INRAE

Annual report

2021

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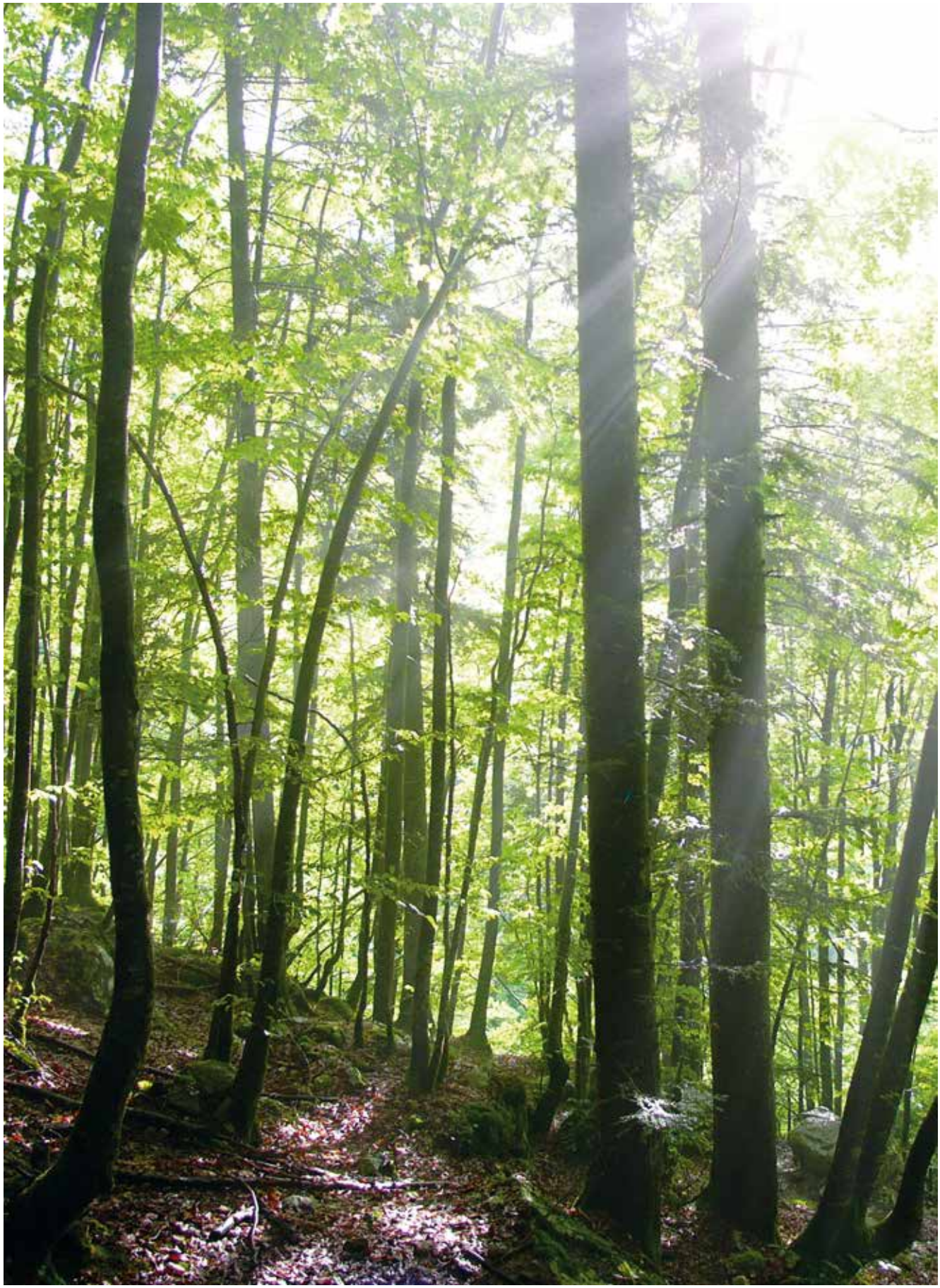
Cover image
Mature sunflower head
Île-de-France-Versailles-Grignon Research Centre

INRAE



Responding to environmental challenges and their associated risks.
Mountain beech forest in the Alps
Clermont-Auvergne-Rhône-Alpes Research Centre

Accelerating agroecological and food transitions while answering socioeconomic challenges.
Organic farming: heads of lettuce at a farmer's market in the Drôme.
©INRAE - M. Meuret

Building bioeconomies based on the efficient circular use of resources.
Hemp chaff, a type of plant fibre biomass.
Hauts-de-France Research Centre
INRAE - C. Maître

Promoting a holistic approach to health.
3-D rendering of Ebola virus.
©Adobestock

Facilitating transitions by mobilising data sciences and digital technologies.
Electron microscopy session
Val-de-Loire Research Centre
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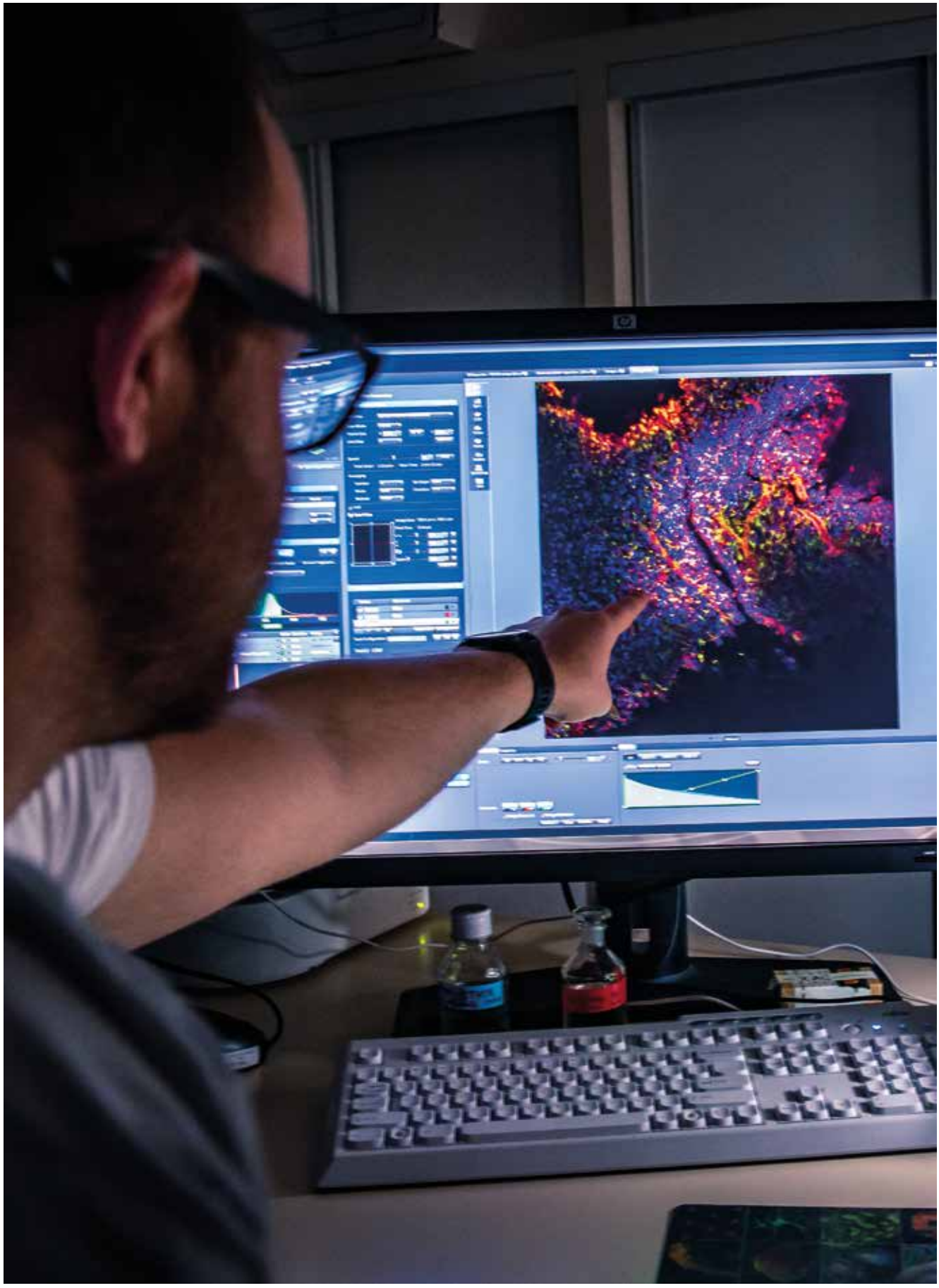

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High-lights

January 11

PREZODE is born

Jointly founded by INRAE, CIRAD, and IRD, PREZODE is an international initiative that aims to prevent zoonotic disease emergence. It was officially launched by France's president on January 10 at the One Planet Summit (OPS) in Paris. PREZODE encourages multilateral collaboration to limit disease risks and fight future pandemics. In 2021, around 100 international organisations, non-governmental organisations, and research institutions signed on to the initiative.

May 19

Work with ADEME promotes ecological transitions

INRAE and ADEME have formally established an extensive partnership to strengthen their current collaboration. The goal? To develop better solutions and decision-making tools for dealing with climate change; storing carbon in soils; bolstering the sustainability of agricultural, food, and forestry systems via the bioeconomy; facilitating regional transitions towards sustainability; and preserving human health and ecosystems.

Soil profile (carbon storage).
©INRAE - G. Levy

May 27

PlantAlliance adds varietal innovation to agroecological toolkit

INRAE brought together 28 French public- and private-sector research stakeholders and experts in the plant sciences to create the PlantAlliance consortium. The aim is to boost innovations in genetics, genomics, and varietal creation. To facilitate agroecological transitions, researchers can create innovative plant varieties via genetic selection. The objective is to reduce the need for plant protection products and other inputs while preserving production quality in the face of climate change and unpredictable weather.

©C. Saidou / agriculture.gouv.fr

May 29

Major campaign focused on agricultural water usage and adaptations to climate change

France's Ministry of Agriculture and Food and Ministry for the Ecological Transition launched a joint campaign to inspire discussion around water use in agricultural systems and responses to climate change. Stakeholders were invited to define basic strategic actions, a process that included prioritising key steps and identifying tools. More than 20 INRAE researchers took part in the campaign. They provided scientific guidance and helped structure the exchanges.

From left to right: A. Petit, CEO of CNRS, F. Vidal, Minister of Higher Education, Research and Innovation, P. Mauguin, Chair and CEO of INRAE
©INRAE - C. Maître

July 6

Research data become accessible to all

French Minister of Higher Education, Research, and Innovation, Frédérique Vidal, inaugurated the second National Plan for Open Science at INRAE, which seeks to promote the country's open science practices. INRAE was tasked with creating and managing a platform–Recherche Data Gouv–for sharing data produced by French research.

September 3

INRAE participates in World Conservation Congress for the first time

Every four years, the IUCN World Conservation Congress brings together thousands of leaders from governmental bodies, civil society, Indigenous communities, private businesses, and academia. The meeting focuses on environmental preservation and the solutions offered to us by nature. In 2021, the congress was held in Marseille. INRAE joined forces with IFREMER, CNES, IRD, MNHN, and the Conservatoire du Littoral to present concrete strategies for better managing natural environments and outdoor spaces.

September 9

French researchers develop nasal vaccine for COVID-19

Scientists at the University of Tours and INRAE (the BioMAP research team) developed a nasal vaccine based on viral proteins that protects against COVID-19. Support came from a public-private consortium and a French National Research Agency grant. Pre-clinical trials have shown that the vaccine provides effective protection against the original virus and its variants by both eliciting an immune response and blocking infection.

October 7

Research for Africa is conducted with Africa

On the sidelines of the New Africa-France Summit, CIRAD and INRAE collaborated to promote exchanges of skills and knowledge between Europe and Africa. The two research institutes have long-standing partnerships with more than 100 African research establishments. The aim is to augment the impact of agricultural research carried out on both continents.

BioMAP research team (INRAE-University of Tours) work on developing a candidate vaccine for COVID-19.
©INRAE - B. Nicolas

October 22

ClieNFarm promotes farm sustainability

The ClieNFarm project (2022–2026) was awarded European Green Deal funding. The project is coordinated by INRAE and brings together 33 European public- and private-sector partners. It seeks to develop technical, organisational, and financial solutions that are locally relevant, thus promoting sustainable, climate-neutral, and resilient farming.

October 30

***Ressources* is born**

The first issue of INRAE's new magazine, *Ressources*, was distributed internally and sent to INRAE's partners. A total of 5,000 paper copies were printed, and an electronic version is available online. Published quarterly, each issue of the magazine addresses three societal issues through the lens of research.

November 5

PEPR funding boosts agroecological and food transitions

In INRAE's circular orchard in Gotheron, new strategies were announced for bolstering the fourth French Investments for the Future Programme. The Minister of Agriculture and Food, the Minister of Higher Education, Research, and Innovation, the Minister of Industry, and the Secretary General for Investment described how research would be stimulated using three pools of priority research programme and infrastructure (PEPR) funding, amounting to a total budget of €155 million. INRAE leads the PEPR dedicated to genetics and varietal selection. It jointly runs the PEPR for agroecology and digital technologies with INRIA and the PEPR for food systems, the microbiome, and health with INSERM.

Visit of the Gotheron circular orchard with F. Vidal, J. Denormandie and B. Abba.
©INRAE - S. Vinzant

November 30

INRAE hands out laurels

INRAE held its second annual awards ceremony in Paris. With the Minister of Higher Education, Research, and Innovation in attendance, the Institute celebrated outstanding members of its community, whose achievements had been evaluated by an international panel of judges. The ceremony recognized the winners in 2021 and 2020, given that the latter had received their awards remotely because of the pandemic.

2021 INRAE Awards ceremony.
©INRAE - B. Nicolas

December 14

INRAE and CNRS sign a framework agreement

INRAE and CNRS have long worked together to identify solutions to climate, health, and environmental challenges. The two institutes signed a new five-year framework agreement, which solidifies their joint commitment to producing and using high-level scientific knowledge to help achieve the UN's Sustainable Development Goals.

December 16

INRAE commits to corporate social responsibility

INRAE's Board of Directors approved the Institute's first-ever action plan for corporate social responsibility (CSR). A newly created department has been tasked with ensuring that CSR principles are consistently applied across all of INRAE's research and work practices. These efforts will involve evaluating the environmental impact of the Institute's activities and promoting social policies that improve the quality of life at work.

Cover of the Sustainable Development Goals Report 2020.
©un.org

Meeting of the Directors General with research centre presidents and scientific division heads
©INRAE - S. Vinzant

A dedicated community

AN INTERVIEW WITH

Philippe Mauguin

INRAE Chair and CEO

The COVID-19 crisis continued throughout 2021. How was INRAE affected?

Our research and support teams have been working together to navigate this long-lasting pandemic and minimise its impacts.

In general, research has fully resumed in all our laboratories and experimental units. Such is apparent in our continuing advances in both the basic and applied sciences. The latest figures show that we are hitting new records in our numbers of general publications, co-authored publications with international researchers, and successful technology-transfer projects.
Simultaneously, our proposals are being funded at high rates by French and European grant programmes.

