foresight and Advanced Studies (DEPE).

2. The role of European agriculture in the world in 2050: between climate issues and food security challenges (2020). Synthesis report: https://url.inrae.fr/2HQjy6h

3. Pluriagri is an association that brings together various field crop stakeholders: Avril, Confédération générale des planteurs de betterave, Unigrains and Crédit Agricole SA.

**METHODOLOGY**

**The study takes into account the combination of the effects of climate change (according to the IPCC's RCP-6.0 scenario) and technical developments (based in particular on the FAO's 2012 and 2018 projections) on agricultural yields. It also incorporates possible changes in the diets of a rapidly growing world population by 2050.**
**The proposed simulations are based on a set of contrasting hypotheses aimed at integrating the uncertainties that weigh on the evolution of these variables and determine, on this basis, the areas under cultivation by 2050 in each region of the world, the levels of production and the use of or contribution to international trade of each region.**

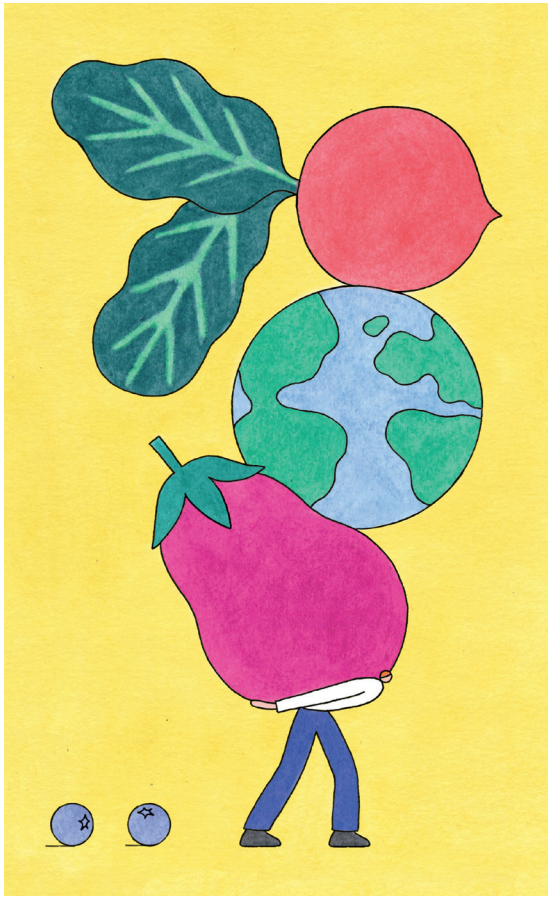
**KEY FIGURES**

**1.5 billion ha**
cultivated in the world in 2010

**–11 to +223 Mha**
Evolution of the need for cultivated areas according to different scenarios for 2050

**–51 to +194 Mha**
Evolution of the need for cultivated areas in the world with healthy diets; from -30 to -14 million ha for Europe

It implies a reconfiguration of agricultural and food systems through new alliances between stakeholders. The food chain becomes more efficient and reduces losses and waste. In this scenario, some regions would still be in a difficult situation, such as India and Sub-Saharan Africa, due to their high population growth and low agricultural yields, with persistent risks of deforestation. However, with favourable global governance, this path would make it possible to have food that is compatible with the health of populations as well as with environmentally friendly agricultural practices and land use. The challenge will then be to prevent food crises, land grabbing, deforestation and mitigate the effects of climate change through concerted international action on food security and land use.



**2 billion**
people in the world live on an unbalanced diet

**1/3**
of global GHG emissions are due to food

**20%**
of food is lost or wasted in Europe

# The transition of food systems represents a powerful lever to promote human health and support environmental, economic and social sustainability.

### A systemic approach to ensure sustainability

In all cases, international trade will play a key role in ensuring global food security in 2050, and some regions, in particular North Africa and the Near and Middle East, are likely to remain highly dependent on food imports. Increasing the volume of food produced and its diversity in order to move towards a healthier diet in 2050 while limiting deforestation, will require a significant diversification of cropping and livestock systems. The Agrimonde-Terra foresight confirms the importance of a systemic vision of the transitions necessary to ensure food and nutritional security for populations, using the levers of agricultural availability, diets and the optimisation of agricultural and food systems to reduce losses and waste.

As well as ensuring the food security of populations, the transition of food systems represents a powerful lever to promote human health and support environmental, economic and social sustainability. In order to succeed in this transition, transformations must take place in a profound manner over the next few years, through immediate actions and the implementation of progressive solutions and adaptive trajectories.

### A challenge for all

Although there are now three main areas of research in the scientific communities on food security – changing production patterns based on

the agroecological transition, reducing losses and waste, and changing food consumption patterns – the challenge is complex, with many issues that overlap and cut across sectors, territories and actors. The preceding pages give an idea of the actions that can be taken to change Western food behaviour.

Other work focusing more on the levers of agricultural production methods and the reduction of loss and waste is being developed in France and around the world *(see double page below)*. Public policies can play a central role by encouraging consumers to adopt diets that reduce the consumption of animal products when excessive, in favour of cereals, legumes, fruit and vegetables. This can be achieved by acting on access to and the cost of food, and by launching education and awareness-raising policies. They must encourage the diversification of farming systems and the development of agroecological practices that are useful for limiting the environmental impact of agriculture and livestock farming. They must also regulate access to agricultural land at the national level and the functioning of international trade in order to guarantee stable access to healthy food for all. The industry is called upon to develop economic models based on an offer that includes new, healthier and more accessible products. Everyone must commit to reducing losses and waste in food systems.

There is no single path mapped out, but rather a systemic transformation to be achieved with actions in each country and region consistent with each other and accountable in the face of global challenges. To study and design these transformations and contribute to the acceleration of transitions, INRAE develops its research with an integrative and interdisciplinary vision, and collaborates with public and private actors to facilitate the transfer of knowledge for innovations and public policies likely to build sustainable food systems, specific to each region, beneficial to both humankind and the Earth.

**Policies need to encourage the diversification of farming systems and the development of agroecology to limit environmental impacts.**

The transformation of our food systems requires close coordination between stakeholders' strategies and between countries. Research is there to accompany them and foster this coordination. ●

# A WHOLE SYSTEM

## PROMOTING A GLOBAL DYNAMIC OF AGRICULTURAL AND FOOD SYSTEMS: EXAMPLES

### Developing efficient and environmentally friendly agricultural practices

And to do so, assess the potential of the land that is available, and for what use.

In 2020, INRAE and CIRAD presented the results of the GloFoodS programme "Transitions for Global Food Security", which financed 45 research projects, mobilising more than 200 researchers over 8 years in France and abroad, particularly in French-speaking Africa and South-East Asia. The work contributed to a better understanding of variations in crop and animal production yields, to assessing on a global scale the potential of land available for food, energy and bio-industrial purposes, to identifying processes and organisations that limit losses and waste, as well as to providing information on the links between household access to food and social inequalities. Among the objectives: to propose more efficient and environmentally friendly production systems and practices and to limit losses and waste. These two aspects of transition rely on innovations in the organisation of food value chains, for better access to healthy and sufficient food, by means of agri-food processes that are more economical with agricultural resources. For example, the GloFoodS "Legend" project studied the adaptation of agriculture to urbanisation in a case study in Madagascar. The results showed that urban and peri-urban agriculture plays a key role in food security: it supplies the capital with fresh produce and covers almost all the needs of its population for eggs and poultry, as well as a large part of its vegetable needs. Agriculture does not inevitably succumb in the face of urban sprawl; it is maintained and developed, thanks to farmers who adapt their production systems by introducing new crops and using agroecological approaches. Another example of mobilising the lever of system change: the GloFoodS "Serena" project aimed to explore the potential benefits of agroforestry parks on food security and livelihoods of rural households in the groundnut basin of Senegal, through the diversity of agricultural landscapes. Using remote sensing data, modelling and statistical methods, the study showed the benefits of trees for crop productivity, but only up to a certain point: namely, when the tree starts competing with the crop. It thus appeared that trees cannot directly strengthen the coping strategies of food-insecure households, but contribute to the improvement of the production system.

**Main goals of research programmes: more efficient production systems and practices, and limitation of losses and waste.**

2

## Creating resilient and solidarity-based food systems

by building solutions at all levels, international, national and local.

Because there is no one-size-fits-all solution, INRAE has partnered with the FAO to study numerous initiatives around the world that aim to produce, share, sell and consume more sustainable food. The study, led by sociologist Allison Marie Loconto, Deputy Director of INRAE's Interdisciplinary Laboratory for Science, Innovation and Society (LISIS), shows that the resilience of food systems depends in particular on innovations for the relocation and diversification of food systems. Incentives can help prioritise access to beneficial foods for vulnerable communities, promote sustainable agriculture, including the protection of biodiversity, and encourage healthy and nutritious diets. Examples include the creation of social networks in Finland to facilitate communication between producers and consumers, the development in France of "field schools" for producers or "incubator farms" so that producers can test new practices without economic risk, as well as the implementation of a plan in Brazil to collect organic waste at 900 weekly markets for compost.

**Bringing producers and consumers closer together**

The fundamental outcome of these initiatives is to increase the interactions between producers and consumers, and to change the way they influence and interact within their food environment.
This study was the subject of a book[1] designed as a manual for actors who wish to innovate in the food systems they are involved in. These types of local food systems have demonstrated their resilience during the COVID-19 crisis in Africa, India or Brazil. They all use sustainable farming practices based on the 10 elements of agroecology producing food for local and regional markets, thus ensuring food security and access to healthy and affordable food for the disadvantaged population and the middle class.

1. FAO and INRAE. 2020. Systèmes alimentaires durables – Un manuel pour s'y retrouver. Rome. https://doi.org/10.4060/ca9917fr

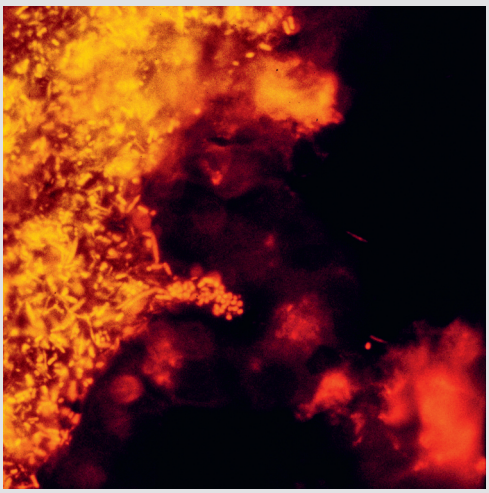
**One of the keys: increasing producer-consumer interactions.**

3

## Stopping food waste along the chain

as 1 in 5 foods are lost or wasted in Europe, or 173 kg per person each year.

Generally speaking, in developed countries 2/3 of food waste occurs at the consumer end, with the rest being lost along the production chain. *"In developing countries, poverty effectively causes consumers not to waste. Instead, losses occur at the harvest, transport and storage stages. Difficult weather conditions, plant diseases, inadequate equipment and poor roads are all factors. In Africa and South-East Asia, post-harvest losses in cereals account for up to 20% of production",* explains Barbara Redlingshöfer, an INRAE engineer at the SADAPT (Science for Action and Development Activities, Products, Territories) joint research unit. Her work proposes combining different solutions to reduce food losses. On the one hand, genetically improving varieties to make them resistant to disease, optimising harvesting equipment and better organising the supply chain. On the other hand, lowering consumer expectations regarding the appearance of products, particularly fruit and vegetables.