We have also learned useful lessons from having stayed productive under pandemic conditions, which was made possible by our dedicated research centre presidents, administrative departments, support staff, research unit directors, and occupational health and safety personnel. I thought it would be useful to formally gather feedback on our first year of crisis management at both local and national levels. The Institute's management staff took on this task. Our analysis underscored that our organisational approach was robust. It also highlighted certain areas of improvement, which we started addressing in 2021. Examples included new digital tools to facilitate collaborative work and contract extensions for doctoral students and staff supported by research funds.

> “The 12,000 members of the INRAE community dedicate themselves daily to confronting the world's greatest challenges. Their scientific solutions and advances help promote multiperformance agriculture, produce high-quality food, and sustainably manage resources and ecosystems on a global scale.”

Setting aside the public health situation, what did you learn in 2021?

We perform targeted research, and our Institute is a global leader in the agricultural, food, and environmental sciences. Consequently, stakes and expectations are high. The 12,000 members of the INRAE community dedicate themselves daily to confronting the world's greatest challenges. Their scientific solutions and advances help promote multiperformance agriculture, produce high-quality food, and sustainably manage resources and ecosystems on a global scale.

To help our staff take on this weighty responsibility while optimising our human and financial resources, I have been working with the Institute's management team to rapidly launch INRAE 2030, a roadmap that defines our major scientific and policy priorities. We have drawn up action plans that stretch onwards from 2021. They are focused on improving innovation, open science practices, scientific data, European and international partnerships, the management of human resources, higher education and training, communication, and corporate social responsibility (CSR). Indeed, we have

created a dedicated department to help us achieve our CSR objectives, which places INRAE in the vanguard among French research institutions. Thanks to the intense reflection and exchanges coordinated by our division heads, we have formulated 14 new division-specific strategic plans in our scientific fields of expertise. The overarching objective is to concretely translate our major scientific priorities, reinforce interdisciplinarity in our work, and schedule our actions in order of priority over the next five years.

I would also like to shine the spotlight on our successful innovations, starting with our nasal vaccine against COVID-19, which is currently in clinical trials. Additionally, we launched six start-ups focused on nutrition, ecotoxicology, soil health, and seed optimisation; established five associated partnership laboratories with technical institutes, SMEs, or start-ups; and obtained accreditation for a fifth Carnot Institute.

In 2021, INRAE signed its first Contract of Objectives, Means, and Performance (COMP) with the French government. Why was this an important step for the Institute?

It was essential for us. INRAE was born in 2020 from the merger of INRA and IRSTEA, and we needed to start off strong by making our priorities clear to the national government. First, I wanted to communicate our traditional objectives, as required of all public institutions. Second, I wanted us to better position ourselves to attain these objectives by dialoguing with the government regarding our resource distribution schedule. For the first time ever, we were able to reach both goals, thanks to a long process of reflection and budgetary projection carried out with the Ministry of Higher Education, Research, and Innovation, the Ministry of Agriculture and Food, and the Ministry of Economy and Finance. Research planning encompasses long periods of time, so it was necessary for the COMP to set out our expectations for the national government. This process clarified how our ministerial subsidies will shift in the coming years and resulted in the allocation of additional resources that we can use for priority actions. Our board of directors validated the COMP (2022–2026) in late 2021.

> “That the government has trusted us with administering substantial means and diverse PEPRs reflects the stellar reputation of our Institute and its research.”

The contract takes into account the funds we will receive thanks to research programming legislation (2021–2030) and ensures we will benefit from a reasonable increase in financial resources. I needed to guarantee that our Institute would benefit from the national investment in French research. Our resources will gradually increase at a rate of more than €20 M per year. Starting in 2021, we will be able to maintain our levels of permanent staff after 10 years of continuous decline. We will be able to fund 15 more doctoral theses and competitively hire 4 early-career researchers for tenure-track positions, in addition to the usual open competition hires. We have also been granted €7 M to increase the salaries of doctoral students, researchers, engineers, technicians, and administrators.

France's prime minister launched the fourth iteration of the Investments for the Future Programme (PIA4) in 2021, which provides substantial funding for national strategies for innovation exploration and acceleration. Research institutions can benefit from PIA4's priority research programme and infrastructure (PEPR) funding. What has INRAE's contribution been?

I want to highlight the major role played by our research teams in developing the PEPRs, which aim to create or consolidate French scientific leadership in priority fields at national or European levels. These fields are essential to large-scale societal transformations.

In late 2021, INRAE was solely or jointly steering eight PEPRs focused on a variety of issues: developing alternatives to plant protection products; preventing zoonoses; creating digital technologies for use in agroecology; exploring the link between food, the microbiome, and health; generating biobased products and sustainable fuels; breeding plant varieties adapted to climate change; taking a holistic approach to water

resources; and investigating carbon dynamics in ecosystems. This work is being carried out in collaboration with colleagues at CNRS, INRIA, CIRAD, IRD, INSERM, BRGM, and various educational institutions.

The resulting €378 M budget will boost the momentum of our scientific community over the long term, allowing us to focus on targeted research of major societal importance that is carried out in collaboration with many research and innovation stakeholders. That the government has trusted us with administering substantial means and diverse PEPRs reflects the stellar reputation of our Institute and its research.

Research issues seem to be growing ever more intertwined and global in scope. It is clear that INRAE's research is firmly established within France and Europe. However, what is happening internationally?

We provide practical knowledge, expertise, and public policy support in specific domains. Thus, our work derives meaning when we operate at different scales. For example, in France, more than 20 INRAE scientists took part in a major campaign that fostered discussion on water usage in agriculture and adaptations to climate change. These efforts were led by the Ministry of Agriculture and Food and the Ministry for the Ecological Transition. In this context, we needed to work at the national level to decide upon a strategic response, priority actions, and key tools. In contrast, climate change and biodiversity loss are issues that must be addressed at a global scale. Consequently, INRAE also attended the IUCN World Conservation Congress in Marseille, an event that brought together several thousand leaders representing governmental bodies, civil society, Indigenous communities, private businesses, and academia. We wanted to present the approaches we are developing for better managing the environment and natural spaces.

Strengthening our international leadership was one of the reasons for creating INRAE. To this end, we have partnered with top-notch research teams by creating international associated laboratories and research networks. More than 20 are already up and running. In tandem, we have launched several ambitious global initiatives. There is PREZODE, which we jointly founded with CIRAD and IRD. Launched by the French President at the One Planet Summit in Paris in early 2021, this initiative aims to limit zoonotic risks and fight future pandemics. In one year's time, over 100 international organisations, non-governmental organisations, and research institutions have joined forces with us. Held in late 2021, the New Africa-France Summit underscored the importance of facilitating agricultural and agrifood transitions in the Global South. On the summit sidelines, we established the TSARA initiative to work with CIRAD and over twenty African research institutions. The objective is to combine our strengths and thus increase the impact of agricultural research being conducted in Africa and Europe.

Yes, we are facing geopolitical uncertainty, and our society is plagued by scepticism. Yes, we are facing multifarious challenges, such as exponential population growth, climate change, resource scarcity, and biodiversity loss. Nonetheless, I want to spread optimism. The first two years of INRAE's existence were marked by a public health crisis without precedent. Yet, our community remained driven by its passion for research and its commitment to the common good. Thanks to our complementary talents, the Institute is making amazing advances and thus generating hope for the future in many different areas. We need to believe that our wisdom, dedication, and desire to protect the welfare of the general public will continue to bear fruit. ●

Our research

MetaGenoPolis' InFuture biobank
Île-de-France-Jouy-en-Josas-Antony Research Centre.
©INRAE - B. Nicolas


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Tackling scientific and societal challenges

We must carry out cutting-edge fundamental and applied research if we want to address the scientific and societal challenges faced by agricultural systems, food systems, and natural ecosystems. Such requires discipline-specific expertise as well as interdisciplinary and transdisciplinary approaches. To address major issues in the agricultural, food, and environmental sciences individually and collectively, some fundamental research strategies are necessary: taking risks, exploring new scientific frontiers, conducting open and engaged research at multiple scales (from single sites to across the globe) in collaboration with diverse stakeholders, utilising state-of-the-art research infrastructures, and exploiting novel methodologies.

Working from this foundation, we spent 2021 deploying the scientific and policy priorities described in INRAE 2030:
- constructing new strategic plans for our scientific divisions;
- supporting systemic and interdisciplinary research by launching 10 new metaprogrammes and building several PEPRs;
- increasing our infrastructure contributions to national and European roadmaps;
- preparing the Horizon Europe Work Programme 2023–2024.

Carole Caranta
Deputy Director General
Science & Innovation

Monique Axelos
Scientific Director of Food and the Bioeconomy

"To facilitate the transition to healthier and more sustainable diets, we must explore people's relationships with food at different ages, accounting for the diverse regions and practices represented within supply chains and characterising the factors that drive stakeholder and consumer choices. We must also develop innovative strategies that ensure commodities are fully exploited within the circular economy, eliminating waste."

Christian Huyghe
Scientific Director of Agriculture

"Agroecological transitions within agricultural systems utilise specific sources of genetic diversity within plots, herds, farms, and regions. They lead to new forms of equilibrium among production, profitability, and environmental quality (e.g., biodiversity, climatic conditions, human and animal health), which are important present and future resources. We must work as closely as possible with stakeholders to facilitate these transitions, which are establishing a new paradigm for research, innovation-centred partnerships, and public policy support."

Thierry Caquet
Scientific Director of Environment

"We need to move beyond our incremental approach and accelerate the changes we must make to production systems if we wish to adapt agricultural and forestry systems to the reality of current and future climatic risks. Individual changes will only have partial effects. They must occur together to truly allow system customisation and sustainability. We must adopt a systemic point of view that accounts for multiple industries. We should examine regional specificities in tandem with issues that span sectors (e.g., water and energy use, soil quality, biodiversity) while ensuring that mitigation strategies are appropriate."

Scientific priorities

Responding to environmental challenges and their associated risks

We are witnessing global changes in real time. To prepare for their future consequences, we must develop and evaluate strategies for safeguarding agricultural, food, and environmental systems, which requires reducing their vulnerability and boosting their resilience. We can accomplish this task by exploiting the adaptive mechanisms used by living creatures as well as by both preserving and sustainably utilising biodiversity. Research should simultaneously be conducted to better characterise the variability and sensitivity associated with different issues so as to improve risk assessment and management.

Climate change: mitigation and adaptation strategies

Conservation agriculture is an ally in adaptation efforts

Conservation agriculture is helpful because it boosts carbon storage in soils. However, it has long had a bad reputation because it is thought to result in lower yields. A recent study compared production levels for conventional agricultural systems (i.e., using tillage) versus systems based on conservation agriculture and its variants. This research used machine-learning techniques to analyse several thousand points of experimental data collected across the world's main agricultural regions. It focused on eight major species grown under current and future climatic conditions. The results showed that, under future climatic conditions, the relative performance of conservation agriculture should increase for certain crops, notably corn.

Nature Climate Change
doi.org/10.1038/s41558-021-01075-w

Aridity-adapted oaks are naturally more drought resistant

Climate change is here, and with it have come increasingly frequent and intense droughts. It is essential to understand how this global shift will impact forest dieback patterns. In trees, drought tolerance is greatly shaped by how well a plant's xylem can resist embolism. Xylem is the vascular tissue that carries water and nutrients from the soil to the leaves. Indeed, under drought conditions, air bubbles can block xylem cells, causing cavitation, and thus lead to tree death. Using an innovative optical technique, researchers at INRAE, UC Berkeley, and Stanford quantified the drought tolerance of different North American oak species. They discovered that, over evolutionary time, the oaks had developed greater drought resistance, which allowed them to colonise more arid areas. At present, these species have a relatively large margin of safety for coping with climate change.

Proc Natl Acad Sci USA
doi.org/10.1073/pnas.2008987118

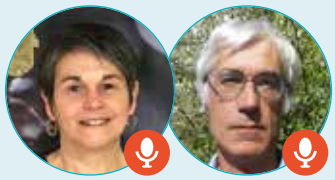
Environmental research observatory: monitoring of experimental plots to characterise soil carbon, soil nitrogen, water, air, and biodiversity dynamics. ©INRAE - C. Maître

Soil carbon storage in mainland France could help limit global warming

Because of their carbon storage capacities, soils can play a major role in mitigating climate change. Notably, by boosting soil carbon storage by 0.4% (4 parts per 1,000) annually, it might be possible to offset yearly anthropogenic CO_2 emissions. Utilising a carbon-balance-based approach, researchers estimated levels of soil carbon saturation in mainland France to gauge the potential for increasing their storage capacity. To arrive at the annual target of +0.4%, inputs of soil organic carbon would need to climb by 30–40% over a 30-year period. The researchers recommended certain farming and land use practices for attaining this objective. A different study focused on western France showed that planting trees in agricultural areas can help augment soil carbon storage.

Global Change Biology
doi.org/10.1111/gcb.15547

Agriculture, Ecosystems & Environment
doi.org/10.1016/j.agee.2020.107174



LACCAVE: 10 years of collaborative research aimed at preparing viticultural systems for climate change

A CONVERSATION WITH

Nathalie Ollat
Joint Research Unit for Ecophysiology and Grape Functional Genomics (EGFV)

Jean-Marc Touzard
Joint Research Unit for Innovation and Development in Agriculture and the Agri-Food Sector (INNOVATION)

Why did you launch the LACCAVE project?
We began LACCAVE in 2012 as part of the ACCAF metaprogramme, which gave a boost to work helping agricultural and forestry systems adapt to the realities of climate change. Our project created a collaboration among 22 INRAE research units studying vines and wines, partner laboratories, and representatives from agricultural organisations. The goal was to identify the major effects of climate change, such as earlier harvest dates, and strategies for dealing with them. We sought to create a network for producing and sharing knowledge on coping mechanisms in this key sector.

How did you foster interdisciplinarity within the project?
This work requires drawing upon diverse fields of knowledge, including climatology, genetics, geography, economics, agronomy, and oenology. We needed to study the biophysical mechanisms in operation within plants, plots, and wines. However, we also needed to clarify the actions that could be taken by winegrowers, winegrowers' organisations, and even wine consumers. We therefore jointly defined our target impacts and adaptation strategies from the start and then organised numerous seminars. We also launched foresight research, which played a key role in nurturing this interdisciplinarity.

What were the key results?
We were able to identify important adaptation mechanisms, tools, and strategies. For example, we clarified the genetic, biological, and agricultural factors that determine how vines respond to climatic stress. This information is needed to create suitable varieties or to choose appropriate grapes. We kept up with oenological innovations, which can be exploited to correct the effects of stressors on wine quality. We acquired a better grasp of consumers' willingness to pay for products, and we learned to utilise a combination of participatory and modelling approaches. Our findings have helped forge methodological advances that encourage local-level adaptations. At the national level, the foresight study stimulated discussion around the future path of viticulture and led the sector to develop an adaptation strategy.

What support did the foresight study provide to industry stakeholders?
It was essential to explore different scenarios, which meant first setting up a framework with the French National Institute of Origin and Quality (INAO) and FranceAgriMer. The 4 resulting scenarios for preparing the sector for climate change by 2050 were reviewed by nearly 500 stakeholders across 7 wine-producing regions, giving rise to 2,700 proposed actions! This work then fuelled the reflections of professional representatives, who developed a formal strategy for the wine industry to use in confronting climate change, which was presented to the Minister of Agriculture and Food on August 26, 2021. Our work also nourished industry exchanges during the major governmental campaign on water usage in agriculture and adaptations to climate change.