# Gut microbiota, an ally for our health

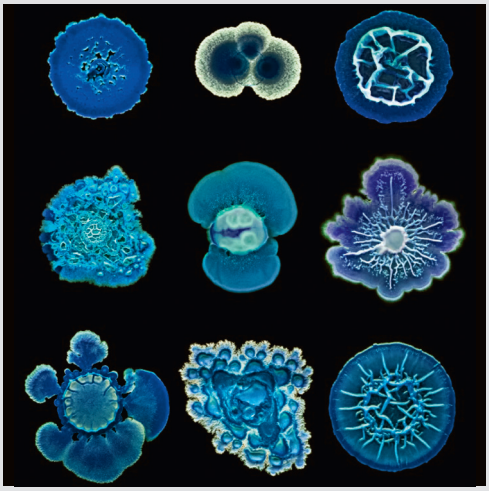
Our body is home to ecosystems full of billions of micro-organisms, known as microbiota, among which, gut microbiota, the set of micro-organisms found in our digestive tract.

Discovery after discovery, international research has led to the conclusion that gut microbiota is decisive to human health, rendering many services to our well-being, helping us produce vitamins, digest well, protect our intestines, and produce natural defences. With this knowledge, we have the means to take care of our microbiota and live in symbiosis with it. As links to several pathologies were established, it represents a small-unforeseen revolution for medicine.

Revealing the link between gut microbiota and our health was the result of global scientific efforts, resulting from INRAE's pioneering research, which started in the 1980s with the study of rumen microbes of ruminant animals and their action on fibre digestion. At this time, studies on the use of probiotics for ruminants started. Microbiome research on animals soon turned to the human microbiome. The results? The ANR MetaHit project coordinated by INRAE led to decrypting the human genome microbiome and questions on links with chronic diseases arose.

Recently, INRAE and its partners launched Le French Gut project, the French national contribution to the international Million Microbiome of Humans Project. Initiated by INRAE through its research unit MetaGenoPolis, it will help understand healthy gut microbiota, model and predict changes in gut microbiota associated with diseases. MetaGenoPolis is a pre-industrial demonstrator, exploring gut microbiota from both quantitative and functional perspectives, using cutting-edge technological equipment, a major international player in microbiota science.

Scan this QR code to access our online dossier



# Fermented foods

The process of fermenting foods has been used for thousands of years to preserve food. It stops the growth of pathogenic micro-organisms, thus, maximizing the conservation time of certain food products without using synthetic additives.

With time, fermented foods were diversified at a global scale, to respond to a wide range of diets. Their benefits include providing vitamins and antioxidants as well as improving the gut microbiota and health.

As economic, social, and environmental challenges are affecting global food chains, food demand is on the rise, making the transition to sustainable agri-food systems even more crucial. In this context, fermented foods appear as a catalyst for sustainability and represent a source of innovation and competitivity with substantial benefits for the agri-food sector. For more sustainable diets, our intakes of plant proteins must increase in order to reduce meat consumption. Fermenting vegetables could boost our consumption of them, with new tastes and textures. It could also help reduce the use of additives and food waste, such as discarded fruits and vegetables for their shapes and sizes. The development of co-products is a promising avenue for the agri-food sector.

INRAE is contributing to this innovative field of research at the national and European levels. In France, the launch of the "Ferments of the Future" Grand Challenge, a project funded by the French government (48 million euros), gathers research and industries around competitive projects, to create an innovation platform at the end of 2023. At the European level, our scientists federate a European network, Pimento, structuring the scientific and socio-economic communities working on fermented foods.

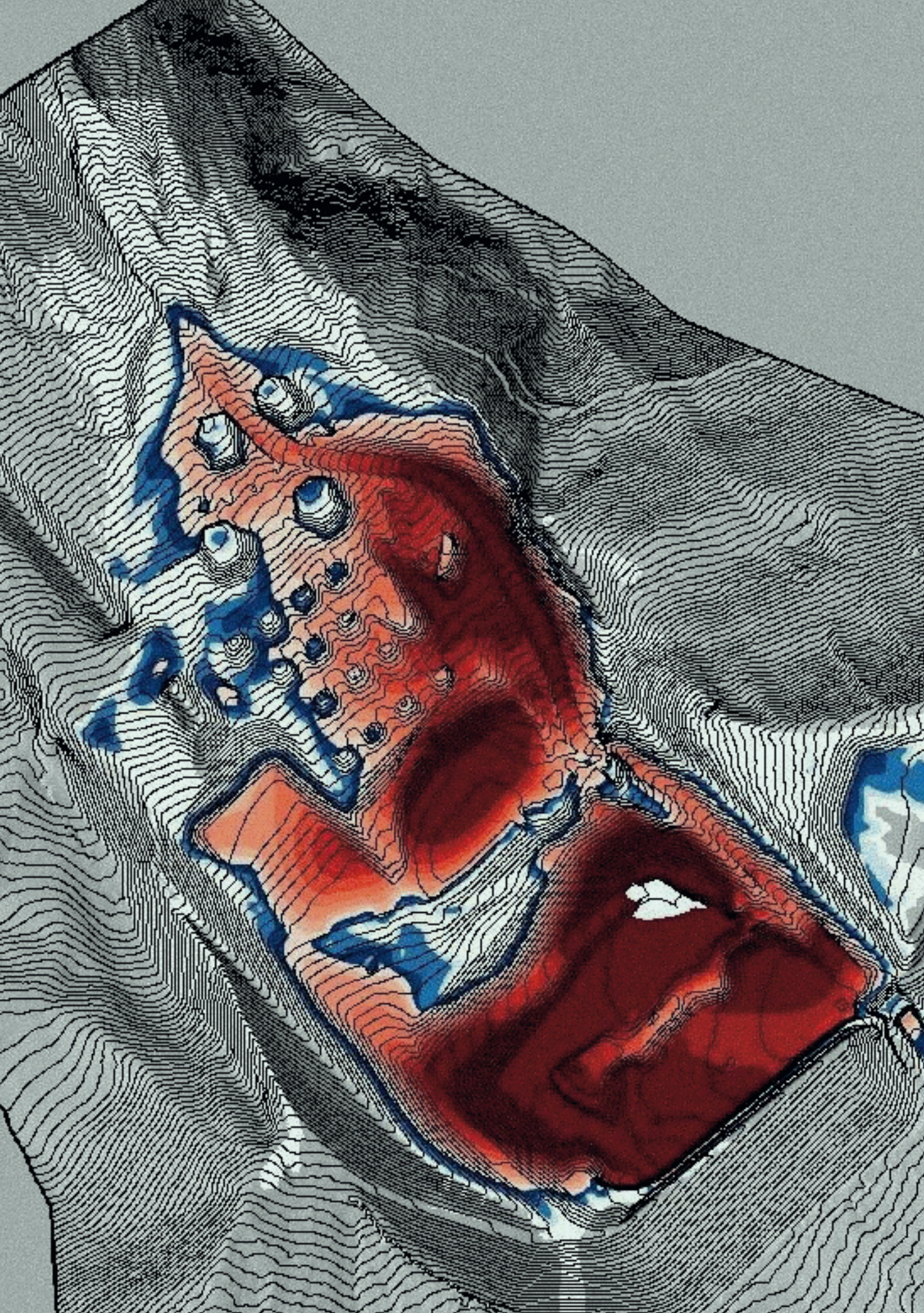
Scan this QR code to access our online dossier

# UNDER-STANDING AVALANCHE RISK

Harsh mountain environments are host to particularly complex interactions between the three dimensions of disaster risk – hazard, vulnerability and exposure. As global temperatures rise, increasingly sophisticated research tools help our researchers to keep pace with the changing patterns of avalanche risk.

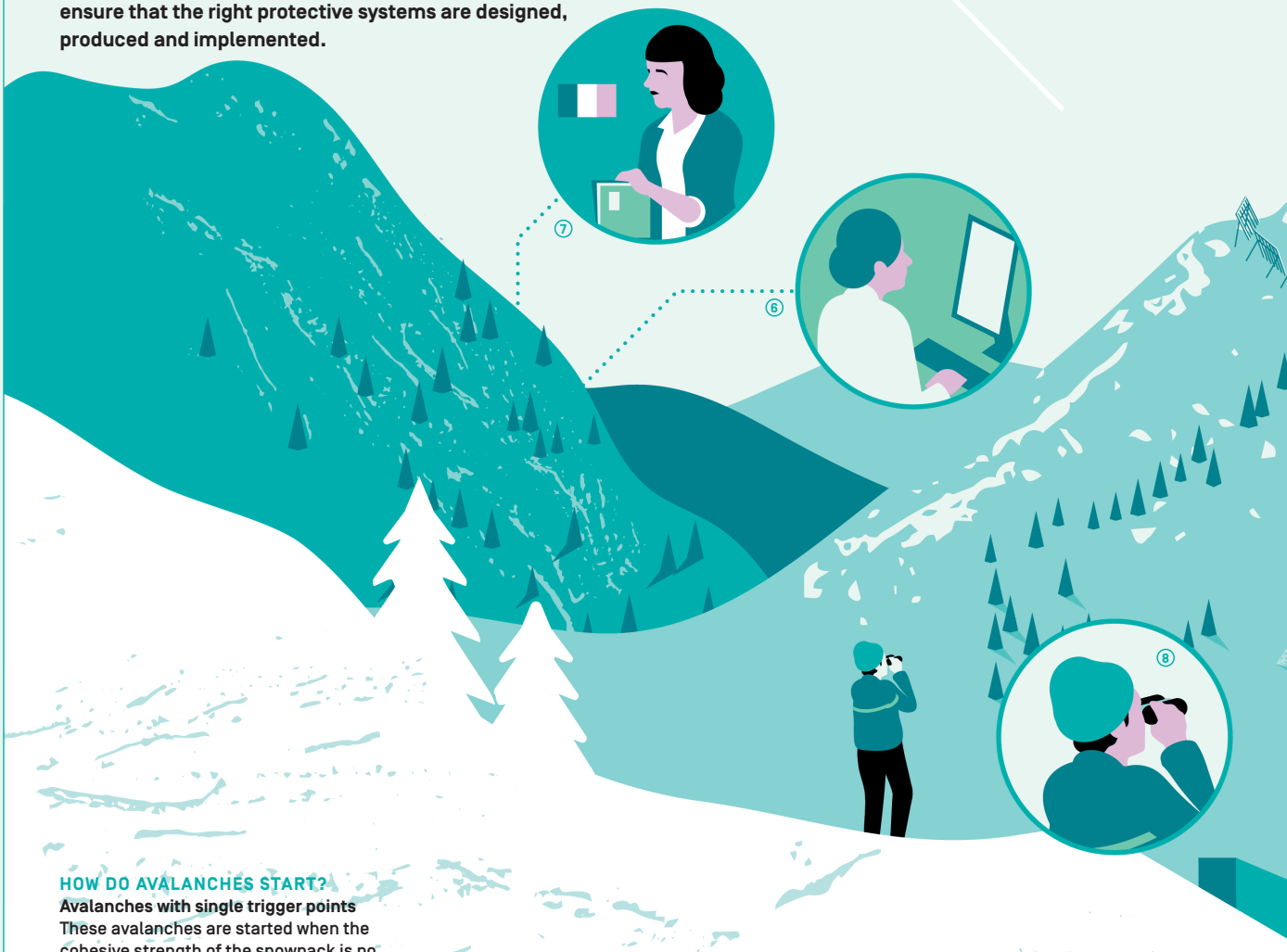
This dossier is dedicated to Xavier Ravanat, a member of the ETNA Unit, killed in a mountain accident in February 2021.

This dossier was first released in French in October 2021.
On the 1st of January 2023, the ETNA research unit joined the Institute of Environmental Geosciences (IGE joint research unit).



# The avalanche risk ecosystem

**An extensive and detailed understanding of the processes at work combined with continuous dialogue between researchers and a whole network of professionals to ensure that the right protective systems are designed, produced and implemented.**




## HOW DO AVALANCHES START?

**Avalanches with single trigger points**
These avalanches are started when the cohesive strength of the snowpack is no longer sufficient to guarantee its stability. This is often how wet avalanches or avalanches formed of fresh snow occur.