> “We were able to collaborate with highly motivated researchers and professionals because there is a broad range of expertise in this domain in France. Furthermore, climate change is a major issue of concern.”

What was behind the project's success?
We were able to collaborate with highly motivated researchers and professionals because there is a broad range of expertise in this domain in France. Furthermore, climate change is a major issue of concern. The industry is extremely well structured at the regional and national levels, and it made an active contribution to the scientific side of the project. It also made a crucial difference to have INRAE support and to be part of a 10-year metaprogramme. Finally, our substantial efforts to foster interdisciplinarity played a significant role!

To learn more (in French):
urLinrae.fr/3rVNJQS

Lakes are ecosystem-level sentinels of climate change

INRAE took part in an international study led by the Rensselaer Polytechnic Institute (USA) that looked at more than 45,000 vertical profiles of oxygen levels for 400 temperate lakes mainly located in North America and Europe. The dates for the profiles ranged from 1941 to 2019. The study found that, since 1980, oxygen levels have undergone average declines of 5.5% in surface waters and 18.6% in deep waters. This loss in lakes is 3 to 9 times greater than that observed in oceans over the same time period. The lower availability of dissolved oxygen directly impacts lake ecosystems and notably affects the life cycles of aquatic species such as fish. It also alters biogeochemical cycles because sediments discharge higher levels of nutrients (e.g., phosphorus) into the water column. Greater quantities of greenhouse gases (e.g., methane) are also released into the atmosphere. INRAE is using these findings to build models that predict changes in oxygen levels in lake ecosystems, which can be used by natural resource managers.

Roselette Lake and the Mont Blanc mountain range in Haute-Savoie.
©INRAE - G. Balvay

Nature
doi.org/10.1038/s41586-021-03550-y

IN BRIEF

DRYRivERS: an app for monitoring river drying patterns

River systems are essential to our well-being and harbour tremendous biodiversity. They are also among the most threatened habitats on the planet. As part of the INRAE-led Horizon 2020 DRYvER project, an international team of scientists is collecting, analysing, and modelling data from drying river networks across two continents–Europe and South America. Everyday citizens can help in this effort by submitting observations of drying rivers via a special app.

www.dryver.eu/

BOOK

BAG'AGES (2016–2021): evaluating how agroecological practices affect soil functions

With funding from the Adour-Garonne Water Agency and the Occitanie regional government, INRAE led the five-year BAG'AGES programme, which brought together 20 collaborators in research, agricultural development, education, and industry along with nearly 60 farmers.
The Adour-Garonne River Basin is experiencing the effects of climate change, which has raised questions about current cropping systems. Notably, is water available when crops need it? Also, are local environments equipped to cope with periods of intense rainfall? Indeed, the latter are expected to increase and can cause dramatic erosion.
BAG'AGES helped identify the impacts of the agroecological approaches used in different cropping systems, particularly in the context of conservation agriculture. It focused on the Adour-Garonne River Basin and quantified the agricultural, economic, social, and environmental performance of soils at multiple levels: within plots, farms, and the watershed.

Read an overview of the programme's findings (in French)
url.inrae.fr/3wLktPV

Biodiversity: a powerful tool and a valuable inheritance

Weeds' contributions to ecosystem services can be quantifieds

Agroecological weed management seeks to balance the harm caused by weed communities, such as smaller crop yields, while maximising the communities' supply of trophic resources that promote functional biodiversity. Since these two objectives are often seen as mutually exclusive, it is essential to identify cropping systems in which the above trade-off provides net benefits. Over the course of the European project IWMPRAISE, researchers developed a set of nine indicators that estimate weeds' positive contributions, namely to pollination (by bees, bumble bees, and syrphid flies) and pest control (of carabid beetles, birds, and parasitoids), as well as their negative impacts on yields, via competition with crops, interference with harvesting, and weed seed bank build-up. Indicator values are now available for 1,000 weed species. This approach provides a quantitative tool for understanding how this group of plants affects ecosystem services in a wide range of settings.

Ecological Indicators
doi.org/10.1016/j.ecolind.2021.108321

Plant diversity promotes sustainable agriculture

Research conducted in natural environments has suggested that plant diversity ensures the presence of multiple mechanisms for increasing ecosystem functioning and stability. At its core, agroecology aims to boost crop diversity in agricultural systems. Although variety mixtures have grown in popularity over the past 10 years, they continue to produce inconsistent yields. To clarify the sources of this variability, researchers analysed a large dataset containing genetic information for the varieties included in durum wheat mixtures. The results showed that, compared to monovarietal situations, mixtures led to higher average yields and were less susceptible to the disease septoria leaf blotch. Researchers also identified a genomic region where varietal diversity was linked to lower yields and higher disease susceptibility. This work represents the first time such an effect has been seen in a crop species. These findings have clear agricultural significance. Additionally, they can help inform burgeoning areas of research, such as the study of plant cooperation.

New Phytologist
doi.org/10.1111/nph.17915

Global risks of pollinator decline are explored

Pollinators play an essential role in maintaining biodiversity, boosting the yields of many crop species, and generating nutritious foods for humans. Researchers established a large international collaboration to assess the global and regional risks faced

IN BRIEF

Human activities have spared only 14% of global river ecosystems and their fish communities

Using a new indicator that accounts for the taxonomic, functional, and phylogenetic facets of biodiversity, researchers discovered that over 50% of 2,456 rivers found across the globe contain ichthyofauna that have been greatly affected by anthropogenic forces. This study highlights the urgent need to protect river biodiversity.

Science
doi.org/10.1126/science.abd3369

Floristic diversity found along the edge of a winter barley field: pheasant's-eye, vetch, and cornflower.
©INRAE - G. Louviot

Refining methodology to assess how agricultural practices unintentionally affect the biology of pollinating insects such as the honey bee.
©INRAE - C. Slagmulder

by pollinators and the implications of existing threats for human well-being. Focus was placed on Europe, North America, South America, Africa, Asia-Pacific, Australia, and New Zealand. For example, no longer having access to managed pollinators was only considered to be a serious risk in North America. However, yields of pollinator-dependent crops were seen as having a serious or high risk of instability in four regions. This risk was just moderate in Europe and North America. Overall, the study's findings suggested that global policy responses should focus on reducing the pressure exerted on pollinators by changes in land use, land management, and pesticide use, which played a prominent role in most regions.

Nature Ecology & Evolution
doi.org/10.1038/s41559-021-01534-9

Method is developed for maximising ecosystem functioning

An international research team led by INRAE and CNRS employed a novel approach to study how resource distribution among species can affect ecosystem functioning. Using 570 miniature ecosystems in which biomass served as the resource, the scientists explored how different distribution patterns affected levels of biodiversity. For example, they tested whether greater benefits were achieved by giving biomass mainly to high-performing sentinel species versus dividing it equally among several species. The results underscored that ecosystem functioning was maximised by equitable resource distribution.

Proc Natl Acad Sci USA
doi.org/10.1073/pnas.2019355118

Organismal adaptations: tools for guiding genetic selection and preserving biodiversity

Are plants and their root microbial communities always allies?

Over recent decades, microbial communities have been found to have significant effects on plant phenotype, growth, development, and immune functions thanks to advances in knowledge and high-throughput sequencing. Not long ago, researchers were able to select for microbiota that increased leaf area (by up to +15%) or decreased chlorophyll concentration (by as much as -12%) in the grass *Brachypodium distachyon*. Such work is the first to demonstrate that microbiota-associated phenotypes can be transferred across generations once microbiota structure has stabilised. That said, these relationships are not always beneficial. In novel research on the model plant *Arabidopsis thaliana*, researchers found they could use specific genes to differentiate beneficial from pathogenic microbes within a large population of endophytic fungi. These findings can help inform the use of microbiota to improve crop health.

Ecology Letters
doi.org/10.1111/ele.13916
Nature Communications
doi.org/10.1038/s41467-021-27479-y

Natural resistance to grapevine fanleaf virus spurs hope

The grapevine fanleaf virus negatively affects grape quality, longevity, and production potential. It has been found in around 70% of French vineyards. The plant's roots are infected with the pathogen by a tiny soil-dwelling roundworm. The virus then moves up to the aerial parts of the plant, where it causes multiple types of damage. Preventive measures can reduce the disease's impact, but no treatment is currently available. A study combining genetics and plant pathology has led to the discovery of a genetic factor that confers natural resistance to Riesling grapes. This discovery paves the way for the very first effective and environmentally friendly technique for genetically controlling infection levels.

Communications Biology
doi.org/10.1038/s42003-021-02164-4

Fungal pathogen adopts host-specific infection strategies

When pathogens acquire the ability to infect new hosts over the course of evolution, new diseases can arise. Some fungal pathogens can infect several hundred plant species. It seems unlikely that this ability stems from the simple accumulation of many molecular weapons. Researchers examined the molecular mechanisms used by the fungus responsible for white mould (*Sclerotinia sclerotiorum*) when it infected plants from different plant families. They found that the pathogen utilises different strategies for different species, which means it adjusts its approach depending on its host. As a result, the fungus possesses a toolkit large enough to allow it to infect many species. This discovery could inspire new means of reducing the severe damage caused by white mould in cash crops.

The ISME Journal
doi.org/10.1038/s41396-021-01058-x

Diseased tomato plant.
©INRAE

Intensive fishing disrupts natural selection

On average, intensive fishing practices cause fish body size to decline by 30%. There are major economic and ecological consequences: fishers obtain lower yields, and the smaller fish are both less effective predators and more vulnerable prey. Researchers explored the evolutionary mechanisms underlying this pattern in fish populations. Their findings have suggested that body size decreases for two reasons. While there is selective harvesting of large fish, intensive fishing also undermines the operation of natural selection, which is shaped by fish densities within populations. This study can help in the development of more sustainable and responsible fishing practices, which are necessary to ensure a fairer distribution of the future food supply.

Ecology Letters
doi.org/10.1111/ele.13677

Bees defend themselves against parasitic mites

Varroa destructor is a mite capable of decimating entire honey bee colonies. However, some colonies can survive attacks by this parasite even if left untreated, demonstrating that they possess natural resistance. A study explored how bees defend themselves against the mite. The researchers discovered that alveoli containing parasitised brood emitted a previously undescribed chemical mixture, which elicited hygienic behaviour from certain bees. These individuals pierced and cleaned the contaminated alveoli, thus protecting the colony. These results may be of great use in the fight against *V. destructor*. Indeed, tests can be developed to help beekeepers identify colonies that are naturally resistant to the mite.

Nature Chemical Biology
doi.org/10.1038/s41589-020-00720-3

Benefits of genomic selection are assessed in plants and animals

Genomic selection is a generalised technique that can be used with all plant and animal species. In France, it has been applied to male cattle since 2009 to improve dairy production. It is now utilised in a number of other species. INRAE researchers in genetics and economics sought to determine whether genomic selection is applied similarly across highly disparate taxa, including cows, poplars, bees, and wheat. This work highlighted three main arguments that can be used individually or in combination to encourage the implementation of genomic selection. It also clarified the major trends in how genomic selection is being deployed. However, stakeholders may make choices that deviate from these trends depending on species biology, breeding structure, or economics.

Frontiers in Genetics
doi.org/10.3389/fgene.2021.629737
Genetics and Genomics
doi.org/10.20900/cbgg20210008.

IN BRIEF

Tree fecundity and biological aging

Forests provide many ecosystem services. A continuous supply of tree seeds is essential to ensure forest regeneration. Thus, in the interests of effective management and conservation, it is important to understand how fertility declines with tree size and age. A large international study conducted across different continents has revealed that tree fecundity peaks when adult size is reached. It subsequently decreases.

Proc Natl Acad Sci USA
doi.org/10.1073/pnas.2106130118

Two young INRAE researchers receive European Research Council Starting Grants

Claudia BARTOLI is a researcher at the Institute for Genetics, Environment, and Plant Protection in Rennes. She is working on the HoloE2Plant project, which explores the mechanisms involved in the co-evolution of organisms and their microbiota.

Kalina HAAS is a scientist at Institut Jean-Pierre Bourgin. She is carrying out the STORMtheWALL project, which uses super-resolution imaging to characterise the mechanisms behind plant growth.

Experiments in grain-growing systems looking at interactions among bee colony characteristics, landscape characteristics, and environmental constraints.
©INRAE - C. Maître

Assessment and management of natural and climatic risks

Avalanche in the French Alps (Lautaret). ©INRAE

Climate change affects avalanche altitude and frequency

Little is currently understood about how climate change will change avalanche patterns. Researchers lack sufficiently long data series on avalanches. Additionally, more statistical techniques are needed to deal with the many biases present in the limited data available. Researchers thus decided to study avalanche patterns in the Vosges mountain range from the late 1700s to 2014. Their innovative multidisciplinary approach employed a combination of historical analyses (e.g., using written archives, graphic material, first-hand accounts), statistical modelling, and climatology. They found that an increase of 1.5°C resulted in an increase in avalanche altitude and a decrease (-7 fold) in avalanche frequency.

Proc Natl Acad Sci USA
doi.org/10.1073/pnas.2107306118

More than 50% of the world's rivers are not perennial

Over the past 50 years, many perennial rivers have become intermittent as a result of climate change, shifts in land use, and changing patterns of water usage. Non-perennial rivers and streams are often inadequately managed or even completely left out of ecosystem conservation schemes. Yet, this habitat type hosts unique species, including many that are adapted to cycles of water presence and absence. Researchers examined river networks around the world, whose summed lengths equalled 64 million kilometres. Based on their findings, they predicted that water flows ceased temporarily each year in 51 to 60% of these systems. This study is the first time that the global distribution of intermittent rivers has been empirically quantified and mapped. It is important to use the knowledge gained to better manage such ecosystems.

Nature
doi.org/10.1038/s41586-021-03565-5

Degradation of the Amazon affects carbon storage

Climate change and human activities are negatively impacting the Amazon rainforest. However, researchers have yet to quantify how environmental policy shifts are affecting carbon storage dynamics. While the degree of deforestation can be fairly well described via satellite images, the damage caused by other factors (e.g., intermittent tree cutting, fires, and/or droughts) are much more difficult to characterise. Scientists from INRAE, CEA, and the University of Oklahoma teamed up to study changes in carbon storage patterns in the Brazilian Amazon between 2010 and 2019. They utilised satellite-based data on both plant biomass and remaining forest area. During this period, carbon losses exceeded carbon gains by about 18%.

Nature Climate Change
doi.org/10.1038/s41558-021-01026-5

Novel participatory science project reveals climate's effects on interactions between trees and herbivorous insects

In 2018, INRAE researchers launched Oak Bodyguards, a participatory science project involving primary and secondary school students in 17 European countries. The students were tasked with collecting data on the resistance mechanisms used by oak trees to cope with insect herbivores under different climatic conditions. For 2 years, teachers, their pupils, and 112 collaborators used the same protocol to estimate the damage caused to trees by insect herbivores along a geographical gradient from Spain to Finland, spanning the range of the common oak. Their first set of findings indicates that not all insect herbivores are influenced in the same way by climatic conditions or tree defences. The project is still underway and gathering long-term data. It will also characterise the biodiversity associated with the common oak.

Global Ecology and Biogeography
doi.org/10.1111/geb.13244

Oak tree.
©INRAE - M. Meuret

Scientific priorities

Accelerating agroecological and food transitions while answering socioeconomic challenges

It is crucial to extensively redesign food and agricultural systems to generate products of sufficient quality and quantity that will meet the needs of human populations. Simultaneously, it is essential to limit the negative effects of production practices. INRAE research is delving into useful and often interconnected tools, including biological regulation; genetic diversity; diversity in production systems, crops, and farm animals; and dietary shifts. However, transition success depends on more than just overcoming technical challenges. INRAE is also examining how public policies can positively contribute and is looking at the forces that help and hinder the adoption of new production methods by the various stakeholders.

An exploration of transitions and obstacles to autonomy

Staff at the Environmental Research Observatory of Lusignan.
©INRAE - C. Maître

Farmers are more likely to adopt agroecological solutions aligned with their values

Farmers are transitioning to sustainable agricultural practices that suit their needs. Such transitions are more likely to be successful if farmers receive guidance from their colleagues. The above issue is being addressed in a participatory research project led by AVEM, a group of veterinarians and livestock farmers based out of Millau. For four years, an evidence-based approach to transitions was tested in collaboration with farmers in and around Roquefort. The project's diagnostic tool was unable to identify solutions that farmers could universally employ, given the complexity and uniqueness of people's situations. Instead, the tool fostered exchanges about the values highlighted in the agroecological approaches presented. Then, workshops were organised in which farmers furnished their professional judgment to their peers about potential transition paths, with a view to improving the likelihood of success. The tool was initially intended to serve a prescriptive purpose. Instead, it took on a new function: to provide peer assessments of solutions that farmers found best suited to their needs. The results of this work have given rise to a conceptual framework for both interpreting transition type and thinking about effective forms of support. It encourages stakeholders to pursue individual solutions while receiving reassurance from their fellow farmers as they take risks. It promotes peer-based learning of new practices and redefines social norms. This framework also served as the foundation for the Agroecological Transitions Campus in Toulouse.

Agriculture and Human Values
doi.org/10.1007/s10460-021-10258-2

Worldwide movement for on-farm experimentation seeks to accelerate agricultural transitions

Across the globe, a new movement is promoting novel approaches to agricultural innovation. Its focus is on-farm experimentation (OFE), in which agricultural experiments are jointly developed with farmers. An international research group has been formed to establish the movement's fundamental principles and to encourage its formal recognition. The group comprises representatives from nine countries–Argentina, Australia, Canada, China, the United States, France, Malaysia, Morocco, and the United Kingdom. The two French institutions involved are INRAE and the Digital Agriculture Convergence Lab (DigitAg). The group's work suggests that this collaborative approach to fostering innovation could boost the speed of agroecological and digital transitions. In this context, experimentation is not simply

Researchers digging up soil-filled capsules in the field, a technique used to trap soil microflora. ©INRAE - C. Maître

a tool for testing hypotheses. Instead, it is a concrete method for encouraging the creation of local, applied knowledge.

Nature Food

doi.org/10.1038/s43016-021-00424-4

Agroecology can be promoted via ecological compensation

In France, land development projects are required to take measures to avoid, limit, and, if necessary, compensate for environmental impacts. Researchers are currently exploring how ecological compensation measures could help promote agroecological transitions. This work is being carried out by CompAg, an interdisciplinary project led by INRAE whose participants include the French National Federation of Conservation Organisations, the private company Agrosolutions, and the farming network Terre de Liens. The project has identified several promising pathways. Notably, it is important for development projects to better account for «everyday» natural spaces (i.e., species and ecosystems that are not specifically protected), a category that includes farmlands. Furthermore, ecological compensation and agroecological transitions should be formally considered at the regional level rather than at the plot level. The latter is far too common.

The report (in French) can be found here: url.inrae.fr/3ofomro

Successful agroecological transitions sprout from varying visions

Agroecological transitions are complex because they are multidimensional and require technical, social, ecological, and political shifts. They also take place at several scales, from individual plots to entire farms to whole food systems. A book on this topic has brought together contributions from researchers in eight countries. It is called *Agroecological transition, between determinist and open-ended visions*. Drawing on case studies provided by different research institutes, the text illustrates that stakeholders undertake transitions by combining multiple strategies. It asks the question: should we adopt a determinist perspective, in which the objective is predetermined, or should we adopt an open-ended perspective, in which the objective is undetermined? This interdisciplinary book examines the diverse approaches that can be used to facilitate agroecological transitions. It thus provides an up-to-date summary of the topic and should inspire new research on agroecological transitions.

Peter Lang International Academic Publishers
ISBN 978-2-8076-1852-7 et url.inrae.fr/3xRaNUT

BOOK

France's National Research Programme for Regional Development

Launched 25 years ago, France's National Research Programme for Regional Development (PSDR) is a partnership-centred effort positioned within the vanguard of research methodology and knowledge production. PSDR develops innovative approaches to regional development issues in collaboration with stakeholders in the field. Founded to tackle complex modern problems, PSDR has grown and evolved in its thinking over the years. Its funding comes from regional governments, and it brings together local stakeholders and authorities.
PSDR is now the subject of a book that is dedicated to the fourth generation of the programme. A number of themes are addressed via a series of interviews. Readers are thus taken behind the scenes of PSDR's projects and learn about both the successes and challenges that the organisation has encountered over time. The lessons learned by PSDR are the foundation for the programme's next iteration, Regional Transitions in Agriculture, Food, and the Environment (TETRAE). Launched in 2021, TETRAE will focus on open innovation (see p. 69).

doi.org/10.17180/1BAH-BZ35

Agricultural systems free from synthetic pesticides

Exploiting landscapes to control crop pests is a complex task

Landscapes are often managed to control pests and limit pesticide use. However, current research suggests the success of this approach is highly pest dependent. To explore this issue, scientists employed French epidemiological surveillance data for 30 key pests found on cash crops. In tandem, they examined country-level maps showing areas covered by trees and cash crops, namely wheat, rapeseed, maize, barley, beet, and potato. In general, pests were more prevalent on crops when those crops had been grown on larger surface areas the previous year. The effect was more complex for crop surface area within the same year. Furthermore, protection against pests was not consistently provided by semi-natural features such as hedges, meadows, and forests. Instead, their effects varied according to pest identity. Consequently, it is hard to come up with universal recommendations for landscape-based pest control systems. That said, steps can be taken to improve crop management at the landscape level and to adapt crop protection practices by accounting for landscape risks.

Ecography
doi.org/10.1111/ecog.05433

Deciphered weevil genome can guide control efforts

The grain weevil (*Sitophilus oryzae*) is the number 1 insect threat to stored grain. At present, chemical insecticides are the main solution for limiting losses. However, they can result in chronic poisoning in consumers, provoke resistance in insects, and negatively impact the environment. A fine-scale analysis of the weevil's genome discovered the presence of many transposable elements (TEs)–mobile, repeated sequences–that have played a major role in the insect's evolution. The TEs are potentially associated with the presence of a symbiotic bacterium necessary to the weevil's survival. This research has numerous potential applications. For example, it can inform the development of new control methods targeting this symbiosis.

BMC Biology
doi.org/10.1186/s12915-021-01158-2

Reverse chemical ecology and machine learning can give rise to effective biocontrol

A safe and targeted control method is to disrupt the behaviour of insect pests by interfering with their olfactory perception. However, this technique requires a detailed understanding of the chemical attractants and repellents detected by the insect of interest, as well as the compounds' effects on its behaviour. A key challenge is that there are potentially an unlimited number of substances to test, and behavioural experiments are both time intensive and costly. A recent study in this field employed reverse chemical ecology, where researchers used olfactory proteins as guides towards

Two male palm weevils illustrating different adult colouration patterns.
©INRAE - D. Rochat

IN BRIEF

Tick peptide could help control Fusarium head blight in wheat

The tick is an infamous vector of pathogens such as the agents of Lyme disease. This arthropod is highly resistant, a trait that has allowed it to persist in many different environments. Essential to its immune system is a family of antimicrobial peptides called the defensins. One defensin has proven itself to be quite effective in inhibiting the growth of *Fusarium graminearum*, which produces mycotoxins and causes Fusarium head blight in wheat.

Scientific Reports
doi.org/10.1038/s41598-021-86904-w

odorant compounds that could interact with insect receptors. Scientists coupled this approach with machine learning and screened 800 natural odorants by examining the relationship between the molecules' structure and biological activity. Around 30 were selected, and their ability to affect pest behaviour was tested *in vivo*. This research demonstrates that *in silico* approaches can efficiently identify new useful odorants.

Cellular and Molecular Life Sciences
doi.org/10.1007/s00018-021-03919-2

Transcriptomics help reveal the life of plant fungal pathogen

Some fungi are plant pathogens that pose a threat to global food security. To design environmentally friendly control strategies, a detailed understanding of their biology and life cycle is essential. However, much remains unknown about the life cycles of fungal pathogens, which can be complicated to observe in nature. Furthermore, technical limitations make it difficult to reproduce life cycle complexities in the laboratory. Researchers performed random high-throughput RNA sequencing over the entire life cycle of the fungal pathogen *Leptosphaeria maculans*. They observed waves of gene expression as the fungus interacted with its host plant. This work is unparalleled in its scope. It gives rise to new possibilities for the control of plant diseases because this approach can be used to identify specific effectors at different stages of plant colonisation. These effectors could then be used when identifying new resistance genes that provide sustained protection.

BMC Biology
doi.org/10.1186/s12915-021-00989-3

Resistance gene is identified for septoria leaf blotch in wheat

Caused by the fungus *Zymoseptoria tritici*, septoria leaf blotch is among the top diseases affecting common wheat crops worldwide. In France, it causes annual losses of €350 to 700 M for the wheat industry. A resistance gene that provides protection against many *Zymoseptoria tritici* strains has now been identified and characterised by a consortium composed of researchers at INRAE, Wageningen University (Netherlands), and the US Department of Agriculture. This work was carried out in collaboration with the seed producer Florimond Desprez. Its results give rise to new wheat breeding possibilities.

Nature
doi.org/10.1038/s41467-020-20685-0

BOOK

Agroecological practices can draw on plant immunity

Plants have innate immune systems that protect them against diseases, pathogens, and parasites. However, the advent of agriculture created environments that favour the emergence of new diseases. Threats to plant health were then further amplified by the intensification of agricultural systems and the pervasive use of synthetic pesticides. This approach to farming is being called into question. It has become clear that agroecological approaches to crop protection are needed. To this end, researchers must describe the arsenal used by plants to defend themselves against pests. This information can be exploited to produce resistant varieties and reduce dependence on chemical plant protection products. Researchers from INRAE, CNRS, and CIRAD recently wrote a book about plant immunity and its potential use in agroecological systems. It explains basic concepts and uses case studies to comprehensively summarise important research in the biological and social sciences, including findings obtained via modelling.

Editions Quae
ISBN 978-2-7592-3233-8

Transitions in livestock farming

Cage-free farming can be facilitated by selection for egg-laying traits

To ease the transition to more poultry-friendly systems, farmers must have access to hens that can freely live their lives in large groups while also maintaining an efficient egg-laying rate. Researchers used "smart" nests to characterise the egg-laying patterns of more than 2,000 hens, which were raised cage free in large groups for 40 weeks. The digital nests continuously recorded a range of information that was, until now, impossible to measure for large groups of hens kept under such conditions. The results indicated that genetics influences the timing of egg laying. Studies are underway to identify the genes and genomic regions that are involved in trait expression.

Plos One
doi.org/10.1371/journal.pone.0251037

Biomarkers can help eliminate hormone treatments in young sows

In conventional pig farming, synthetic hormones are used to synchronise the cycles of sows being bred for the first time. Synchronisation is the cornerstone of batch management, which has many health and structural advantages. Indeed, it greatly simplifies breeding operations. However, hormone residues have been found in both meat and manure. They can have a negative effect on human health and the environment. Alternative approaches are therefore needed. A recent study examined sow metabolites and salivary steroids to identify nine potential biomarkers of sexual receptivity. This work is continuing with a view to further breaking down the results and expanding their applicability.

Animal
doi.org/10.1016/j.animal.2020.100095

Resilience of French organic farms is characterised

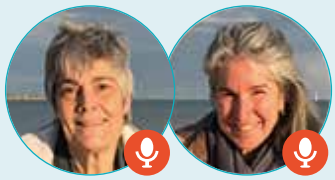
For the last 10 years, organic dairy farms have experienced favourable conditions, notably stable and profitable milk prices. Farms are currently facing a less certain future: production that is impacted by increasingly frequent extreme climatic events, market deregulation, and increased input costs, among other challenges. It is unclear how well farmers will be able to weather these difficulties. Researchers have developed a set of tools that utilise a generalised and interdisciplinary approach to analyse farm resilience from a combined qualitative and quantitative perspective. They found that resilience is rooted in several factors, including the adoption of more self-sufficient and cost-effective grazing systems, more balanced management of natural and human resources (e.g., equilibrium between surface area and herd size and/or between herd size and labour force), occurrence within a well-structured industry, or the ability to sell milk at stable and profitable prices. This research is novel because it took into account the perspectives of farmers, examined farm trajectories, and established

IN BRIEF

INRAE creates a joint technology unit dedicated to innovations for tropical agroecology-driven production systems

A new joint technology unit, ISATI, was created on January 1, 2022, thanks to the funding programme launched by the Ministry of Agriculture and Food in 2021. It is associated with INRAE (French West Indies-French Guiana Research Centre) and two technical institutes–IT2 for plants and ITEL for animals. ISATI seeks to jointly construct and evaluate different types of innovations. They may be biotechnical, such as foods generated from local resources, bioinputs, circular systems for managing biomass, or participatory breeding approaches. They can also be organisational, such as equitable supply chains linking farmers to consumers or forms of public policy support. ISATI functions like a Living Lab. It works with local stakeholders to facilitate transitions in agricultural and food systems. The greater objective is to promote food sovereignty and build resilience to climatic, public health, and economic crises.

Piglets.
©INRAE - G. Vasseur Delaitre



Tomorrow's livestock systems

A CONVERSATION WITH

Frédérique Pitel
Joint Research Unit for Genetics, Physiology, and Livestock Systems (GenPhySE)

Tatiana Zerjal
Joint Research Unit for Animal Genetics and Integrative Biology (GABI)

The GEroNIMO project is addressing the current challenges faced by livestock farming. What are they?
The demand for animal products is climbing because the human population is growing, economic conditions are improving in lower-income countries, and consumer preferences are changing. Genetic selection has been an extremely powerful tool. It has boosted the growth rate and feed efficiency of farmed species. However, this largely production-oriented strategy is confronting shifts in sociocultural values and has prompted concerns for the environment and animal welfare. We have reached the point where we must rethink our production systems: we must couple efficient production, sustainable resource use, and improved animal health and welfare.

Is your project aiming to further advance genetic selection approaches?
Selection has historically utilised variation in DNA. However, there is a complex relationship between the genome and its cumulative expression as traits, also known as the phenome. The phenome is also shaped by epigenetic mechanisms, which allow for rapid adaptive responses to environmental changes. Future selection approaches should incorporate this complexity. Indeed, in addition to this applied facet, GEroNIMO grew out of an intellectual, or even philosophical, interest in how environmental effects are transmitted across generations via epigenetics.

Several livestock industries have multiple needs. What traits and pathways are going to be prioritised?
Pork and poultry are the two main sources of animal protein consumed by the global human population. In both industries, there are often significant differences in the environmental conditions experienced by the populations under selection and the populations used in production, which can prompt lower yields. It would be useful to conduct research on large-scale epigenetic variability, especially that seen across different environments, to breed commercial livestock that are better adapted to local conditions. While maintaining high production levels, livestock farming systems must become more ethical by using resources responsibly, limiting their environmental impacts, preserving genetic diversity, and ensuring animal health and welfare.