**Avalanches that start along a fracture line**
These avalanches are triggered when a "weak layer" with little cohesive force is located below a more cohesive harder layer. A simple overload, such as a skier crossing the snowpack or a fall from an outcrop, is sufficient to fracture the weak layer, destabilising the upper layer and triggering the avalanche.

## AVALANCHE TYPES

**① Wet dense flow avalanches**
Wet snow avalanches contain at least 10 kg of water per $m^3$. When the water content rises above 30 kg per $m^3$, friction is greatly reduced and the avalanche can travel longer distances. Despite their generally slower speeds, these avalanches can exert very great pressures, especially where large volumes of snow are involved.

**② Dry dense flow avalanches**
The density of these avalanches is between 200 and 400 kg per $m^3$. They are capable of exerting extreme pressure on buildings when they travel quickly (they can reach speeds of up to 150 km per hour).

**③ Powder (aerosol) avalanches**
Here, powder clouds form from snow suspended in the air above dense snow avalanches. They can reach 50 metres in height and, unlike dense avalanches, can climb the opposite side of a valley.

## PREVENTIVE STRUCTURES

**④ Active preventive structures**
Designed to prevent avalanches from forming, these structures include snow racks, screens or nets, windmill structures, jet roofs or baffles, and snow fences. They are installed in the starting zone to stabilise the snowpack or alter the distribution of the snow, thereby avoiding the overloading that could trigger an avalanche.

**⑤ Passive preventive structures**
These structures are intended to slow, divert or stop an avalanche. Examples are braking mounds, diversion berms, retention dams and snow sheds or tunnels.


## WHO IS INVOLVED?

The IGE Joint Research Unit ⑥ would not be able to carry out its mission to expand our knowledge of avalanches and develop avalanche control tools without strong synergies with other laboratories. Its closest partner is the French Snow Study Centre (CEN) at the French National Centre for Meteorological Research (CNRM), and its projects are delivered through a collaborative network across France, Europe and beyond. The unit works closely with all those responsible for managing natural hazards in mountain environments, providing a risk prevention service that takes the needs of all stakeholders into account. Managers and operational teams at the Directorate General for Risk Prevention (DGPR) at the Ministry for Ecological Transition (MTE) ⑦, members of the Mountain Landscape Restoration Service (RTM) at the French National Forest Office (ONF) ⑧, professional consultants ⑨, local communities ⑩ groups and associations are all involved.

# A WHOLE-SYSTEM APPROACH TO A FAST-CHANGING RISK

Half a century of sustained research has produced an advanced framework and tools for the study of avalanche risk, firmly underpinned by the principles of multi-disciplinarity and inclusiveness. These will prove vital as the changing climate presents us with new challenges. **Overview.**

Should all development be banned in high-risk zones, or should these areas instead be provided with protective infrastructure? The twin demands of development and safety mean that planning decisions are always hard-fought in mountain areas. Decisions concerning avalanche risk can cost millions of euros, but their cost can also be counted in human lives. The evaluation of this risk demands complex research at widely differing scales and in different domains, from the study of the physical processes involved in avalanches to monitoring the ever-changing patterns of hazards, vulnerability and exposure that combine to produce it.

### A research unit to investigate all aspects of avalanche risk

1970 was a difficult year for French mountain communities. On 10 February, an avalanche engulfed a UCPA holiday-centre chalet in Val d'Isère, leaving 39 dead. Then, two months later, on the Assy plateau, a landslide formed of a mixture of mud, snow and water buried a sanatorium, causing 72 further deaths. These two tragedies acted as a wake-up call. The French authorities realised that the country had few defences against natural events such as these, events that were both recurrent and hard to predict. They asked the CTGREF[1] to set up a snow study service, which would eventually evolve into the current ETNA Research Unit on Torrential Erosion, Snow and Avalanches at INRAE. The newly fledged service's principal mission was to build a better understanding of avalanche risk. *"In its early days, the unit was chiefly interested in mapping avalanche locations and in developing and improving protective structures"*, Florence Naaim, ETNA's current head tells us as she looks back over the unit's development. *"We then began to study the snow itself, looking more closely at the physics of avalanches. Nowadays we also take account of the potential impacts, the vulnerability of those at risk, and we factor in all the physical and social mechanisms that contribute to the risk. So, we don't just concentrate on the hazard, we look at the risk in the round, adopting a whole-system approach."*

This methodology recognises the systemic nature of risk and the fact that each of its three dimensions – hazards, vulnerability and exposure – evolves differently. It is an approach that the Sendai framework (2015)[2], in particular, has worked hard to promote. Indeed, to be able to predict the harms caused by an event, we must understand how several different factors (such as climate, topography, the spatial practices of societies and their development choices) can combine to produce a disaster, calling for a vision that is both



comprehensive and interdisciplinary. The current profile of the research team reflects this need – the researchers, engineers and technicians who make up its thirty members hail from different disciplines, so that specialists in physics, modelling and measurement work alongside statisticians and historians...

**Observe, model, quantify**

The tradition of recorded observations in this field goes back to the creation in 1899 of the French Permanent Avalanche Survey (EPA, *see page 59*), still jointly managed with the French National Forest Office and the Ministry for the Ecological Transition. At first, the survey's approach was largely founded on the natural sciences, but it expanded in the 1970s to include research in physics and process modelling. In the early years of the millennium, in order to improve risk quantification, designate zones where risk could be considered acceptable, and optimise mitigation strategies, the Institute's researchers coupled deterministic models of avalanche spread with the statistical data provided by the EPA. This resulted in increasingly accurate probabilistic numerical models designed to evaluate "exceptional avalanches" (with a 100-year return period). Working first at the scale of a single avalanche path, the modelling was then scaled up to take in entire ranges, making it possible to evaluate the hazards for paths that were either poorly documented or unrecorded. This probabilistic hazard analysis, carried out first at local and then at regional scale, has enabled us to characterise the variability of avalanche activity at different spatio-temporal scales. It helps us to understand why certain ranges are more active than others, taking account of their topography and locations, and to use meteorological "forcing" to explore the links between avalanche activity and weather *(see glossary page 54)*.

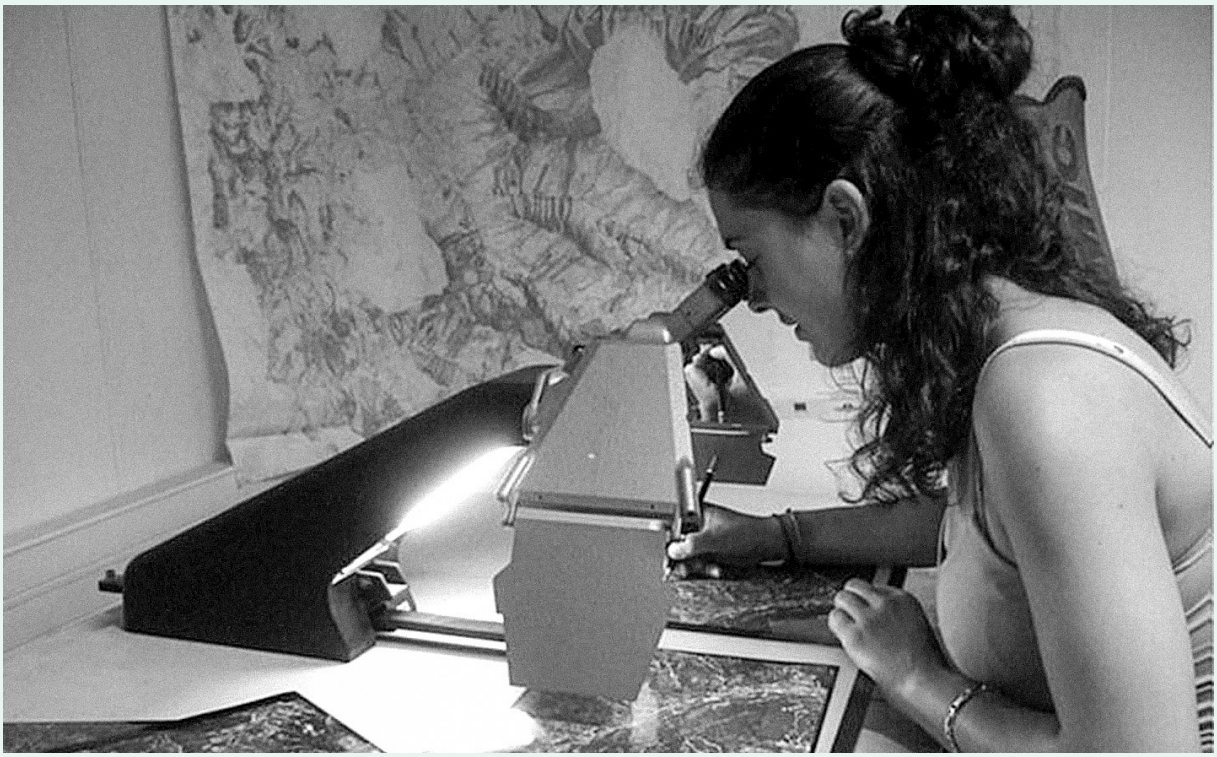
Meanwhile, methods were also developed to model vulnerability to the impacts of an avalanche, examining how vulnerabilities in both the built environment and those who live in avalanche zones could contribute to the risk. These models →

↑ **Powder (or aerosol) avalanche, recognisable by the formation of a cloud of air and snow above the surface as an avalanche descends the slope.**

p. 7
**Computer model of the Taconnaz avalanche (15 April 2021) which was brought to a halt by an avalanche protection system.**

1. CTGREF: This technical centre for the French National School of Rural Engineering, Water Resources and Forestry was an early predecessor of IRSTEA, which merged with INRA on 1 January 2020 to form INRAE.

2. The Sendai framework for Disaster Risk Reduction 2015-2030, adopted by the third United Nations World Conference, was the most recent in a series of documents ratified since 1994 to improve risk reduction at global level.



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↑ Researchers interpret information taken from aerial photographs to produce the French Avalanche Event Location Map (CLPA).

were then coupled to the quantitative hazard models, enabling individual risk models to be calculated that could be expressed in mortality figures or destruction levels, and protective structures to be optimised. Further parameters drawn from the human and social sciences are now adding to the sophistication of the models.

This fresh input means that expert historians can, for example, help to make better use of archive materials to feed current models. Likewise, historical analysis of development decisions taken by businesses and of their perceptions of risk can be incorporated into our understanding of current vulnerabilities and exposure factors, enabling us to act appropriately.

We might be forgiven for assuming, therefore, that avalanche risk is under control. Sadly, this is far from the case. At present, the socio-environmental systems in our mountains are undergoing a process of very rapid flux brought about by global change (to the climate, society, etc.), meaning that the risks, too, are changing.

### The many impacts of a changing climate

To deal with this, we first needed to understand how climate change is affecting the hazards themselves. The research teams began by studying changes in avalanche activity at climate-process scale. This enabled them to show that a series of very harsh winters produced a peak in avalanche activity in France at the beginning of 1980 and that, from the mid-1980s onwards, avalanches at low and mid altitudes then became less frequent and smaller, with a greater proportion of wet snow avalanches. Looking to the future, work conducted jointly with the French meteorological service's Centre for Snow Studies using the IPCC projections *(see page 54)* made it possible to demonstrate that current trends are set to intensify. Thus, for example, a 20 to 30% overall reduction in avalanche activity is projected during the 21st century as the consequence of drastic losses in snow cover. We should nevertheless note that avalanches at high altitudes do not follow this trend.

**New patterns of avalanche risk threaten high mountain communities, despite the overall decrease in snow cover.**

Indeed, at these altitudes, extreme snowfall may cause the number of avalanches to increase for a time before it falls again, with a continued chance of major dry and cold snow avalanches occurring, such as the 1999 Montroc avalanche in the Chamonix valley. In that event, 14 chalets were swept away and 12 people were killed. The team is currently working to improve the accuracy and detail of future projections of avalanche patterns, incorporating their number, intensity, location and seasonality into the calculations.