Which stakeholders did you bring on board to guarantee project success?
Above all, the project's success depends on having a strongly unified team. GEroNIMO is the fruit of a collaboration with Sandrine Lagarrigue of Institut Agro. We designed the project together, and we are coordinating it together. From the very beginning, we sought to get multiple stakeholders involved. To this end, we organised transdisciplinary exchanges with a broad range of participants, namely producers, private breeders, non-profit organisations, and union representatives for the pork and poultry industries. We defined the major issues

> “We have reached the point where we must rethink our production systems: we must couple efficient production, sustainable resource use, and improved animal health and welfare.”

we wanted to address as a group—a group that also included our academic collaborators in the Netherlands and Sweden. Next, we broadened the consortium by bringing in partners from other European countries and other disciplines, notably the humanities and social sciences.

For more information
www.geronimo-h2020.eu

an explicit link between farm resilience and farm labour management.

Ecology and Society
doi.org/10.5751/ES-12583-260313
Agricultural System
doi.org/10.1016/j.agsy.2021.103082

Quality pig feed can be produced in an environmentally friendly way

Depending on location and processing methods, feed production can contribute to the negative environmental impacts of pig farming. INRAE performed research on pig feed in the 1980s and 90s that led to reduced levels of nitrogen and phosphorus in animal waste. However, more remains to be done. Researchers have identified and tested new environmentally friendly feed formulations by conducting life cycle analyses on ingredients and prioritising local production sites. The different feed types resulted in similar growth patterns, feed efficiency, and carcass characteristics (carcass yield, % lean meat in four main cuts).

Frontiers in Veterinary Sciences
doi.org/10.3389/fvets.2021.689012

Hybrid salmonid broodstock.
©INRAE - S. Kaushik

New method is developed to assess environmental impacts of aquaculture systems

Across the globe, aquaculture is becoming increasingly common. Questions have been raised about its environmental, economic, and social sustainability. From methodological and practical perspectives, it remains challenging to characterise the sustainability of agricultural and aquacultural systems. However, a European project has designed a multicriteria evaluation tool, DEXiAqua, specifically for aquaculture. DEXiAqua calculates indicators from established frameworks such as life cycle analysis and social life cycle analysis as well as indicators of technical and economic performance. When applied to data from a salmon farm, the tool demonstrated its ability to determine the strengths and weaknesses of system sustainability.

Sustainability
10.3390/su13147779

FOCUS

LiPh@SAS devotes itself to farm animal phenotyping

Livestock farming is transforming itself to adapt to global changes and social expectations for animal welfare. LiPh@SAS collects data and samples for research projects focused on transitions to more sustainable systems that espouse the principles of agroecology and ensure better conditions for animals. The facility has 10 experimental areas that host different types of animals, including cattle, small ruminants, pigs, and fish. Experiments range from fine-scale explorations of biological functions in small numbers of animals (vertical phenotyping) to non-invasive measurements made on large numbers of animals (horizontal phenotyping).

At **LiPh@SAS**, researchers can work with animals whose health, genetic background, and physiological status have been characterised in great detail. The animals have also been produced via commercial populations or using unique lineages that allow particular biological functions to be studied. Measurements are carried out under different rearing conditions with a view to accounting for interactions between animals and their environment. All research is designed and carried out with the greatest respect for animal welfare and animal welfare regulations.

The Ministry of Higher Education, Research, and Innovation has officially recognised LiPh@SAS as providing strategic infrastructure, and the facility is included in France's 2021 Research Infrastructures Roadmap.

https://www6.inrae.fr/liph4sas

Building higher-quality diets

Plant-based steaks.
©Adobestock

What nutritional effects are plant-based substitutes having on French diets?

Plant-based substitutes for animal products are booming. However, their nutritional quality has only been roughly evaluated in a piecemeal fashion. In a series of studies, researchers used survey data from French consumers in simulations to explore the effect of such products on dietary nutritional quality and deficiencies. It was found that the substitutes had highly variable effects that depended on product type (i.e., composition) and use (i.e., target of the substitution). Legume-based meat substitutes helped consumers meet nutritional requirements and did not increase the risk of deficiencies. Unfortified plant-based alternatives to dairy products increased the risk of iodine and, sometimes, calcium deficiencies. Work is ongoing to characterise the long-term health impacts of plant-based diets.

The Journal of Nutrition
doi.org/10.1093/jn/nxab146
British Journal of Nutrition
doi.org/10.1017/S0007114521002130

New approach is developed to study food nutritional quality

It is important to ensure that the elderly can access healthy diets. This population requires new foods that both are nutritionally sound and suited to their capabilities, which presents a particularly complex challenge. To find the right solutions, we need research on food processing mechanisms that examines the entire digestive process under controlled conditions. The elderly have specific oral and digestive capacities. They need foods with appropriate corresponding textures. Furthermore, a crucial objective remains developing food products that are both nutritious and functional. To this end, researchers conducted a study in which a protein-rich emulsion was utilised in a simulation that mimicked oral and digestive processing in elderly individuals; the fate of proteins in the stomach was also modelled. The result was a new approach, which was named the Food Oral and Digestive Process (FODP). This technique can be used to quantify the bioavailability of nutrients at any stage of digestion.

Food & Function
doi.org/10.1039/D1FO00969A

Healthy, sustainable, accessible, and satisfying food for all

Genetics helps rescue pea organoleptic quality

Pulses such as peas are gaining in popularity as ingredients in protein-rich plant-based food products. However, flours or protein isolates obtained from pea seeds have an unpleasant taste, which limits their use. Such results from the accumulation of several undesirable compounds, including saponins and triterpene glycosides, which can impart a bitter taste. Researchers exploited pea genetic variability and identified a lineage whose saponin content was reduced by more than 97%. At the same time, its nutritional quality (i.e., protein content) and physiological features (i.e., germination capacity) were maintained. Identifying such lineages is the first step in efforts to develop pea varieties better adapted to consumer tastes.

Plant Cell Physiology
doi.org/10.1093/pcp/pcab049

Ramrod pea variety.
©INRAE - J. Weber

IN BRIEF

Ideas are proposed for reducing food waste

The causes of consumer food waste and ways to reduce it were the focus of a study conducted by researchers at INRAE and the Technical University of Denmark. This work was commissioned by the United Nations Environment Programme (UNEP). The findings gave rise to detailed ideas for cutting down on food waste, whether using green technologies (e.g., biological and biochemical preservation methods, solar-powered cold storage) or digital technologies (e.g., mobile applications or product traceability).

UNEP DTU Partnership and United Nations Environment Programme (2021). Reducing Consumer Food Waste Using Green and Digital Technologies. Copenhagen and Nairo
ISBN 978-87-93458-06-2.

Read the report at
url.inrae.fr/3p6beEz

Sustainability of value-oriented industries is evaluated within Europe

As part of the European project Strength2Food: Food quality for sustainability and health, researchers in economics and sociology used a combination of quantitative and qualitative approaches to examine several value-oriented industries (i.e., organic agriculture and geographical labelling) and short supply chains. They found that the industries' economic and social performance exceeded those of their conventional equivalents. In contrast, environmental performance was similar. Consumers were much more likely to recognise national than European labels. When they recognised a label, they said that it influenced their purchasing decisions. On average, consumers were also more familiar with the «organic farming» label than the geographical labels.

The rhetorical analyses revealed that producers and consumers participated in short supply chains for three reasons: proximity, social and environmental values, and profitability (particularly for producers). Using an ethnographic analysis of consumer attitudes, it was found that price greatly influenced product choice. In contrast, labels had a limited effect on consumer discussions and dietary practices. Finally, it was more important that a food be produced locally than via a certified system.

Vegetables for sale at a market.
©INRAE - C. Maître

Ecological Economics
doi.org/10.1016/j.ecolecon.2021.107244
www.strength2food.eu/

BOOK

Agricultural and food systems co-exist and clash

Professionals and politicians have long debated how agricultural and food systems co-exist and conflict. However, this topic remains little studied. A book addressing the subject has been written by researchers from French and foreign institutions. Reviewing the current state of knowledge, the book analyses conflicting systems from four major perspectives: the friction between specialisation and diversification; innovations; adaptations; and transitions. It furnishes an original analytical rubric and explores 25 case studies that occurred in France and abroad. Its aim is to examine how governance works when multiple systems exist within regions. Overall, the authors' work can inform thinking on regional development.

Editions Quae
ISBN 978-2-7592-3242-0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Strategic priorities

Building bioeconomies based on the efficient circular use of resources

Diversifying bioresources and finding multiple new uses for them is necessary to sustainably meet food needs and produce materials, molecules and energy. We can do so by exploring the structures of living organisms in greater depth, developing new ways of promoting plant and animal by-products, and by improving processes for converting waste into energy. INRAE teams also study the conditions for the development of a sustainable circular bioeconomy.

Processing and uses of biomass, by-products, wastewater and organic residues

Exploring and mobilising fungal biodiversity to break down stubborn polymers

The fungal kingdom is estimated to contain between 2.2 and 3.8 million species, some of which have extraordinary biocatalytic potential in biomass. In particular, filamentous fungi that break down plant tissue have the unique ability to efficiently break down lignocellulose, a biopolymer notoriously resistant to biodegradation. Using a large-scale approach to phenotyping fungal strains, researchers were able to assess the growth and decomposition potential of five man-made industrial compounds and map the biotechnological potential of 1,000 strains from 78 different families. This work demonstrates the relevance of this type of unbiased screening to exploit the richness of phenotypic biodiversity catalogued and preserved in biological resource centres and identify the most relevant natural catalysts.

Communication Biology
doi.org/10.1038/s42003-021-02401-w
Industrial Crops and Products
doi.org/10.1016/j.indcrop.2021.113718

Compost. ©Pixabay

Anaerobic digestion: Nuclear Magnetic Resonance (NMR) coupled with chemometrics – a fast and reliable method to assess the gas production potential of organic waste

One important factor to consider in anaerobic digestion is the lipid content of organic waste. High lipid content increases the production of gas, but an excessive amount can also inhibit the process. The composition of organic waste, which is often heterogeneous and collected from different sources, needs to be analysed before it is re-used. Scientists have developed a new method based on NMR, a technique that uses a magnetic field and radio frequency to analyse the molecular composition of samples. The process is more accurate, faster, pollutes less than the current method used to measure lipid content in organic waste, and is a welcome improvement for the development of their re-use.

Waste Management
doi.org/10.1016/j.wasman.2021.11.013

FOCUS

Scientific facilities at their best: two sites winners of the EQUIPEX+ French Investments for the Future programme (PIA3)

ALADIN — Active learning to accelerate the development of biocatalysts for industrial biotechnology

Coordinated by INRAE, this multi-partner platform project (INRAE-INSA-CEA-CNRS) is based on combining genetics and artificial intelligence. It will enable the exploration of natural molecular diversity, its potential for building new catalysts (enzymes and microorganisms), and the rapid acquisition of knowledge needed to better understand biological systems. This national platform enhances France's contribution to IBISBA, Europe's Industrial Biotechnology Innovation and Synthetic Biology Accelerator (www.ibisba.eu)

MetEx+ - Metabolomics and fluxomics: from populations to single cells

Coordinated by INRAE, this facility draws on MetaboHUB know-how and partners (www.metabohub.fr). to develop tools for the interoperability, reuse and standardisation of data for large-scale metabolomics studies and for the contextualisation of biological data. It aims to better understand the complexity of metabolism in organisms by applying fluxomics to the study of an entire organism to improve our grasp of the actual dynamics of metabolism and biological integration.

These two facilities, which are open to scientific communities and companies, foster synergies between teams and between disciplines, and between public and private research.

From fruit skins to the genesis of new elastomer-based materials

A CONVERSATION WITH

Bénédicte Bakan

Biopolymers Interactions Assemblies (BIA) Research Unit

You study the processing of plant products for food and non-food purposes. What made you turn to fruit peel?
In my early research on fungal pathogens in cereals, and later on the reduction of water needed for barley malting, it became clear to me that a plant's first barrier to pathogens —and water— is its cuticle. This "plant skin" is a hydrophobic barrier that covers the aerial organs of plants, the (polymeric) structure of which we still know little about. The relationship between cuticle structure and the processing of plant products (fractionation, post-harvest preservation, etc.), for example, received no attention at all. Tomato cuticle is easy to isolate, which facilitates the combination of genetic techniques to modify its structure, and (bio)chemical and physical techniques to study its structure and properties. These methods were mobilised together at INRAE to make important progress on our understanding of the structure and growth of the cuticle, in particular the discovery of the enzyme responsible for the polymerisation of cutin, the major component of the cuticle, and the identification of the specific polysaccharide structures associated with this lipid polymer. In the course of our research, the cuticle emerged as a unique natural composite that can be used to develop new materials.

Has it been necessary to innovate biorefinery processes?
Yes, this is one of the advantages of being familiar with a raw material's structure. We first focused on the production of cutin monomers (hydroxylated fatty acids) from skins using a far more efficient saponification process than those used so far. This process is being industrialised via a project funded by ADEME and applied to the re-use of spent grain and apple pomace with the development of combined re-use solutions based on pectins, waxes and cutin monomers. These biorefinery processes have made it possible to produce novel hydroxylated fatty acids, which are present only in the cuticle of plants. These monomers can be used as plant defence stimulators and/or as synthons in the laboratory to generate new materials. Differing cutin monomer compositions in plant species will make it possible to diversify uses and formulations.

What is the next step for the genesis of new materials and their industrial applications?
I cannot emphasise enough that this work is a cross-disciplinary undertaking that includes a plant biochemist, a polymer specialist and a materials specialist: all skills which are available in the laboratory — a major asset for the project. We have imitated nature to create polyesters that resemble plant skin and are recyclable, using polycondensation and no need for catalysts. The addition of glycerol, an oil mill by-product, to form a copolyester of hydroxy fatty acids and glycerol has yielded elastomers with mechanical and surface properties that can be modified by the formulation or by the process. Other materials have been generated in a similar manner and findings are being published. We are currently working with companies and technical centres to identify applications for our research.

> “We have imitated nature to create polyesters that resemble plant skin.”

Frontiers in Plant Science
doi.org/10.3389/fpls.2021.782773.
Patent WO2020109729 (A1)
Industrial Crops and Products
doi.org/10.1016/j.indcrop.2021.113718

Bio-based products: new market opportunities and social dynamics

The INRAE station in Mirecourt. Grand Est-Nancy INRAE Centre.
©INRAE - E. Gaujour

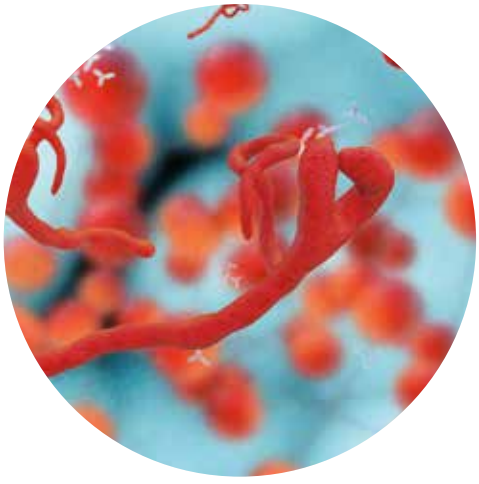
Understanding the links between the circular economy, agriculture and territory(ies)

In a context of growing climate challenges, the circular economy can provide solutions for minimizing as much as possible the use of non-renewable resources. Scientists published an overview of research on building local-level circularities in coordination with the agricultural sector. More specifically, this work focuses on how territories and the resources within them, their stakeholders and the institutional context influence the development of a circular economy and, conversely, how building circularities impacts territories. This overview appeared in a special edition of European Planning Studies.