**The impacts of tourism and buildings**

The pace of change for other determinants of avalanche risk is no slower, indeed, it may even be faster. As the climate heats up and agro-pastoral activities are abandoned, we are seeing a rapid reafforestation of the slopes. Meanwhile, the footprint of development continues to expand overall, spurred on, in particular, by the growth in winter tourism. Brand new avalanche protection structures are going up alongside existing structures that may be showing signs of wear, sometimes for lack of maintenance, producing a shifting picture of overall exposure levels. Research is ongoing to reveal the workings of this complex process (which can vary greatly from one local context to another), pulling together qualitative and quantitative analysis at different spatio-temporal scales. It has been possible to show, for example, that in very high alpine valleys, the risk to buildings and their occupants would appear to have risen in the past few decades, as their exposure increases to a continued hazard. By contrast, at lower altitudes, risk levels are falling due to a combination of reduced snow cover and the gradual regeneration of trees along avalanche flow paths, sometimes all the way up to the avalanche starting zones. Quantitative analysis has helped us demonstrate that it may be possible to adapt to these changes by strengthening exposed buildings and managing our forests for protective purposes, gaining greater control of risk levels.

This, then, is the new pattern of avalanche risk that threatens high mountain communities, despite the overall decrease in snow cover. Stakeholders in such areas are being asked to develop an adaptive approach in their long-term investment strategies, but to do this they must have access to detailed and reliable information. The whole-system approach and increasingly detailed studies produced by the research community will help these decision-makers to develop a detailed understanding of the changing nature of the threat they face. ●

RESOURCES

## A dataset unlike any other

**It is a commonplace that one avalanche will be followed by another. In 1899, when out surveying avalanche damage, Paul Mougin, an engineer working for the French Water and Forests service, decided it was time to try something new – the creation of an inventory of every avalanche that had occurred in Savoie. He intended his records to preserve details of the events along with details on the extent of the forest damaged each year.**

**Paul Mougin could not know that, 120 years on, his work would be ongoing. Every winter, year after year, 260 ONF staff still collect the avalanche data for 3,600 flow paths in 11 départements across the French Alps and Pyrenees. They scrupulously record dates, starting-point and run-out altitudes and volumes, along with a wealth of other details. These data are recorded in the EPA, the French permanent avalanche survey which, to date, has amassed more than 100,000 observations.**

**Following the Val d'Isère disaster in 1970, the French government asked for a map to be produced to accompany this catalogue of events. The map would show the maximum extent of the damage caused by the events in the catalogue and is known as the CLPA (French Avalanche Event Location Map). The CLPA provides a record of historic and observed events by mapping the extreme limits of the areas physically impacted by them. It is produced by members of the IGE Joint Research Unit, who first record photographic interpretations and field observations before collating archive documents, interviews and witness statements from local mountain inhabitants and professionals. The EPA and the CLPA, both of which are funded by the DGPR (Directorate General for Risk Prevention) of the French Ministry of Ecological Transition, and are managed by INRAE, allow each event to be tracked through time and space, their complementary visions offering a unique dataset for use by expert advisers and researchers. They are in open access on *www.avalanches.fr.***

CLPA – FRENCH AVALANCHE EVENT LOCATION MAP

**850,000** hectares mapped

**25,000** avalanche impact sites catalogued

**13,000** interviews and witness accounts collated

GLOSSARY

## Hazard

A dangerous phenomenon that may occur in a given location, characterised by its situation in time and space, intensity, size, frequency and the level of probability associated with its occurrence.

## Vulnerability

The conditions, determined by physical, social, economic and environmental factors or processes, that render individuals, communities, material assets or systems, more susceptible to hazards.

## Exposure

The location of individuals, infrastructure, dwellings, production capacity and other tangible assets in risk zones.

## Mitigation measures

Measures that reduce or restrict the negative consequences of a dangerous event.

## Forcing

The introduction to a model of specific meteorological conditions or events (temperature, precipitation, wind, etc.) that determine the condition and extent of the snowpack and hence local avalanche activity.

(Glossary based on ANR Cahier 10: Risques et catastrophes naturelles, INRAE)

CLIMATE CHANGE

# What does the IPCC have to say about avalanches?

Best known for its international advisory reports (see 6th Report, published on 9 August 2021), the Intergovernmental Panel on Climate Change (IPCC) also publishes special reports. The *Special Report on the Ocean and Cryosphere in a Changing Climate* (SROCC), which appeared in 2019, was the first to devote a full chapter to mountain regions.

*"While IPCC reports traditionally have plenty to say on glaciers and the polar regions, they had previously contained almost nothing on avalanches and their associated risks, because the issue was so complex that there was a lack of available research results"*, explains Nicolas Eckert, a researcher from the ETNA unit. Indeed, to be able to track past changes, a long and homogeneous series of observations is needed, and a relatively sophisticated armoury of statistical tools must be assembled to process them. Likewise, the forecasting of future changes in avalanche activity calls for the conversion of general scenarios for climate change into local scenarios that show changes in weather and snow cover. Complex techniques must be employed to manage the change of scale and error corrections, to force regional climate models (RCMs) using conditions from general circulation models (GCMs), to adapt models to mountain topography, and to create snow-cover models where the results from physical models must then be corrected by cross-referencing them with observations. Last, once all these tasks have been completed, data on historically-derived empirical relationships between snow cover and avalanche activity can be fed into the models.

The IPCC report, to which INRAE contributed, concludes with a high level of confidence that future natural hazards in mountain areas, including spontaneous avalanches, will occur in locations and/or seasons where they have not previously occurred. This formulation, the result of a scientific and political compromise, acknowledges the possibility of localised reductions in snow cover that would bring down hazard levels, but also emphasises the problems that could arise from rapid changes in the spatio-temporal distribution of dangerous events. We may thus expect more wet snow avalanches at high altitudes in the middle of winter in locations where there is currently no issue with snow cover. These changes must be taken into account, for example, when calculating the size of ski lifts that could find themselves on new avalanche paths, placing strong pressure at the peak of the tourist season.

# MULTI-FACETED RESEARCH

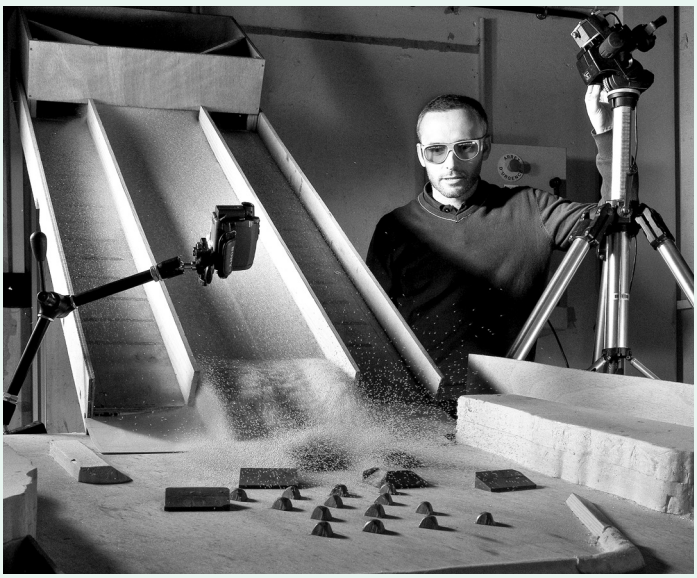
From the scale of a micrometre to that of a mountain range, from observation to modelling, INRAE's researchers draw on the full range of current techniques and technologies, in both snow studies and other disciplines, to understand and predict this complex phenomenon.
**Fields of research.**

*"The physics of avalanches continues to be a key area for investigation ... The scale of our work extends from snow grains to mountain ranges"*, explains Florence Naaim, who heads up the ETNA research unit. Indeed, where avalanches are concerned, *"you can only make sense of the very large things if you know the tiny things"*, she says. *Observation, experimentation and modelling form the triptych of research activities that generate the necessary knowledge to improve anticipation and preparedness.*

**On the mountain: working at landscape scale**

The ETNA researchers use a series of local investigation sites to carry out their observations. Of these, one exceptional site, the Lautaret avalanche test site in the Hautes-Alpes, has, since 1973, served as a rich source of data on avalanche dynamics. With the help of a gas explosive device, the team can artificially trigger avalanches on site, analysing their every feature. *"We study their characteristics, for example, their speed or the volume of snow they displace. Our imaging systems allow us to record an avalanche using a rapid camera, or in 3D, so we can gain a better understanding of the interactions between the avalanche and the local terrain. We use sensors fixed to an obstacle along the avalanche's route to measure how much pressure it exerts"*, Emmanuel Thibert, a researcher in the ETNA unit, explains. Setting up this system *"meant that we could demonstrate quite how much snow an avalanche can bring down – up to ten times the volume of the snow in motion in the starting zone. And it allowed us to show that the coefficient that was being used at that time to calculate the pressure exerted on an obstacle based on an avalanche's speed and density had been grossly underestimated (by a factor of 10) in zones with slow speeds (run-out zones)"*, Florence Naaim tells us.

High up on the wind-swept pass known as the Col du Lac-Blanc which sits at 2,700 metres above sea-level near the Alpe d'Huez ski station in the Val d'Isère, INRAE's researchers are also studying the interactions between snow and wind, working with their colleagues from the Snow Study Centre at the CNRM (the French National Centre for Meteorological Research). Indeed, wind is a key factor in the triggering of avalanches. It affects how the snow is deposited and creates cornices or wind loads that can, at any moment, lead to avalanches. *"A natural wind tunnel where we have been recording measurements for 30 years, this site has* →



© H. Raguet

↑
Physical model of a dense avalanche. The development of this model allowed the dimensioning of anti-avalanche structures in Taconnaz.

*made it possible to test out new measurement techniques and to build a unique climate database which has attracted scientific teams from both Austria and Japan. Our sensors are effectively able to record the movement of hundreds of tons of snow per linear metre of ridge each year"*, says Florence Naaim.

**In the lab: physical models and x-ray machines**

But it is not enough to study how avalanches behave out on the mountain. To gain an understanding of the way that each snow grain moves against its fellows, how it speeds up or slows down, other methods are needed. Here, reduced-scale models come into their own, making it possible to set up experiments on the dynamics of snow flows. *"We use two analogous physical processes"*, says Thierry Faug, one of the unit's researchers and an engineer. *"For dense dry flow avalanches, we simulate the behaviour of the dry snow grains in terms of their cohesion and friction using glass beads and PVC powder. For powder avalanches, we release a flow of heavy fluid such as salt water into a lighter fluid, such as clear water. The heavy fluid allows us to simulate the mixture of air and suspended ice particles that make up this sort of avalanche."*

But an even closer examination is required to identify the laws that govern the changes in form and the flows within the snowpack during an avalanche. *"The snow's mechanical properties depend on its microstructure"*, Guillaume Chambon, deputy head of ETNA tells us. To access this microstructure, the research team uses x-ray tomography machines. *"These machines allow us to observe details that are just a few micrometres in size. This enables us to study changes in the snow as a function of various parameters such as temperature or pressure and to build three-dimensional models to explore the material's mechanical response using virtual experiments"*, the researcher adds.

**Going virtual: digital models to process and exploit the data**

Full benefit can only be gained from the practical observations and experiments described above, though, especially in the realm of forecasting, if the unit carries out further work, this time using digital modelling to process the results. What makes digital modelling so necessary? *"We are trying to integrate knowledge on scales ranging from the microscopic to a whole mountainside in a single model"*, Guillaume Chambon explains. The models and digital simulations allow the team to set off virtual avalanches, varying the start parameters. By then combining their models with the IPCC's climate predictions, they can build a picture of the future characteristics of avalanches. This combination of methods has already borne fruit. The models for dense and powder avalanches are already very reliable and, for example, allow the team to make detailed recommendations on the anti-avalanche structures that should be installed on the ground.

Now, though, the changing climate calls for further research on wet avalanches, which are formed of a mixture of liquid water and ice and whose dynamics are not yet well understood. Here, observation, experimental work and modelling will doubtlessly once again turn out to be a winning combination as we improve our knowledge of this complex phenomenon, and will help us to optimise our predictive tools. ●

CLIMATE

# Wet avalanches as an emerging risk

**One of the main developments brought about by climate change is the increase in the frequency of wet avalanches. Faced with this emerging risk, some sites are ill-prepared for the impacts.**

The flows generated by wet avalanches, when these occur earlier in the winter season, can set large volumes of snow and water into motion. They also have high pressure loads, of the order of 10 t/m$^2$, despite their slow-moving character and can cause significant damage. In some extreme cases, when they contain a very high proportion of water, such flows can cover astonishingly long distances, ranging from several hundred metres to a kilometre in length and exceeding their usual boundaries. A further problem lies in the fact that the dynamics of wet avalanches are not yet fully understood: *"We have come up against the limits of our knowledge of these events. We haven't yet managed to create satisfactory models of how they behave"*, Thierry Faug, a researcher in the ETNA unit confesses ruefully. This current limitation has consequences, because the protection provided by anti-avalanche structures installed in many mountain locations is designed for cold and dry snow avalanche scenarios. When a large wet avalanche hits, there is a chance that these protective structures could, in some cases, prove insufficient.

**The need to revisit existing protection systems**

In such cases, active defence structures, such as racks, nets, screens or windmill structures, designed to prevent avalanches from being triggered at the top of the slopes, could be swept away or could fail to do their job. As the climate continues to heat, the creep[1] behaviour of the snow has changed as a consequence of its increased wetness. *"The higher water content makes the snow heavier and causes more slides in the snowpack, increasing the pressure exerted on structures"*, Thierry Faug explains. The structures must also be designed to resist greater future pressures, so they will be able to cope with the changing nature of the snowpack and starting conditions for avalanches. Equally, care will have to be taken with regard to the siting of new structures in locations where slides at the snowpack base have previously been rare.

Passive defences could also be affected by this change in the snow's water content. Such devices are intended to slow, divert or halt an avalanche and take the form of braking mounds, diversion berms or catching dams. However, in some locations, the margin of protection provided by these structures against hazards is already narrow. To complicate matters, the routes of wet avalanches can sometimes confound expectations by failing to follow the steepest slopes. A high-volume wet avalanche, because its trajectory is difficult to predict, could thus overwhelm passive structures and cause damage. The message is clear: it is not yet time to panic, but preparations should be made. Thierry Faug, provides some reassurance: *"There is no need to reinvent our anti-avalanche strategies. There are some locations, though, where we will need to upgrade the structures to reduce vulnerability and will need to plan in particular for a wet snow scenario that would either supplement or replace the dry snow scenarios"*. Upgrading has already begun, as the Institute's researchers continue to collaborate with the mountain authorities to introduce the appropriate adaptations. ●

**1. Slow movement of snow under the force of gravity, combining compaction and shearing with sliding at the base of the snowpack.**

© C. Maréchal/RTM73

# RISK PREVENTION IS ALL ABOUT PARTNERSHIP

Global warming is bringing rapid changes to avalanche risk. Research and professional expertise must therefore be combined, as scientists and the many practitioners and stakeholders involved in risk prevention join forces to build the collective knowledge needed to anticipate and prepare for both current and emerging risks. **The case of France.**

As temperatures and precipitation patterns change, French mountain regions must be quick to adapt to protect their inhabitants' future economic activities, not least a sizeable part of the country's tourist industry, all the while remaining vigilant that high standards of safety are in place. They do this by developing local adaptation strategies in line with the national risk prevention policies of the French Ministry for Ecological Transition (MTE) and, in particular, the Directorate General for Risk Prevention (GDPR). The scientific evidence base for these strategies comes, primarily, from the results and outputs of the research activities of INRAE and the French National Centre for Meteorological Research (CNRM).

### Collective action for more effective risk prevention

Treated as a major danger in French national risk prevention policy, avalanche risk is managed by many actors. Overall responsibility lies with national government and this is delegated to the French National Forest Office's RTM (Restoration of Mountain Terrain) services. It is the RTM's job to characterise the risks that must be taken into account in local planning strategy and policy. This is mainly achieved through Regional Plans for the Prevention of Predictable Natural Risks (PPRNP) that local planning authorities must follow. Other statutory risk managers for avalanche risk prevention and the protection of buildings and infrastructure are the municipalities, who are responsible for hazard prevention and the organisation of disaster relief, the départements and the regions, who are responsible for highway infrastructure safety, spatial planning and hazard warning information. Local citizens themselves constitute a further group of stakeholders. Most directly affected by the risk, they are served by this emergency planning structure.

### Scientific expertise and risk prevention, a fruitful dialogue

While the development of knowledge and acquisition of new data is essential to the creation of emergency plans and the specification of an overall response framework (design of active and passive structures, routes and construction of mountain roads, planting of protective forests, building

of shelters, etc.), scientists may also be called upon to advise local communities, consultants and municipalities on anti-avalanche protection measures. *"We only intervene in complex cases, where the outcomes depend on the most recent research and/or where the nature of problem is such that we are assigned sole responsibility for the expertise by the requesting body"*, explains Florence Naaim, head of the ETNA research unit. *"In fact, last January INRAE received its first ISO 9001 certification for the entirety of the quality-assurance system that underpins its delivery of expertise on the prevention of gravity-based risks in mountain areas, including avalanches"*. Here, as in other areas of INRAE's work, there is constant dialogue between researchers and expert practitioners. Research outcomes are used to help public policymakers in their work. In return, dialogue with local officers feeds back into research, allowing fresh directions to emerge and helping to give meaning and purpose to the research.

**Data and modelling as a force for prevention**

An example of such teamwork can be found in the design and construction of the Taconnaz berm, where the ETNA research team have worked with Ingérop consultants on behalf of the Chamonix-Mont-Blanc Valley inter-community group. This massive structure, 25 metres high, has been built across the foot of the longest avalanche corridor in the Alps, located in the Mont Blanc range. *"Our task was to specify the size, position and form of the berm and the other passive defence structures required"*, explains Thierry Faug, a researcher in the unit. By combining historical data from the EPA (Permanent Avalanche Survey) with digital spread models, it was possible to determine the reference events for the past century (defined by the volume and energy of the avalanches).

A range of protection strategies, devised to halt dense avalanches, was then tested in the lab, beginning with reduced-scale physical modelling (using glass beads and PVC). After estimating the residual risk for the powder element of the flow by measuring salt-water flows in fresh water, the team constructed a digital model fed with real-world topographical information from the site to test their results. *"And since you can't take the research DNA out of the scientist, we took advantage of the construction phase of the project to install automatic sensors for speed and pressure in the anti-avalanche structures, so we could assess their effectiveness and extend our understanding of how they influence the flow"*, continues Thierry Faug. Impact pressures of up to 95 t/m$^2$ could thus be recorded and compared with the model predictions, confirming the latter in what was effectively a vast quality-control exercise...

**Disseminating knowledge**

Meanwhile, to help project consultants and contracting authorities to reduce the vulnerability of inhabited zones, a number of technical guides on protection structures were produced. They enabled the publication in 2009 of a European reference guide on the construction of avalanche catching dams and diversion berms, that drew on the work of research teams across Europe, including ETNA. Since the guide's appearance, a regular flow of further knowledge dissemination materials has been produced.

The rapid impact of climate change, in particular, on the incidence and nature of avalanches, makes it imperative to continue research on hazards and risks, and to incorporate the most up-to-date data. However, it is clear that the most important driver in developing a form of risk prevention that is both adapted and effective will be the collaboration between our researchers and national and local authorities and organisations. ●

**Dialogue with public policymakers feeds back into research, allowing fresh directions to emerge and helping to give meaning and purpose to the research.**

# Science-led risk management

An interview with Véronique Lehideux,
Head of Natural Hazards and Water Risks at the French Ministry of Ecological Transition

Véronique Lehideux runs the French government department responsible for the production and management of national policy on natural risk prevention and the coordination of actions to address major risks. We talked about avalanche risk, the work of her department, and the latter's partnerships with the world of research. **Interview.**

**Given climate change and urban expansion, how can we make sure our procedures for the assessment and prevention of avalanche risk are kept up to date?**
Natural risk management in France starts with regional plans known as Regional Plans for the Prevention of Natural Risks (PPRN). These are designed to ensure that hazards are taken into account in urban planning, protecting communities from development that would increase the vulnerability of high-risk zones and reducing risk elsewhere by setting out the precautionary measures to be adopted in other zones. They are based on the worst known event or on a reference that is specific to the hazard – an avalanche or flood with a hundred-year return period, for example. For avalanches, a three-hundred-year return reference value has been added to the mapping so we can identify hazard zones for more exceptional events (yellow zones). As we discover more about the effects of climate change on hazards, we may have to adjust our reference thresholds – this has already been done, for instance, for coastal flood risk. For such changes to be approved, the impact must also be very well documented. In the case of avalanches, we have to consider a further parameter that is subject to change – the nature of the snow itself. The water content of snow is rising. To better understand how this affects the behaviour of the snow, the DGPR has been commissioning studies and modelling for wet avalanches from INRAE for some years. For risks in mountain areas, the Ministry established a programme on glacial and periglacial risks with assistance from INRAE. Now run by the ONF, the programme continues to benefit from very substantial input by INRAE.

**What is the goal of this work on glacial risks?**
In terms of outcomes, we have asked this glacial hazard risk programme to provide foresight on new risks such as the melting of snow cover that was previously permanent and glacier collapse. INRAE supplies scientific support concerning the second of these, working with the French Institute of Geosciences and the Environment (IGE) to monitor and anticipate future developments in the increasingly temperate Taconnaz glacier. Laboratories (ETNA, IGE, Isterre) from the Grenoble Observatoire des Sciences de l'Univers are helping the local Prefecture and the Municipality of Saint-Gervais by studying the water pockets discovered in the Tête-Rousse glacier. Back in 1986, INRAE was also involved in draining the Arsine glacier lake. In both

"Cross-border dialogue is very important in maintaining a certain level of harmonisation and in meeting the expectations of local elected representatives."

cases, we see public research put to practical use, both for diagnostic purposes and to provide solutions that lie beyond the field of operation of private consultants. The DGPR provides support for the scientific investigation of these sorts of hydrological threats and their characterisation.

**How do you take local economic and social factors into account in your work on the prevention of natural risks?**
The prevention of natural risks takes, as its primary goals, the conservation of human life and the reduction of damage. Priority is given to zones where both hazards and social and economic impacts are strongly indicated, and our response in these zones is proportional to the risk. By introducing a moratorium on development in the zones most exposed to certain natural hazards, we can help to preserve their economic and social fabric, and ensure that the national compensation system, known as "Catnat", remains sustainable. The prevention of natural risks is given its full weight in decisions on sustainable development and adaptation to climate change. The degree of legitimate feeling aroused when disasters are triggered by natural events is a reminder that we are acting responsibly when we take the decision not to build in zones with high exposure to natural hazards.

**Internationally, how does France manage its research, expertise and support for public policies on avalanche risk?**
France is a member of the Alpine Convention and served as its President in 2019 and 2020. We have also been the Chair of the EU strategy for the Alpine Region (EUSALP) since 2020, agreeing to stay on for a further year in light of the health emergency. These two roles enable us to connect researchers, academics, businesses, managers and policymakers throughout the alpine countries. Our participation in working groups gives us the chance to share and develop knowledge and good practices, while adapting the latter to the individual circumstances of each country in terms of governance and legal frameworks. The European Interreg projects are good examples of this. Cross-border dialogue is very important in maintaining a certain level of harmonisation and in meeting the expectations of local elected representatives.