European Planning Studies
doi.org/10.1080/09654313.2021.1973174

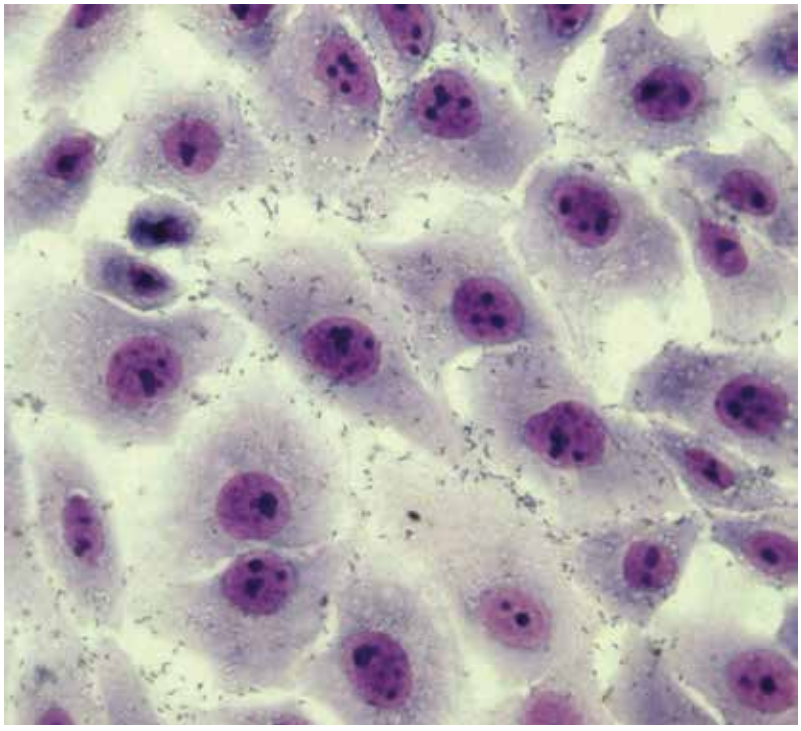
Strategic priorities

Promoting a holistic approach to health



Global warming and human activity pose numerous risks to plant, animal and human health and to the environment. The emergence of pathogens, chemical contaminants in the environment and food, and the impact of diets on health are just some of the challenges explored in research conducted at INRAE. Understanding the relationship between food, environment and health, for example, is key to efforts towards positive change in food systems and environmental protection.

Emergence and re-emergence of transmissible diseases within and between environmental, agricultural and food systems



Enterocyte cell line infected with *Listeria monocytogenes*.
©INRAE - P. Velge

Improving risk mapping for Ebola virus outbreaks in humans

Several questions remain unanswered about the outbreak, transmission and spread of this filovirus. In light of this, and with little epidemiological data available, it is difficult to predict which regions are most at risk of future Ebola outbreaks. Researchers used a spatialised multi-criteria assessment approach to combine different categories of data –climatic, environmental, anthropogenic and even ranges of animal species– potentially involved in the transmission of the virus. Doing so made it possible to more accurately map the risk of Ebola outbreaks in different parts of Africa.

PLOS Neglected Tropical Diseases
doi.org/10.1371/journal.pntd.0009683

How to better combat antibiotic resistance in Africa

According to international data, antibiotic use in livestock appears to be very limited in Africa. The prevalence of antibiotic resistance in foodborne pathogens found in animals and animal products, however, is significant, and attributed to an uncontrolled use of antibiotics. The authors of this study recommend the development of policies that take into account the specific challenges of smallholder and commercial livestock production in Africa and respond to the double challenge of simultaneously improving access to veterinary medicines while strengthening the regulation of their use.

Emerging Infectious Diseases
doi.org/10.3201/eid2710.210076

Advances in understanding the virulence of the foodborne bacterium that causes listeriosis

Listeriosis is a foodborne disease that can have serious consequences – meningitis or miscarriage, for example – in immunocompromised, elderly or pregnant people. The most serious listeriosis epidemics in humans are linked to certain particularly virulent strains of the bacterium *Listeria monocytogenes*. Scientists identified an ability in these strains to modulate the composition of the intestinal microbiota by weakening the membrane of certain bacterial species with which they come into contact, and therefore endure less competition from other bacteria. As a result, they infect the intestine more effectively, followed by deep organs such as the liver or the spleen and finally the brain or the placenta.

The Proceedings of the National Academy of Sciences
doi.org/10.1073/pnas.2108155118

Bacterial viruses, allies against antibiotic resistance

An increasing number of bacteria are becoming resistant to antibiotics, a phenomenon most often explained by the massive and inappropriate use of the latter. Another hypothesis has emerged in the last decade involving the role of bacteria viruses –bacteriophages– in the transmission of antibiotic resistance genes.

This controversial hypothesis compelled a team of INRAE researchers specialised in bacteriophages to carry out metagenomic research, (analysis of the whole gene pool), on bacteriophages from 14 pig farms. The bacteriophages studied do not possess a single antibiotic resistance gene. Bacteriophages therefore retain their status as allies in the fight against antibiotic-resistant bacteria, via phage therapy.

ISME Communications
doi.org/10.1038/s43705-021-00054-8

Tick microbiota involved in carrying and transmitting pathogens

Ticks are the primary vectors of human and animal disease in Europe. In addition to pathogens, ticks carry other microorganisms which form their microbiota. Researchers used high-throughput sequencing to analyse the microbiota of 557 ticks. Using special statistical analyses, they identified interactions between microbiota components and pathogens. Results indicate that the structure and composition of tick microbiota change over time. They also show that several members of the tick microbiota promote or prevent the presence of pathogens in ticks. This study paves the way for the development of control strategies and the biological control of ticks.

Microbiome
doi.org/10.1186/s40168-021-01051-8

Identification of pathways for SARS-CoV-2 entry into cells: towards new therapeutic strategies

Treatments to limit the spread of SARS-CoV-2, the virus behind the COVID-19 pandemic, should ideally target the early stages of infection, before the virus penetrates cells. Building on studies of MERS-CoV, another coronavirus identified in 2012, responsible for Middle East Respiratory Syndrome, a research team studied SARS-CoV-2 infection in different cell types to identify the virus's entry pathway(s). During testing, scientists observed that certain cells were infected very quickly –in less than 10 minutes– while others were infected in about 50. This difference stems from the presence of a specific protease on the surface of cells infected via the 'fast-route' pathway. Without the protease, the virus follows another route through the endolysosomal pathway via small vesicles. This study offers new perspectives for developing therapeutic strategies to target these two pathways of SARS-CoV-2.

EMBO Journal
doi.org/10.15252/embj.2021107821

Adult-sized ticks suspended in a gel tube in the CiTIQUE project laboratory.
©INRAE - B. Nicolas

IN BRIEF

The French National Forest Ownership Centre (CNPF) joins forces with INRAE for the CiTIQUE programme

As forestry professionals working outdoors, CNPF employees are regularly exposed to the risk of tick bites. This purpose of this partnership is to generate large quantities of data which INRAE researchers and other partner labs in the CiTIQUE participatory research programme can use in order to deepen their understanding of tick ecology and develop risk models. This joint endeavour will consolidate the CNPF's prevention policy for employees exposed to the risk of tick-borne diseases.

Development of alternative approaches to animal testing

In the context of infectious diseases, there is an urgent need for appropriate models to better predict the pathogenicity of (re) emerging animal pathogens (viruses, bacteria, parasites, and combinations of these) that are likely to cross from one species to another, including humans (zoonosis), and to screen for new therapeutic approaches. Furthermore, from an ethical and social point of view, the development of alternatives to animal experimentation is now a necessity. The recent development of 'organoids', a new type of three-dimensional *in vitro* model based on the plasticity of embryonic or adult stem cells, may compensate for the current lack of pertinent and effective *in vitro* lung models. These models mimic respiratory tissue functions and make it possible to study how complex, 3D reconstructed tissue responds to a physiological change such as stress or infection.

Veterinary Research
doi.org/10.1186/s13567-021-00946-6

FOCUS

A nasal vaccine against COVID-19

In 2020, the BioMAP team of the INRAE/University of Tours Infectiology and Public Health (ISP) Joint Research Unit, a member of the Institut Carnot's France Futur Elevage programme, launched the development of a nasal vaccine against the SARS-CoV-2 virus. Nasal vaccines are believed to prevent the presence of the virus in the nose —the initial stage of infection— by inducing immunity in the nasal mucosa, which is the entry point and multiplication site of the virus, which is not the case for intra-muscular vaccines.

This SARS-CoV-2 protein-based candidate vaccine builds on the BioMAP team's expertise in mucosal vaccine design. In partnership with the biotech company Vaxinano, the team has already successively developed an effective candidate vaccine to protect monkeys from toxoplasmosis. The vaccine, consisting of the Spike protein and non-mutated viral proteins, is thought to better ensure stable protection regardless of viral mutations and the coronavirus strain in circulation. Pre-clinical lab tests demonstrated the efficacy of the candidate vaccine after two nasal immunisations spaced three weeks apart, both in terms of immune response and early neutralisation of the original virus.

LoValTech, a start-up with Deeptech certification from BPI France, was created recently to accelerate the development of the vaccine project. The purpose of the start-up is to pilot the project from the development phases of vaccine formulation through to human clinical trials. The project is supported by the ANRS/ Maladies infectieuses émergentes, the ANR, the INRAE Val de Loire Centre and several industrial partners.

Find out more
url.inrae.fr/33xA1L2

Pollution, contaminants and the exposome

Pesticide exposure in vegetarian diets

Vegetarian diets are becoming increasingly popular. However, while the nutritional profiles of people who eat a plant-based diet are well documented, less is known about exposure to pesticide residues. Furthermore, the consumption of plant-based products is correlated with the consumption of organic products. Levels of exposure to 25 natural and synthetic pesticides via plant-based foods were studied in omnivorous, pesco-vegetarian, vegetarian and vegan individuals taking part in the NutriNet-Santé study. The research took into account the organic valence of the diet. In general, individuals on vegetarian diets were less exposed to pesticides overall than those in other groups. Food produced using conventional methods accounted for most exposure to the different pesticides, with the exception of the three pesticides allowed in organic farming. Eating large quantities of organic food could therefore be a way to reduce exposure to synthetic pesticides, especially in individuals following vegetarian diets.

Food and Chemical Toxicology
doi.org/10.1016/j.fct.2021.112179

Monitoring of water pollution assisted by sentinel species adapted to the risk studied

Many pollutants in water are found to be endocrine disruptors. They can alter the balance of lipid composition in the cells of aquatic species such as the gammarus (*Gammarus fossarum*), a family of crustaceans considered to be a good bioindicator of water quality. A complete characterisation of all the lipids and their spatial distribution was carried out in this species to ascertain the mechanisms of toxicity induced by pollutants. It provided a deeper understanding of biochemical changes during growth in *Gammarus fossarum*. These results serve as a reference for future ecotoxicology studies.

iScience
doi.org/10.1016/j.isci.2021.102115

Evaluating the potential transfer of pesticides to the atmosphere

Air contamination by pesticides is monitored locally on a more or less regular basis, but science is still unable to identify the main transfer route of pesticides to the atmosphere. During crop treatment, a portion of applied pesticides can reach the atmosphere through sprayer drift, post-

Insecticide spraying in a conventional fruit orchard.
©INRAE - J.C. Bouvier

application volatilization from the soil and/or plants and wind erosion. Post-application volatisation is thought to effect up to a double-digit percentage of the initial dose of certain compounds. Researchers mobilised the molecular properties of pesticides to explore the volatilization potential of 178 such products. This study made it possible to differentiate between pesticides observed in the air and those that were not. Such an approach can be used to make an initial estimate of the risk of air contamination by pesticides and contribute to the protection of the environment and human health.

Journal of Hazardous Materials
doi.org/10.1016/j.jhazmat.2021.125613

IN BRIEF

Creation of an associated partnership laboratory (LPA) to develop innovative solutions for the monitoring of water quality

INRAE and ViewPoint have launched an associated partnership laboratory (LPA) to monitor toxic discharge in water. Named ViewTox, this four-year LPA will enable INRAE and the French company ViewPoint to expand efforts to develop an innovative video analysis system to study the behaviour of aquatic invertebrates sensitive to a variety of chemical substances released into the environment.

Preventive nutrition for public and environmental health

A blood biomarker to assess the risk of visual impairment caused by AMD

Age-related macular degeneration (AMD) is the leading cause of vision loss in Western countries, with nearly 20 million people affected in Europe in 2020. Only certain forms of the disease are receptive to treatment, which only slows its progression. One risk factor is a deficiency in Omega-3 fatty acids, a condition that was previously impossible to measure. By analysing retinas and blood from 46 human donors, scientists were able to identify a blood biomarker that predicts retinal levels of Omega-3 fatty acids. Thanks to this biomarker, at-risk individuals can receive dietary support.

Clinical and Translational Medicine
doi.org/10.1002/ctm2.404

Close-up of an eye.
©Pixabay

The impact of maternal nutrition on the eating behaviours of offspring

A CONVERSATION WITH

Patricia Parnet

Physiopathology of Nutritional Adaptations
Joint Research Unit (PhAN)

The PhAN unit studies the impact of maternal nutrition in the foetal and neonatal stages of life. What subjects has your research focused on in recent years?
Research at the PhAN unit is based on the "Developmental Origins of Health and Disease (DOHAD)". This concept was developed in the 1980s by an English epidemiologist named David Barker, who used retrospective cohorts to demonstrate that individuals born with a low birth weight had a greater risk of contracting a chronic disease in adulthood. Rapid postnatal growth increased this risk. The hypothesis is that maternal malnutrition —and consequently foetal malnutrition— at key periods of intrauterine development could result in the necessary metabolic adaptation of the foetus but cause chronic disease in adulthood. A large amount of research has led to a concept commonly known as the critical 1,000-day period, which runs from conception to the child's second birthday.
I was particularly interested in the consequences of under-nutrition on the processes underpinning eating behaviours in children. We have shown that in rodents, impaired prenatal nutrition, followed by increased postnatal growth, causes excessive food intake in offspring that predisposes them to obesity.

> “This project identified maternal microbiota as a communication/ transmission channel between the mother and her offspring.”

What hypotheses guide your current work?
Part of the unit also studies the effects of perinatal malnutrition on gut-brain axis function, based on the idea that maternal gut microbiota could be an early determinant of newborn health. In collaboration with our colleagues from the MICALIS Joint Research Unit and MetaGenoPolis, we used a rodent model to test vertical transmission to newborn rats of another strain of intestinal, vaginal and milk microbiota from mothers with or without a genetic predisposition to obesity and fed a hyperenergetic diet. Consistent with our hypothesis, the transfer of these microbiota permanently altered their feeding behaviour, with a higher risk of overconsumption of milk or food at different periods of their lives for those who received the obese rat inocula. This project identified maternal microbiota as a communication/ transmission channel between the mother and her offspring and identified potentially predictive biomarkers of altered feeding behaviour. We need to learn more about how the microbiota affects feeding behaviour in offspring by studying its impact on the neurodevelopment of brain structures.