**Can you give an example of work that has been carried out in cooperation with neighbouring countries?**
By pooling our methods, models and practices in joint studies involving Italian, Swiss and French experts, we have been able to establish the extent of the PPR Avalanche red and blue zones for the most sensitive avalanche paths in the Chamonix valley. Likewise, in the Pyrenees, the maximum extents of avalanches in Catalonia and Spain have been mapped using the methodology developed in France by INRAE. ●

# Managing tomorrow's forests

Forests are part of our natural and cultural heritage, providing multiple essential services to life on earth, serving as biodiversity hotspots and carbon sinks, supplying wood, and much more.

However, as the consequences of climate change are increasing the intensity and frequency of extreme climatic events – namely wildfires, droughts, storms – forests are weakened by successive shocks, making recovery harder. Other global changes linked to human activities, such as international trade, also increase their vulnerability to contagious diseases and insect proliferation.

Thus, their capacity to produce wood and capture carbon is at risk. Although forests can store carbon, contributing to climate change mitigation, their capacity to do so is not systematic and depends on many factors. The development of the Biomass Carbon Monitor, to which INRAE contributed, is now providing Government, NGOs and professionals with a monitoring system of variations in forest carbon stocks. While digital solutions are an interesting field of research to provide the necessary knowledge, how do we ensure that we still have forests tomorrow?

Our research has identified several levers: changing species, adapting forestry practices by shortening cutting systems, developing genetics reserves and mixing the most resistant species. These levers have been experimented on a range of temperate forests, in partnership with the public and private sector, offering efficient solutions for other European countries. Research is in action, working with all stakeholders, but adapting public policies remains essential to create the right incentives for private owners to transform management practices, ensuring forests can adapt to climate change.

Scan this QR code to access our online dossier

# Biobased construction materials – a sustainable solution?

According to the Global Status Report for Buildings and Construction (UNEP, 2022), buildings represented around 37% of global $CO_2$ emissions in 2021, including building operations (10 $GtCO_2$), reaching an all-time high, and the production of building materials of around 3.6 $GtCO_2$ (i.e. concrete, steel, aluminium, glass, and bricks).

The building sector is one of the most energy-intensive and polluting sectors in France, also utilising some materials that cannot be recycled.

Given the environmental challenges the world is facing and in order to meet net zero emissions by 2050, biobased construction materials could be part of the solution. They can help us reduce GHG emissions drastically and even store carbon. Hence, INRAE researchers are developing products and processes that are 100% biobased and biodegradable to offset the use of exhaustible resources (oil, sand, minerals). However, they require waste from forestry and agrifood systems, which are produced locally in small quantities. Taken directly from the living world, biobased construction materials rely on various resources, such as wood, hemp, cork and flax.

Thus, for such use to truly improve the carbon footprint of buildings, several sustainable and environmental impact criteria must be met, especially concerning the use and management of resources and soil fertility. INRAE's research is dedicated to find innovative solutions and support their implementation to preserve the environment and the capacity of soils to store carbon.

Scan this QR code to access our online dossier

# 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.

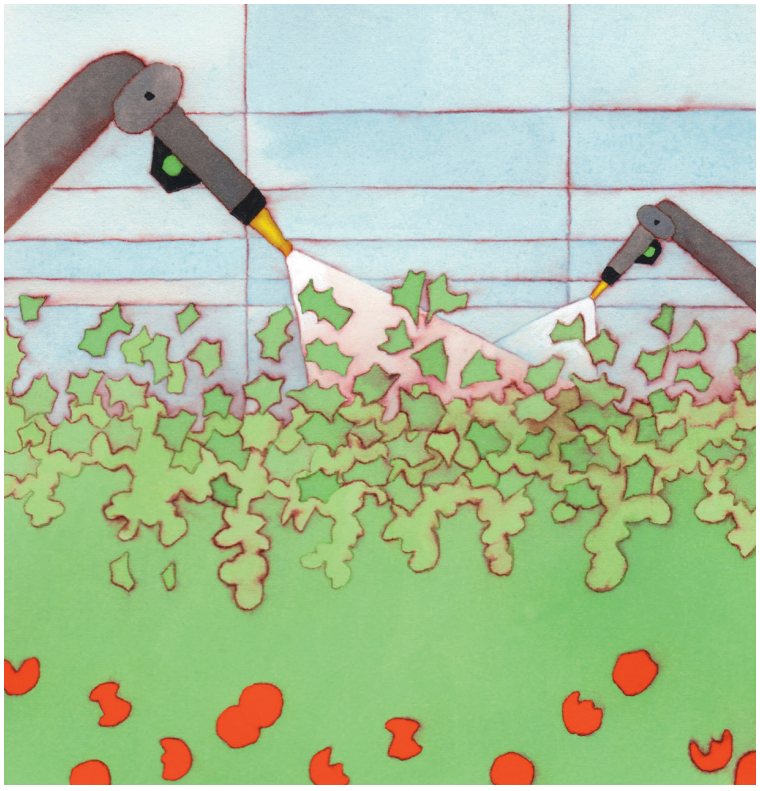
More recently, a new generation of decision support systems is making use of remote sensing, via satellites, GPS or the internet, to add even greater detail to the data provided. Drone images are now also available to replace or supplement the data from satellite images. →

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

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



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.

**With the advent of Big Data, new processing technologies have been developed. Artificial intelligence now allows us to produce original knowledge from vast quantities of data.**

**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.

**98%**
of farmers own a computer

**80%**
of farmers own a smartphone

**68%**
of farmers are members of at least 1 social network

**57%**
on YouTube

**54%**
on Facebook

**51%**
on WhatsApp

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

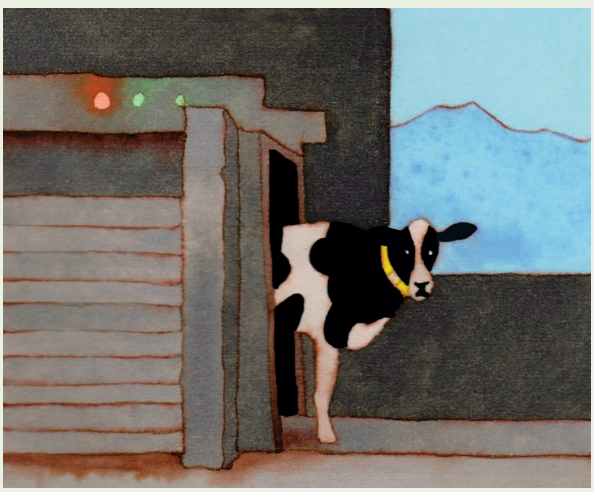
6. The Alimentation Locale joint technological network (RMT), which INRAE co-organises, created ObSAT, the observatory for local food systems, working with the Brittany CIVAMs, a federation of centres set up to promote and valorise farming and the countryside.

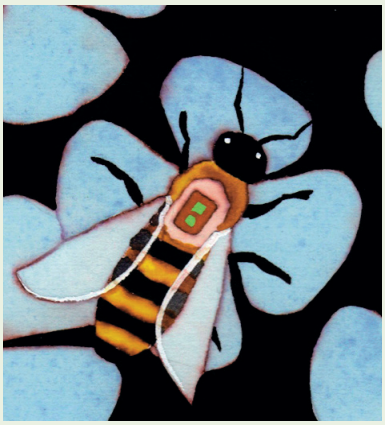
7. https://www.rmt-alimentation-locale.org

# 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

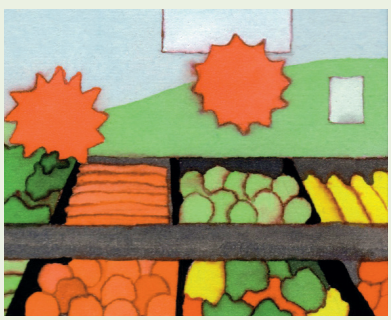
The DINAMIS[3] platform brings together public and private partners from research and industry, including the French national centres and institutes for space studies (CNES), scientific research (CNRS), development research (IRD) and agricultural research for international development (Cirad), along 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.

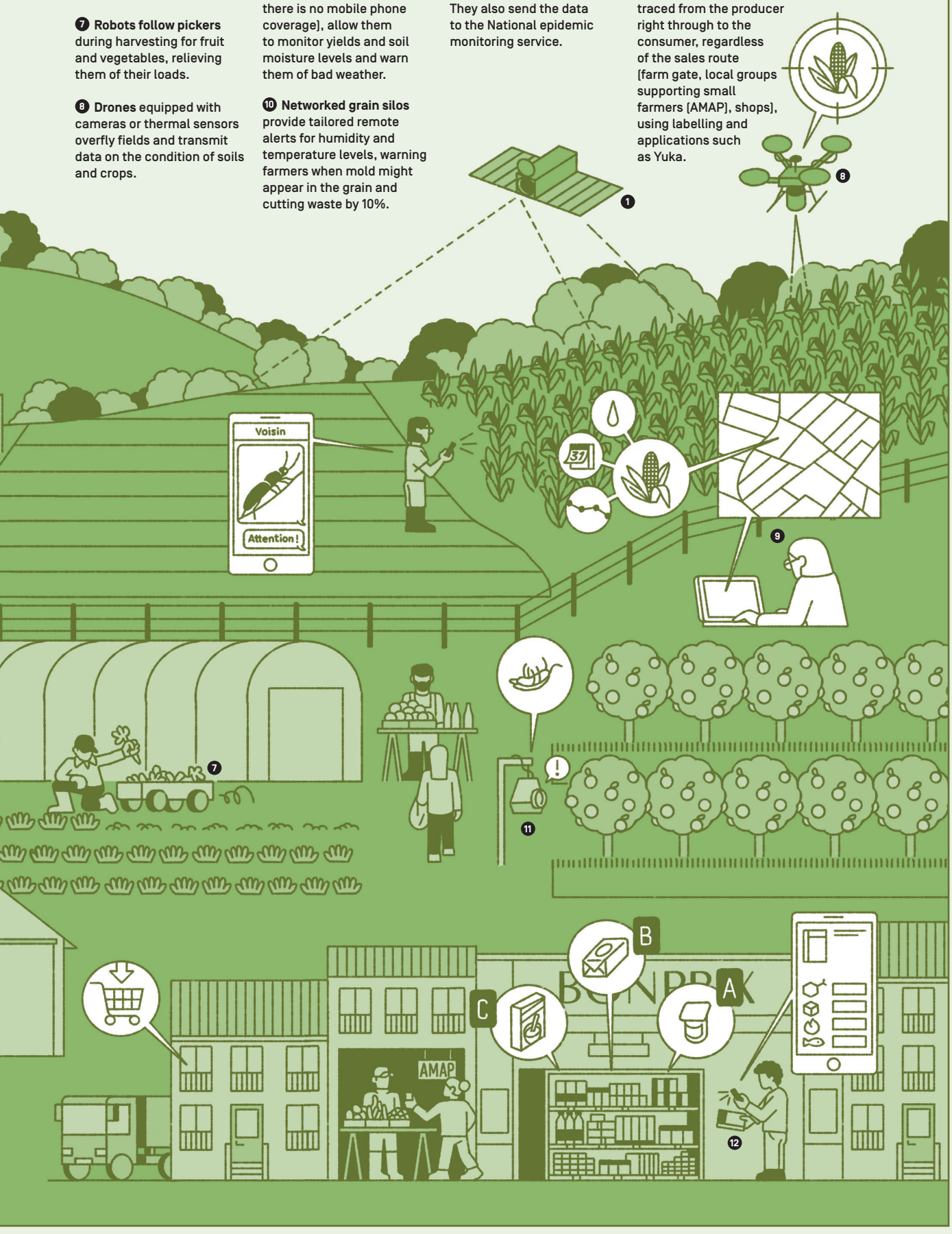
❽ **Drones** equipped with cameras or thermal sensors overfly fields and transmit data on the condition of soils and crops.