Did you identify other issues to explore in relation to maternal nutrition?
One interesting avenue would be to work on the impact of new diets such as vegetarianism and veganism on maternal nutritional intake during pregnancy and breastfeeding: are they all adequate for correct *in utero* and postnatal growth and psychocognitive development?
I would like to point out that a cross-disciplinary approach is essential for all the studies mentioned here: initial results are derived from epidemiological studies, but many hypotheses still need to be confirmed on a biological level. It is also fundamental to study the individual as a whole and consider the psychological relationship between mother and child, which may be altered by the mother's economic, social and health circumstances.

Frontiers in Microbiology (2021)
doi.org/10.3389/fmicb.2021.672224
Hal
inrae.fr/hal-03271317

Discovery of a biological signature to assist in the diagnosis of metabolic syndrome

Metabolic syndrome, a cluster of conditions that occur together, affects 20% of the population in France. Because differences in how it presents make the disease difficult to identify, it is crucial to develop tools that facilitate diagnosis. Using the national MetaboHUB infrastructure, teams of French and Canadian scientists were able to identify a unique signature of 26 metabolites sufficiently robust for future diagnosis. Similarly, links were found between diet, gut microbiota, metabolic signature and diagnosis of the syndrome. Further research is needed to establish a simplified procedure for the inclusion of this approach in routine diagnosis.

eBioMedecine
doi.org/10.1016/j.ebiom.2021.103440

A healthy diet (illustration).
©Adobestock

IN BRIEF

A new European project to coordinate research on the human microbiome

The European Human Microbiome Action project, launched on 1 May 2021 and coordinated by INRAE, brings together 17 partners from 9 countries to coordinate, structure and stimulate research and knowledge transfer in the field of the microbiome. The project will cover all the phases involved in developing new prospects for human microbial nutrition and health management.

humanmicrobiomeaction.eu

FOCUS

CALIS: a research infrastructure to meet the challenges of guaranteeing access for all to a healthy and sustainable diet

Food is a major public policy concern and presents major economic, public health and environmental challenges. It has become crucial to federate technological capabilities in the scientific community in the fields of nutrition, dietetics, food science and diet, in relationship to health. The CALIS infrastructure proposed by INRAE and its partners will enable the development of integrated and multi-scale approaches, including food design, assessment of its impacts on health, the conditions in which consumers adopt foods, and the assessment of environmental impact.

The infrastructure's three divisions —Consumer, Food and Health— offer French public and private stakeholders a cross-disciplinary, original and unique offer across the value chain.
CALIS brings together 29 French institutions including research organisations, a national agency, universities, engineering schools and hospitals. The infrastructure is part of the 2021 national infrastructure roadmap of the Ministry of Higher Education, Research and Innovation.

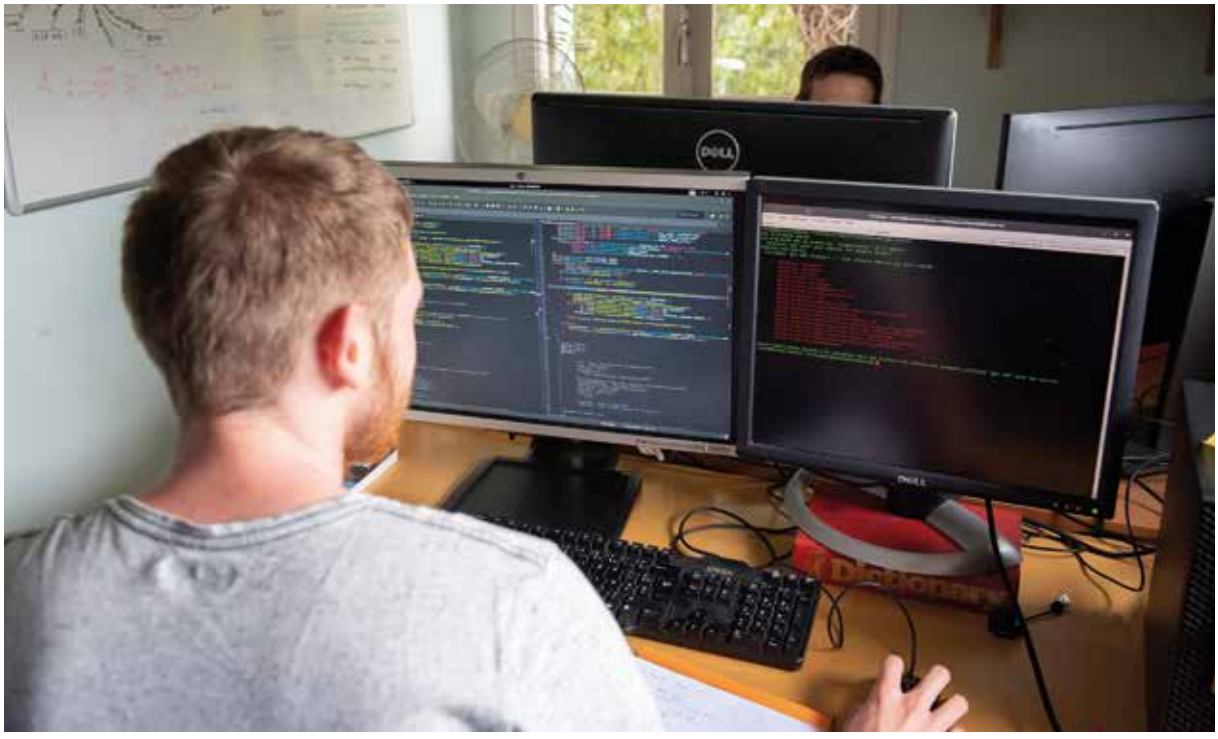
url.inrae.fr/3kc8iEm

Strategic priorities

Facilitating transitions by mobilising data sciences and digital technologies

Scientific, technological and methodological progress, made possible by the development of digital science and technologies, is driving new ways to explore the complexity of biological systems and ecosystems at different scales and predict the behaviour of living organisms. The growing intersection of experimental science and artificial intelligence offers numerous opportunities for new applications, for example in animal health monitoring and the optimisation of food processing.

Complex and evolving systems



Big data. Software development and information systems. Occitanie-Montpellier Centre.
©INRAE - C. Maître

Whole-cell simulation of biological processes

In predictive biology, specific tools are needed for the effective simulation of a cell's biological processes. It is currently impossible to simulate molecular events due to the computation time required. Detailed whole-cell modelling requires the integration of heterogeneous cell processes with different modelling formalisms. Under a partnership between INRAE and INRIA, teams developed BiPSim, an open-source stochastic simulator for the efficient simulation of certain cell processes. Designed to be generic for easy adaptation to different types of cells, BiPSim makes stochastic simulation of cell processes accessible to the biological community and enables the comparison of simulations and heterogeneous single-cell omic data.

Scientific Reports
doi.org/10.1038/s41598-021-92833-5

Using artificial intelligence (AI) for animal health

Animal health research increasingly mobilises artificial intelligence. This interface opens new doors in animal health science, removes methodological barriers and enables a better response to future challenges in agriculture. Recent existing results and prospects identified by researchers in this field reveal the diversity of potential applications in animal health. AI assists in the diagnosis and detection of diseases; in increasing the reliability of predictions and reducing errors of interpretation; in producing more realistic models of biological systems; in making computer code more readable; in speeding up decision-making and improving risk assessment accuracy, and, lastly, in targeting interventions and anticipating possible side effects. This assessment was carried out in the framework of a bibliometric study of 110 international publications and a survey of concerned

Interdisciplinary research for responsible digital agriculture

A CONVERSATION WITH

Isabelle Piot-Lepetit

Scientific Director #DigitAg

What were the main reasons for creating #DigitAg?
The Digital Agriculture Convergence Lab #DigitAg was created in late 2016 to coordinate the development of responsible digital agriculture in France and the South, by supporting interdisciplinary research projects and initiatives in higher education and innovation. Five years on, #DigitAg has 738 members, including 60 PhD students, and 548 students enrolled in its graduate school. It promotes innovation through its digital showcase, the organisation of hackathons and more.

What is your assessment of the first years in activity?
#DigitAg brings together three scientific communities: engineering sciences, life sciences and the humanities/social sciences. Research conducted at #DigitAg addresses two major social challenges: improving production and the social integration of agriculture. #DigitAg supports the development of research that reflects the scientific excellence of the communities working in the lab, as well as the implementation of interdisciplinary research within and between these communities. #DigitAg activities are based on proposals for theses, post-doctorates and master's programme internships, as well as international mobility schemes, scientific events, workshops, the development of pilot studies, etc. Since its launch, #DigitAg has provided financial support for 181 projects. Between 2017—2020, the number of interdisciplinary projects combining two or three #DigitAg disciplines increased from 60% to 92%. Some 70% of these projects addressed the issue of improving production while the other 30% addressed the issue of social integration of agriculture. Interdisciplinarity at #DigitAg is not only reflected in its research projects, it is also part of its governance. Over time, the humanities and social sciences community at #DigitAg has been strongly mobilised in the area of digital agriculture, with a special focus on responsible research and innovation that meets the expectations of all stakeholders. #DigitAg has also benefited from partnerships with the South to further its reflection on the energy efficiency of the digital solutions proposed.

What do you see in the future in terms of partnerships or focus areas?
#DigitAg's standing has resulted in new researchers joining the adventure who are not members of the lab's founding institutions and units. An associate researcher position was created in 2019, and a partner researcher position in 2020. The establishment of the OccitANum Living Lab (2020-2027) has allowed the inclusion of farmers and their partners in the development of digital solutions tested in real conditions. #DigitAg is involved in several Horizon Europe projects, which strengthens its position at the European level. Among the founding members of #DigitAg, eight are private-sector companies. Private stakeholders who wished to join the lab after its creation are members of the AgroTIC business chair programme,

> “Over time, the humanities and social sciences community at #DigitAg has been strongly mobilised in the area of digital agriculture.”

in which #DigitAg plays an active role. In the longer term, #DigitAg aims to expand interdisciplinary research on responsible digital agriculture at a participatory and international level and with a focus on the development of sustainable food systems. This holistic project, which connects the three fields of science at #DigitAg, would enable new partnerships with scientists working on this issue in Europe and internationally, and the incorporation of other private stakeholders, thus strengthening the interdisciplinary nature of the research carried out.

For more information
www.hdigitag.fr/fr/

INRAE teams, to identify progress along with existing methodological hurdles and future challenges.

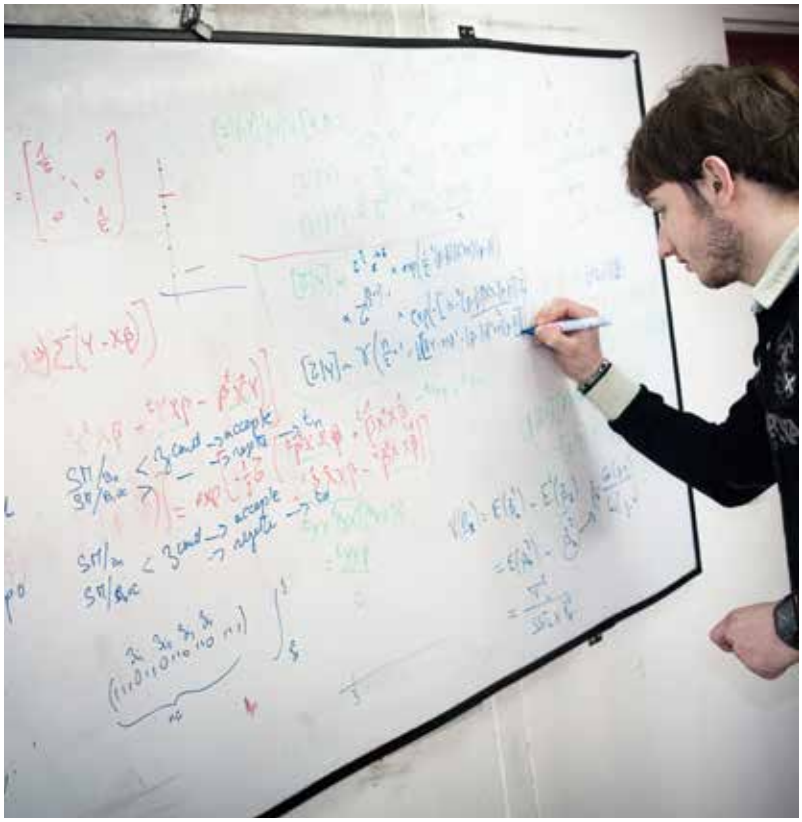
One recent study explored an example of AI applied to the analysis of farm animal behaviour with the aim of improving their welfare.

Veterinary Research
doi.org/10.1186/s13567-021-00902-4
Frontiers in Animal Sciences
doi.org/10.3389/fanim.2021.784376
Biosystems Engineering
doi.org/10.1016/j.biosystemseng.2021.09.014

Optimising food processing

Optimisation in food processing is a complex task made difficult by a lack of knowledge about processing limitations, and by the complexity of models and the food products themselves. To overcome these difficulties, researchers developed an original approach that combines multi-objective optimisation and knowledge integration: two distinct sub-fields of artificial intelligence. Scientists took the example of the optimisation of skimmed milk microfiltration, a process used to separate the two main proteins in milk. The results obtained offer new perspectives for the optimisation of food processing, for which a lack of scientific knowledge and data prevents the modelling of processing mechanisms and their subsequent improvement.

Food and Bioproducts Processing
doi.org/10.1016/j.fbp.2020.09.002



IN BRIEF/PARTNERSHIP

INRAE and SABI AGRI create the TIARA joint laboratory to design tomorrow's robotic farming equipment

Robotics is increasingly seen as a lever in the ecological transition of agriculture that also reduces physical drudgery. The TIARA joint laboratory will act as a sector-wide accelerator, proposing equipment with adjustable levels of autonomy and shared decision-making capabilities, in order to meet farmers' expectations. The joint laboratory is founded on the basis of SABI AGRI's combined expertise in agricultural land and electric farm equipment towing chains, together with the expertise of INRAE's agricultural robotics research team.

Whiteboard at the Joint Research Unit for Applied Mathematics and Informatics (MIAT), composed of statisticians and computer scientists specialised in statistical and computer modelling for biology.
©INRAE - B. Nicolas

Open Science

INRAE has long been committed to open science. The Institute continues to re-shape its activities and published a bold and ambitious open science policy in 2021 together with a multi-dimensional action plan.

INRAE: a pioneering institute for open access to publications and data

Open access publishing is making great strides. With a target of 100% by 2030, INRAE reported an open-source publication rate of 76.5% in its 2021 open science barometer, compared to the national average of 62%. The commitment is also evident in the case of INRAE-published journals. For example, since 1 January 2022, Annals of Forest Science now publishes all its articles in open access on BioMed Central, and the contracts of Springer-published journals have all set a target of 100% open access publication by 2024.

76.5 %
of publications in open access format

Making science available also means making data available for transparent and replicable results. This is an issue that INRAE has been addressing for several years, leading the Institute in 2018 to establish Data INRAE, a self-produced open data repository. Recognising this expertise, the Ministry of Higher Education, Research and Innovation (MESRI) has entrusted INRAE with the development of a national catalogue and repository of French research data as part of the implementation of the national platform for the deposit and sharing of research data, Recherche Data Gouv.