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

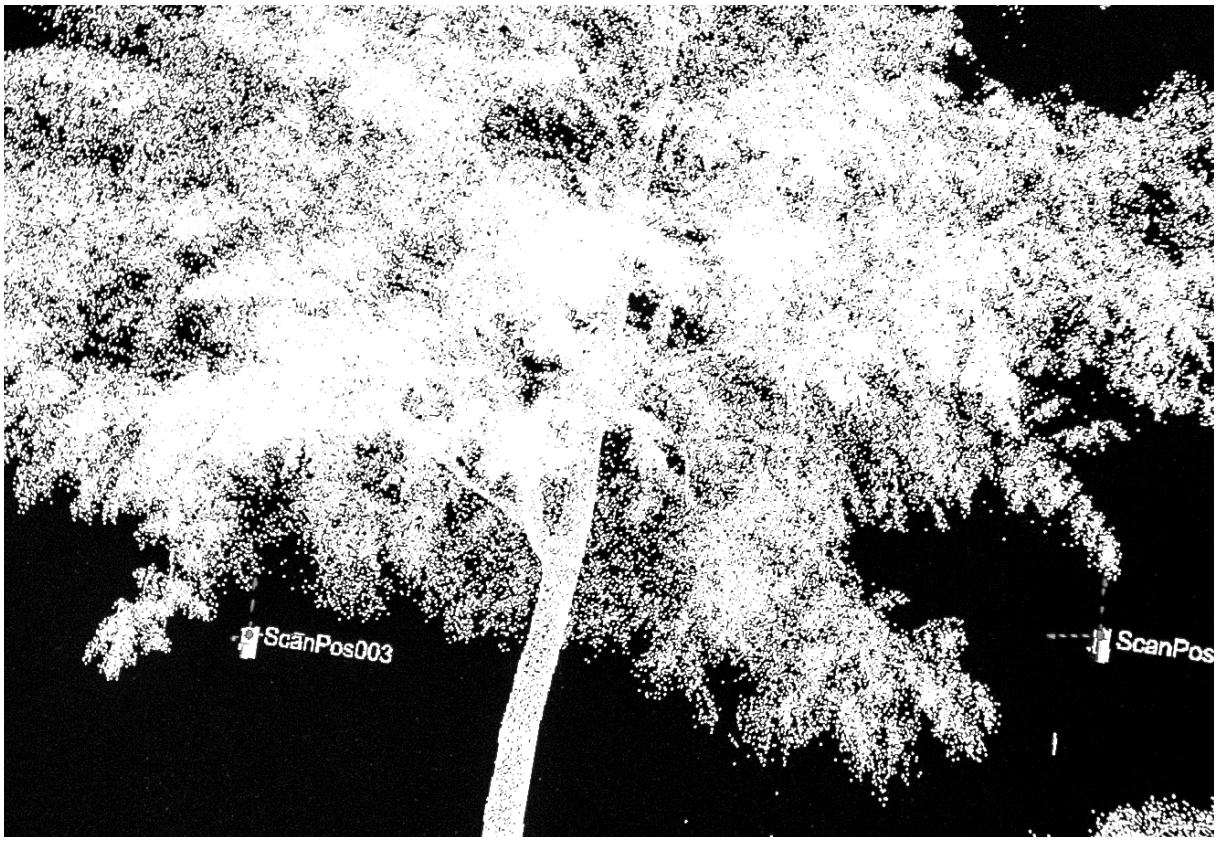
tural models have been recommended by the HLPE: sustainable intensification and agroecology. The second, which is a break away from the conventional agricultural practices of developed countries, has been adopted by INRAE, pursuing a model that is supported by both the European Union and France.

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."* →

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




© Bertrand Nicolas /INRAE

↑ 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.

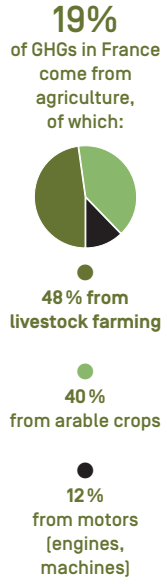
### Looking beyond the field boundary

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.




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

### 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.** →

EXPERIMENTATION

# 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].


© Naïo Technologies

← **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

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.

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

**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.

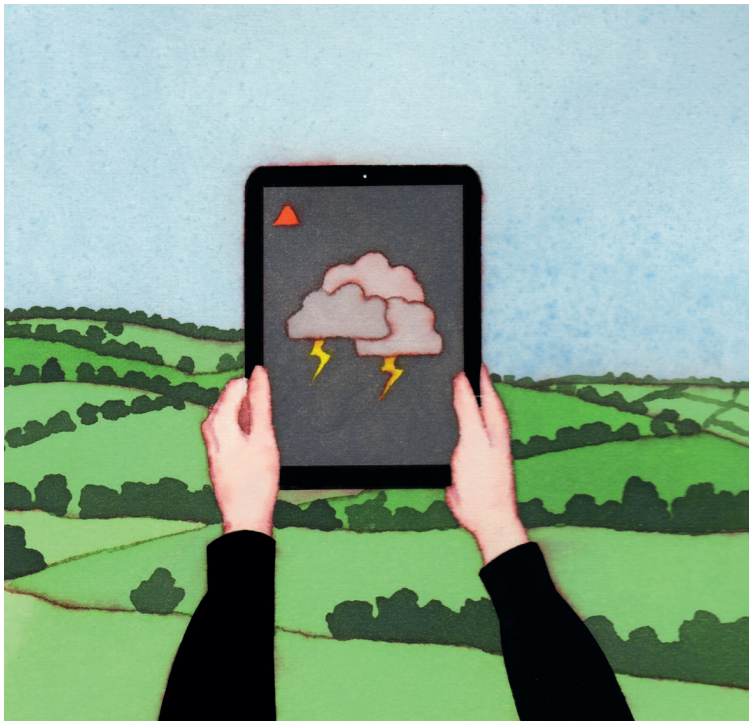
In its 2019 report, "Cost of not having FAIR research data", the European Commission reported an annual cost to Europe of 10.2 billion euros[4] from poor data management in research, measured in time spent, cost of storage, licence costs, research retraction, double funding, lack of interdisciplinarity 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.

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.



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*

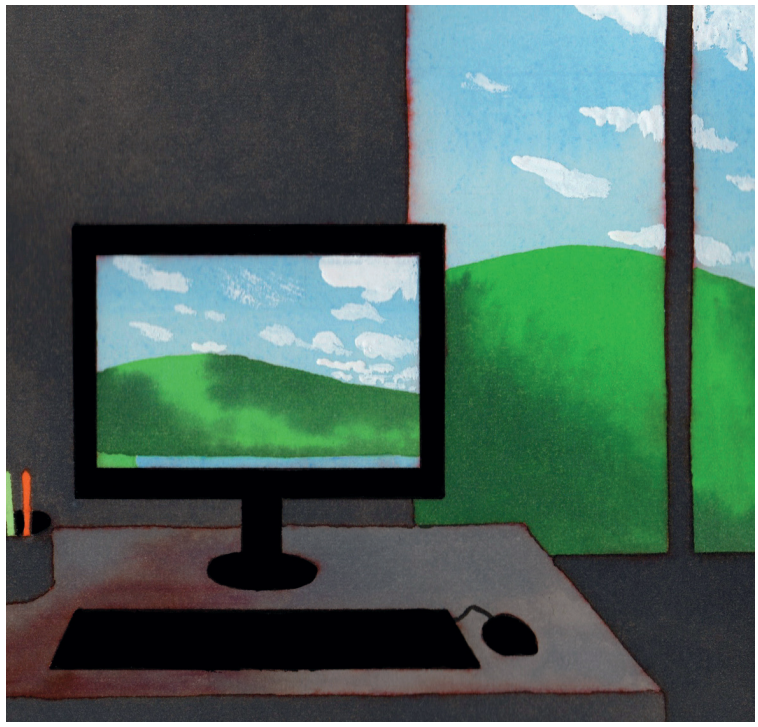
*in our sentence. You could say that we are the editors of a common dictionary for the sector",* explains Marie Buerret, head of the projects and communication section at Agro EDI Europe.

### 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

© Occitanum

↑
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.


© Christophe Maître/INRAE

↑ 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.

## OTHER DOSSIERS ON AGRICULTURE

# Dairy cows: Grazing to the future

Rich in proteins, vitamins, minerals and essential amino acids, milk is a nutritionally complete food and is consumed at all ages and on all continents. According to the FAO, cow's milk accounted for 81% of global milk production in 2019.

Production levels have increased significantly since World War II thanks to advances in livestock genetics and feed efficiency. While bucolic images of dairy farming persist in our collective imagination, cows are no longer always found grazing in pastures. Dairy farming has taken on extremely different forms, including among regions within the same country. The difference often lies in how the animals are fed, determined by the geography, climate and crop types of each country. Worldwide, the dairy industry is grappling with a steady increase in demand. At the same time, it is attempting to mitigate its environmental impacts, as the intensification of dairy farming has led to a strong dependence on inputs (fuel oil, fertilizers, purchased feed). European milk production represented 176 to 241 million tons of CO2 in 2010, due in part to enteric fermentation, petrochemical fertilizers, food production and farm energy consumption. Livestock farming, via food imports and over-fertilization of the soil, also impacts biodiversity and ecosystems. Additionally, the industry faces growing societal expectations around animal welfare as well as going up against the increasing cost of feed. At the global scale, cow feed now represents 65% of milk production costs according to the World mapping of animal feeding systems in the dairy sector (2014) report, which include fuel oil, fertilizers, concentrates, and more.

Self-sufficient dairy systems such as a return to grazing are an interesting avenue for cow milk production. They are more energy efficient, use fewer fertilizers and no pesticides, thus reducing cost, while ensuring the protection of the environment, animal welfare and nutritional qualities of the milk. This is the dominant model used in Ireland and New Zealand.

However, dairy systems that rely on grass and winter fodder must consider seasonal change and meteorological events such as drought and frost, heightened by climate change. Experimentations in France and Europe have shown how to design systems responding to this multiple criteria dilemmas.

Scan this QR code to access our online dossier

# Farming futures: out of water?

While water is essential to life in all forms, it is a finite resource with a closed cycle. Global warming is now affecting this cycle, causing localized water shortages and extreme climatic events.

With demographic growth and its effects on human needs, world food and health security are threatened. At the same time, economic and social inequalities are increasing globally. As such, water is a common good that must be collectively preserved and used in a sustainable way. How do we feed the planet under water constraints?

Today, irrigated agriculture produces more than 40% of the world's food and the demand for water for irrigation is on the rise with a changing climate making it harder to rely on rainwater. INRAE's teams are looking at alternative approaches to irrigation that could help to conserve water supplies, favouring the adaptation of rain-fed agriculture rather than the systematic development of irrigation. Irrigation must be taken as a potential additional lever for crop diversification and a safety practice, rather than a means of systematically maximizing yields.

Agroecology can help develop crop and livestock systems that are both water efficient and capable of mitigating climate change. Increasing soil carbon storage and the resilience of agriculture to climate change effects rely on several practices: soil preservation, livestock-crop complementarity, diversification of animal breeds and crop varieties, selecting species more tolerant to drought, landscape elements to curb runoff, etc. The radical transformation of agriculture will come with heightened risks for individual farmers. We look at decision-making mechanisms and public policies favourable to this agro-ecological transition, with an integrative vision encompassing the whole society.

Scan this QR code to access our online dossier

# REPLAY → 2022

10.11.22 ONE HEALTH

## FIRST GENERAL ASSEMBLY OF THE PREZODE INITIATIVE

The PREZODE (PREventing ZOonotic Disease Emergence) initiative is now implementing its first operational and scientific programs. Its first General Assembly held on 11 October 2022, took stock of the actions undertaken and established the roadmap for the next steps. The World Health Organization (WHO) and PREZODE announced the creation of a joint working group to establish a body of indicators to quantify the risk of zoonotic disease emergence, creating a detailed framework to evaluate the impact of prevention strategies and making the "One Health" approach operational.

Launched at the One planet Summit in January 2021, at the initiative of INRAE, IRD and CIRAD, now supported by 180 partners, including 18 governments, PREZODE is placing research on animal, human and environmental health at the heart of the global efforts needed to better understand, prevent, monitor, and detect early zoonotic pandemic risks.

© IRD

01.20.22 START-UP

## A French nasal vaccine against COVID-19

The development of a protein vaccine candidate for nasal administration, led by the BioMAP research team, moved forward with new pre-clinical results. Obtained with the Delta variant during the winter of 2022, they demonstrated the robustness of the concept of this vaccine toward blocking the contagiousness of SARS-CoV-2. The French start-up LoValTech was created by researchers and associates to accelerate the development of the project and consolidate the investment announcements. The new company now holds an exclusive worldwide license to exploit the patent on the vaccine. LoValTech's main objective is to manage the project from the development phases of the vaccine formulation through the clinical trials leading to a market to be launched between the end of 2023 and the beginning of 2024. BioMAP is part of the Infectiology, and Public Health (ISP) joint research unit run by INRAE and the Université de Tours.

10.18.22 AGRIFOOD SYSTEMS

## A NEW COOPERATION AGREEMENT WITH FAO

At its Science and Innovation 2022 Forum in Rome, the Food and Agriculture Organization of the United Nations (FAO) signed a Memorandum of Understanding with three French Research Institutes, INRAE, CIRAD, and IRD, for the five-year period from 2022 to 2027, in order to continue their collaboration to support agrifood systems' transformation. This cooperation agreement conveys a strong desire to develop international partnerships to tackle the challenges of climate change, biodiversity, sustainable management of natural resources, and the transformation of agrifood systems. The three French research institutes are building and mobilizing their partner networks worldwide.

03.16.22 ECOLOGY

© Jean-François Humbert/INRAE

# MONITORING WATER IN AFRICA

Initiated in February 2016, the Water Sources in Africa (WaSAf) project on the monitoring and sustainable management of surface freshwater sources in Africa ended in 2022. It aimed to implement a process for inspecting and assessing the quality of water in three of the continent's lakes used to supply three large cities (Abidjan, Dakar, and Kampala). Paving the way for the first measures to be taken for the sustainable management, preservation, and restoration of these ecosystems. The main findings were presented during the World Water Forum, held from 21 to 26 March 2022. It provided water institutions with data about the state and vulnerability of their resources and offered training to young scientists, technicians, and engineers in the water sector institutions on the issue of cyanobacteria.
The project also participated in raising awareness among local populations about water quality issues and the risks associated with degraded water resources. Working with local institutions, environmental observatories were set up, to allow for the long-term surveillance of these ecosystems and improve their management. WaSAf was coordinated by Jean-François Humbert, an INRAE research director at the Institute of Ecology and Environmental Sciences in Paris.

03.07.22 AI

**A tool for pig welfare on-farm**
Pigs express their emotions through vocalizations. Recognizing these sounds, and the emotions they express would provide the necessary information for farmers to adapt their interventions and ensure the welfare of pigs throughout their lives. Therefore, the PEGASE* joint research unit, the Swiss Federal Institute of Technology (ETH), and the University of Copenhagen have coordinated the development of a system for recognizing pig vocalizations as part of the European SOUNDWEL project. Their results, published on March 7 in Scientific Reports, point to the possibility of an automatic recognition tool for vocalizations to monitor and improve pig welfare on-farm.

* PEGASE - Physiology, Environment, and Genetics for the Animal and Livestock Systems – is a joint research unit run by INRAE and Agrocampus Ouest (Institut Agro – Rennes-Angers).

SPRING 2022 CLIMATE

© INRAE/Marie-Christine Lhopital

**Winter frost impacts on vineyards**
As a record-breaking cold hit several countries in April 2022, scientists raised awareness on the impacts of "false springs" and other climatic events on early-blooming plants and crops. In France, INRAE funded and coordinated LACCAVE, a ten-year-long research project, involving one hundred researchers on the adaptation of French wine industry to climate change. The findings highlighted the incresaing vulnerability of vineyards and the existence of adaptation solutions provided that global warming is contained under 2°C and that the joint mobilisation of the industry, public authorities, and research is sustained.

JUNE FOOD SECURITY

## New book: GloFoodS results

**Between 2014 and 2020, INRAE and CIRAD led an ambitious interdisciplinary flagship programme on the transitions for global food security called GloFoodS. This book, authored by the main investigators and contributors to research projects, presents the results of the programme, including recent research findings from many disciplines in life, engineering, and social sciences. Drawing from different analysis scales as well as from the combination of local and global food security approaches, the book explores food system governance, balance, and discrepancies between agricultural supply and food needs, the role of innovations in providing high-quality foods and promoting resilient value chains, as well as the role of local resource management in achieving food security.**

JUNE, 10 AFRICA

© National research foundation NRF

**First General Assembly of the Franco-African research initiative TSARA**

The TSARA initiative aims to strengthen partnership research to promote sustainable agriculture, food systems, and agricultural, pastoral, and forest landscapes. Since its launch in March 2022, 8 thematic groups have been working through webinars to draw up an inventory of scientific knowledge, listing the priority challenges to be addressed.

The first General Assembly of the TSARA Initiative was held on 5 December in Cape Town, South Africa during the World Science Forum 2022. It laid the foundation for its implementation with its 19 African and French member institutions from 11 countries and other participants. It was an opportunity to set up its governance and establish the operational schedule. INRAE is already devoting new resources to projects that will feed the initiative.

MAY & OCT. 22 POLICY

## BIODIVERSITY

INRAE delivered with its partners, two collective scientific assessments*, commissioned by the French Ministries in charge of agriculture, research, and the ecological transition.

**Biodiversity and services provided by nature: what is known about the impact of pesticides?**

The collective scientific assessment led by INRAE and Ifremer provided updated information on the impact of plant protection products on biodiversity and on the services that ecosystems provide to society. In addition to reducing the use of pesticides, which remains the primary lever for preserving biodiversity, the expertise identified three main types of action levers: mitigation of effects, regulation, and the use of less persistent and impacting products such as biocontrol products.

**Protecting crops by increasing plant diversity in agricultural areas**

Plant diversity helps to regulate crop pests such as pathogenic fungi, weeds, and insect pests with the aim of reducing or eliminating pesticides, all without lowering yields. Many barriers both upstream and downstream of the agricultural sector limit the use of these crop protection strategies, but public policies could be an important tool for farmers encouraged to adopt such methods. These are the main findings of a collective scientific assessment carried out by INRAE.

* These scientific assessments are produced by a team of experts from different organizations and gather validated scientific knowledge in support of public policies.

10.28.22 HORIZON EUROPE

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**ORCaSa project: Global coordination of research and innovation on soil carbon**

As a carbon sink or source – depending on pedoclimatic conditions and use – soils may represent a strategic tool for a carbon reservoir that is two or three times larger than plant biomass or the atmosphere. Understanding this sequestration phenomenon is therefore crucial in terms of efforts towards mitigating climate change and improving agricultural soil quality. Following on from the 1st Coordination Action, CIRCASA, the European Commission is now funding ORCaSa through its Horizon Europe programme. ORCaSa, is launched for 3 years and coordinated by INRAE, involving 12 international partners. The project aims to federate research efforts, share knowledge and prepare the foundations for an assessment system.

NOV-DEC.22 ENVIRONMENT

## COP contributions

**Contributing to the Global Environmental Governance and collaborating with its worldwide partners to solve our century's pressing challenges, INRAE was an observer member at the COP27 on climate change, and the COP15 on biodiversity. Urgent action from policymakers was requested, with evidence and solutions based on science, to guide the necessary transitions in the land sector during a side event organized by INRAE, Cirad, and IRD during COP27. At COP15 Biodiversity in Montreal, research called for the inclusion of the protection of genetic diversity in the Global Biodiversity Framework adopted there.**

JAN - JUNE 22 EUROPEAN UNION

FRANCE22

INRAE organized two conferences in the context of the French Presidency of the Council of the European Union.

11 February, online

**PREZODE – Joining forces to escape the era of pandemics**
A presentation of the European challenges identified through one year of co-construction workshops organized around the world in 2021.

2-3 June, Dijon, France

**Towards Pesticide Free Agriculture – What research to meet the pesticide reduction objectives embedded in the European Green Deal?**
Bringing together researchers and professionals from all over Europe to discuss the latest research results to pave the way towards 0 pesticides in agriculture.

OCTOBER 22 EUROPEAN RESEARCH COUNCIL

# 5 ERC GRANTS

The ERC programme funds exploratory research with a criterion of scientific excellence allowing researchers to identify new opportunities in any field of research while recognizing the status and visibility of Europe's brightest minds. The ultimate goal of the ERC is to build a European research prepared to respond to a knowledge-based society's needs and provide frontier research necessary to meet global challenges. INRAE obtained five ERC grants in 2022:
**2 Starting Grants** Claudia Bartoli, for exploring the Holobiont concept through a novel plant experimental evolution study, and Kalina Haas, for resolving the mystery behind plant growth mechanisms.
**2 Consolidator Grants** Moussa Benhamed, for identifying hidden targets controlling heat stress and priming in wheat, and Harry Sokol for exploring the impact of the gut microbiota on host cells' energy metabolism.
**1 Advanced Grant** Jean-Christophe Simon for his project on the evolutionary and molecular determinants of host alternation allowing aphids to feed on different plants depending on the season.

# AGENDA 2023

**March 1-2**
One Forest Summit
Libreville, Gabon

**March 21**
Restitution Conference of the foresight study on pathways to chemical pesticide-free agriculture in Europe in 2050
Paris, France

**March 22-24**
2023 UN Water Conference
New York, USA

**August 27-31**
World Conference on Animal Production (WCAP)
Lyon, France

**October 2-6**
International Forum on Agroecosystem Living Labs
Montreal, Canada

**November**
2023 International Science Festival for Agriculture – Food – Environment
Rome, Italy

**Nov 30 – Dec 12**
2023 United Nations Climate Change Conference (UNFCCC COP28)
Dubai, UAE

WWW...
inrae.fr/en/events

# INRAE

**the French National Research Institute for Agriculture, Food and Environment**

## 2022 KEY FIGURES

**11,000+**
people community

**2,000+**
doctoral students

**Budget**

**1.071M€**

↓

**207**
research units

**43**
experimental units

**23**
support service units

**14**
scientific divisions

## INVOLVEMENT WITH RESEARCH, HIGHER EDUCATION AND INNOVATION ECOSYSTEMS IN FRANCE

**18**
research centers

**33**
academic partnerships

**40**
shared facilities with businesses

**450+**
private-public partnerships

## H2020 RESULTS

**4th**
most funded organization in France among the first beneficiaries in the societal challenge

## HORIZON EUROPE: 2021

**34,1%**
success rate

## CONTRIBUTING TO THE UNITED NATIONS SUSTAINABLE DEVELOPMENT GOALS OF THE 2030 AGENDA

ZERO HUNGER

GLOBAL HEALTH AND WELL BEING

CLEAN WATER AND SANITATION

AFFORDABLE AND CLEAN ENERGY

DECENT WORK AND ECONOMIC GROWTH

RESPONSIBLE CONSUMPTION AND PRODUCTION

CLIMATE ACTION

LIFE BELOW WATER

LIFE ON LAND

## INTERNATIONAL COLLABORATIONS

**18,208**
**INTERNATIONAL CO-PUBLICATIONS**
Between 2017-2021

**COOPERATION INSTRUMENTS**

**20**
International associated laboratories

**5**
international research networks

**6**
Joint Linkage Calls for scientific mobilities

**6 INTERNATIONAL RESEARCH INITIATIVES**
On global challenges related to :
–
climate change
–
carbon in soils
–
one health
–
agroecology transitions
–
forests and water resources

INRAE

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INRAE Science for people, life & earth

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