→ projet-recherchedatagv.ouvrirlascience.fr/

> “As a driving force in both the opening of research processes and results (publications, data, code, etc.), INRAE applies the principle of opening all that can be opened and closing all that must be closed.”

Odile Hologne
Director of the INRAE Directorate for Open Science (DipSO)

Strengthening participatory research

At INRAE, the term 'participatory science and research' covers a broad spectrum of practices, ranging from massive data collection from volunteers (crowdsourcing) to more intensive participatory approaches involving non-academic partners in multiple stages of the research process. "The common denominator of these approaches is that they generate a society-wide interest in how research works, in a variety of ways. Inversely, they also help connect researchers to the questions posed by society," says Christophe Roturier, Head of Science in Society at INRAE.

In 2021, under the aegis of the Ministry of Higher Education, Research and Innovation, INRAE established the Prize for Participatory Research. Open to all Agreenium members the first year[1], the prize was awarded to two projects. The Crowdsourcing prize was awarded to CiTIQUE, a research programme on ticks with and for citizens, led by a collective of academic and community actors. The Participatory Prize was awarded to the *Semences à l'assiette* programme which, for 20 years, has carried out collaborative projects, from the participatory selection of cereal varieties for organic farming and innovative cropping systems to the development of collective sectors and food-centred 'third-places' that promote biodiversity. The 2022 edition will be open to the entire French scientific community.

INRAE provides support to staff who wish to engage in participatory research or improve their practices, in the form of training courses (at research schools) and a support system –Dia-pause– which organises two-day events with non-academic partners to review current practices and how they can be improved. In addition, *NOV'AE*[2] published a special edition at the end of 2021 on participatory science and research.

A citizen science research internship at the CiTIQUE participatory platform. ©INRAE - B. Nicolas

Information analysis to support scientific strategy

In scientific strategy, it is essential to identify new challenges, emerging subjects and those requiring further study, and to position one's research within the scientific ecosystem and assess the positioning of others.

INRAE has therefore developed new and promising tools in this field. eVeille, our strategic intelligence intranet portal, was launched in July 2021 to inventory existing intelligence at INRAE, provide tools for developing and understanding strategic intelligence, and to federate a culture of scientific foresight within the Institute.

Since April 2021, bibliometric studies have been conducted on five different priority research programme subjects with the goal of building a vision of the state of the art and the positioning of the French scientific community, and of identifying new frontiers in each focus area.

1 Members of Agreenium: INRAE, CIRAD, AgroParisTech, Bordeaux Sciences Agro, Université de Lorraine-ENSAIA, Toulouse INP-ENSAT, ENSFEA, Université de Lorraine-ENSTIB, ENVT, Institut Agro (Dijon, Rennes-Angers, Montpellier), Oniris, VetAgro Sup.

2 *NOV'AE* NOV'AE is an online journal for INRAE staff that replaces the *Cahiers techniques de l'INRA*.

Partnerships and impacts

Larch wood section.
©INRAE - R. Canta

Strengthen scientific partnerships in France, Europe and the world

“To tackle the challenges of global change and the necessary transitions within food and environmental systems, INRAE has a robust policy of cooperation with research and higher education institutions. Its activities include creating regional divisions of major national university partnerships and working on projects with a European and international scope.

This approach to international cooperation has enabled INRAE to drive a global impetus in 2021 on several major challenges on the international agenda: biodiversity, global health, climate, natural resources, soil and water, and food systems. The Institute has laid the foundations for large-scale scientific initiatives in Africa and the Mediterranean with the French Agricultural Research Centre for International Development (CIRAD), the Institut de recherche pour le développement (IRD), several French higher education partners and partners from different regions of the world.
In addition, several key partnerships have reached new milestones with world-renowned partners.”

Jean-François Soussana
Vice President of International Policy

Higher education and site policy

A new action plan for higher education and training

In 2021, the Institute rolled out a new action plan for higher education and training for 2022-2025. In line with the INRAE2030 strategy, the new plan reinforces INRAE's role at major university sites as a driving force in a rapidly changing ecosystem, via its Joint Research Units and site agreements. The plan aims to improve the funding, hosting, training and mobility of doctoral students and to expand initiatives to agricultural high schools, sector professionals and, more broadly, the 'learning society'. It encourages the involvement of scientists in higher education, at the master's, engineering and doctoral levels, and in hosting students and trainees in its units.

> "Higher education and training are major challenges for INRAE in view of the necessary transitions."

Cyril Kao
Director of Academic Partnerships, Regional and European Affairs

Key figures

2,000
Approximately 2,000 doctoral students conduct their research at INRAE units; 30% are on contract with the Institute.

30
INRAE is active at over 30 university sites..

As part of the French Investments for the Future programme, INRAE is involved in 5 IdEx[1], 5 I-Site[2], 9 EUR[3], 11 SFRI[4] and 5 Excellence projects (first round).

(1) IdEx: Initiatives for excellence
(2) I-Site: Initiatives for Science, Innovation, Territories and Economy
(3) EUR: University research schools
(4) SFRI: Structuring training through research in initiatives for excellence

IN BRIEF

INRAE signs a strategic agreement with the MUSE I-SITE

At the New Africa-France Summit organised on 8 October in Montpellier, INRAE, the Institut Agro and 13 other partners signed a strategic alliance agreement with the *Université de Montpellier* for the MUSE I-site. This agreement firms up the commitment to work together to protect the environment, food security and human health.

INRAE strengthens its participation in site strategies

INRAE provided support for five of the 15 projects selected in the first call for proposals of the PIA4 ExcellenceS programme. These projects consolidate the strategic priorities set by several university sites:

Université de Bordeaux
Innovation
A distinctive culture, agile practices and space for innovative and high-potential opportunities

Université Paris-Saclay
Springboard
A springboard for the long-term attractivity of Université Paris-Saclay

Université de Montpellier
ExposUM
Human health in our environment

Université de Pau
Irekia
The Basque country open campus project

Université Bourgogne-Franche-Comté
Harmi
Harnessing microbiomes for sustainable development

Europe

INRAE and European framework programmes

A review of Horizon 2020, the European Union's research and innovation funding programme, ranks INRAE as the fourth largest recipient of funding in France, with €140 million provided over seven years for 313 projects, 55 of which are coordinated by INRAE. The vast majority of these projects (122) fell under the programme's Societal Challenge 2: Food security, sustainable agriculture and forestry, marine, maritime and inland water research and the bioeconomy.
INRAE had an overall success rate of 18%, higher than the French average (15%) and that of the programme as a whole (12%).
The European Green Deal, the last call for proposal, which introduced the key themes of the new Horizon Europe programme, qualified 17 INRAE projects in January 2021, including one coordinated by INRAE.
INRAE has been mobilised since the start of this new programme with a budget of €95.5 billion for the next seven years. In 2021, the Institute submitted 190 projects, including 15 which it coordinated, mainly in Cluster 6: food, bioeconomy, natural resources, agriculture and environment.

> "2021 is a pivotal year for our increasingly active and successful European policy."

Isabelle Albouy
Deputy Director of European Affairs

INRAE results in the H2020 programme (2014-2020)

Global	Challenge 2
€140 million	€69 million
313 projects including 55 in coordination	122 projects including 34 in coordination

IN BRIEF

An INRAE representative in Brussels
INRAE has strengthened its presence in European institutional networks with the appointment of a new representative, Bénédicte Blaudeau, based at the Maison Irène et Frédéric Joliot-Curie.

Funding to boost biology
The European Research Council (ERC) programme funds exploratory research based on scientific excellence. Four grants were awarded in 2021: Two ERC Consolidator Grants in plant biology and microbiology to researchers at the Institute of Plant Sciences of Paris-Saclay and the Micalis Institute; and two ERC Starting Grants to Claudia Bartoli and Kalina Haas, two young researchers in ecology and evolution and cell biology.

Bioeconomy reaches for the stars
Every year, Stars of Europe prizes are awarded by the Ministry of Higher Education, Research and Innovation in recognition of the commitment of French researchers to Europe. On 2 December 2021, two projects coordinated by INRAE were honoured: Zelcor received the special jury prize, and NoAW the open science prize. These projects work to re-use agricultural and food waste by leveraging circular economy and bioeconomy approaches.

INRAE and the University of Bologna strengthen their collaboration
Building on joint research at the European and international level since 2015, on 15 April the two research institutions renewed their cooperation agreement in the fields of sustainable agriculture, food and the bioeconomy for a further six years.

International

International partnerships have been strengthened

Renewal of key partnerships with:

- the Belmont Forum on environmental change and sustainability,
- the Chinese Academy of Agricultural Sciences,
- the National Agriculture and Food Research Organization (NARO) in Japan,
- CGIAR, a consortium of international agricultural research centres, together with CIRAD and IRD, for the France-CGIAR action plan on nutrition and food systems, climate change and agroecology,
- and a new agreement with the World Meteorological Organization (WMO).

Two major projects involving international and national partners:

- The MACLIFE International Associated Laboratory (LIA), with the University of California Berkeley, the Universidad del País Vasco in Spain and the Université de Pau in France. This LIA aims to better understand and anticipate the impact of climate change on aquatic biodiversity.
- The Galactinnov International Research Network (2RI), with the Université de Montreal, Université Laval, University of Sherbrooke and McGill University in Canada, and the Institut Agro, National Veterinary School of Toulouse (ENVT) and the University of Tours in France. This 2RI focuses on the theme of milk and dairy product quality and the health and welfare of the dairy cow.

INRAE promoted key messages at major international events

- The prevention of emerging zoonotic diseases and nature-based solutions by supporting biodiversity in the management of agricultural land and forest at the International Union for Conservation of Nature (IUCN) World Conservation Congress in Marseille (September 2021).

2020 IUCN World Conservation Congress.
©D. Carles / Terra

- Agriculture, Forestry and Other Land Use (AFOLU) solutions in the pursuit of global carbon neutrality at the Glasgow Climate Change Conference (COP26) (October-November 2021).

- A global and integrated approach to building sustainable and resilient food systems in the preparation of the first **UN Food Systems Summit,** in which participated Jean-François Soussana, climatologist and Vice President of international policy at INRAE. INRAE also produced a report on **the Royaumont Process** (hal.inrae.fr/hal-03167966/document), in addition to scientific events organised beforehand with various international academic partners, including UC Davis in California, the University of Pretoria and the Australian Centre for International Agricultural Research. Contributions to the UN summit are ongoing via INRAE's involvement in the two **action coalitions** on school meals and agroecology that were launched at the summit.

International laboratories to strengthen our culture and visibility

A CONVERSATION WITH

Mathieu Buoro

Biologist specialising in the evolutionary ecology of migratory fish at the ECOBIOP Joint Research Unit and INRAE coordinator of the MACLIFE International Associated Laboratory (LIA)

How did the MACLIFE LIA start and why?
Since 2012, ECOBIOP has maintained close bilateral ties with our colleagues in Bilbao and UC Berkeley through the joint supervision of PhD and post-doctoral students, as well as frequent researcher exchanges between our laboratories.
The MACLIFE LIA takes this cooperation to the next level by providing a more coherent and comprehensive scientific framework and strengthening tripartite partnerships. The goal is to forge an international outlook on a theme for tomorrow's scientists and boost the Institute's visibility and attractiveness on the international academic stage.

Tell us about the new scheme
The LIA enables us to better organise our activities and to respond to calls for proposals on a joint basis. We receive support from the E2S UPPA I-Site consortium via INRAE, allowing us to launch more comprehensive projects. In fact, a joint experiment is currently underway at a University of California site. We will complete this study in France by conducting experiments in the ECOBIOP's Lapitxuri experimental spawning channel. We also have two theses in preparation on the bioenergetic and phenological responses of migratory fish to climate change. In parallel, we are developing digital simulation tools with the help of a thesis under our co-supervision with the University of California, Berkeley and funded in part by a Fulbright grant. This project also serves as a model and fosters a similar approach on the Pacific coast for salmon populations on the west coast of the United States

How does the LIA take this research further at a global level?
Due to a dispersion of projects and resources, we still know little about the functioning and network dynamics of aquatic ecosystems and their inhabitants. Pooling our efforts, expertise and facilities, defining protocols and developing common tools will help us address this issue. The multidisciplinary nature of the LIA and its geographical scope gives us the clout needed to respond to international calls for proposals while at the same time enabling us to diversify our approaches at the local level.

> “The LIA gives us the influence needed to respond to international calls for proposals and at the same time diversify our approaches at the local level.”

Priority projects of international scope (PPIs) for dynamic international science

INRAE supports priority projects of international scope which promote the incubation and co-sponsoring of multi-partner, international scientific initiatives on key subjects identified by the Institute. In particular, PPIs facilitate the development of a shared vision and a strategic research agenda with French, European and international partners. INRAE's role and involvement in the international PREZODE initiative, following a PPI on the reduction of emerging zoonotic diseases, illustrates this strategy.

Preventing emerging diseases and PREZODE

INRAE took a PPI approach (with CIRAD and IRD in its early stages) to develop an international initiative initially driven by research on emerging diseases and now focused on preventing zoonotic disease emergence: PREZODE. Launched on 11 January 2021 by the President of France at the One Planet Summit in Paris, PREZODE was forged at the national level through the development of a Priority Research Programme and Infrastructure (PEPR) with French research stakeholders. In conjunction with the ministries involved and in support of the action of special presidential envoy Jean-Luc Angot, numerous meetings were also held with potential scientific and institutional partners and several international

organisations: FAO, WHO, OIE, UNEP and the World Bank. More than 100 partners from 10 countries, scientists and stakeholders from NGOs and companies currently take part in this programme.
→ prezode.org

TSARA to transform food and agricultural systems through research in partnership with Africa

INRAE and CIRAD are working with around twenty partners from across Africa from the design phase forward to build an ambitious research, innovation and training partnership to meet the major challenges facing agricultural and food systems: ecological transition, the fight against desertification and soil depletion, water stress management, adaptation of forests and agroforests to climate change, a joint approach to human, animal and ecosystem health, nutrition in all its forms, and the work and employment opportunities that all of this entails.

This partnership contributes to achieving the joint priorities of the European Union and the African Union for collaboration in research, innovation and training. These efforts led to the launch of the joint initiative "Transforming Food and Agricultural Systems through Research in Partnership with Africa" (TSARA) in March 2022. The purpose of the TSARA initiative is to foster high-quality joint research focused on impact, training and the co-development of innovation with rural and urban stakeholders. It is also intended to build capacity, expertise and policy support.
INRAE's 14 scientific divisions and international cooperation system are taking part in the project and the Institute will initially contribute around €250,000 per year in new resources.

> "INRAE and CIRAD are strengthening their research in partnership with African institutions."
>
> Ségolène Halley des Fontaines
> Head of International Affairs

IN BRIEF

Maghreb-France: R&D to meet the challenges of Mediterranean agricultural and food systems

On 9 and 10 December 2021, INRAE, IRD and CIRAD co-organised a Maghreb-France regional scientific workshop on the new challenges for research and innovation in Mediterranean agricultural and food systems and on the changes and water stress problems with which the region's countries are increasingly confronted. The primary objective of the workshop was to build a common, updated vision of interdisciplinary research geared towards regional innovation with support from pilot sites until 2030. Plans are in place to establish a partnership mechanism to enhance the strategic action research agenda. It will launch in Northwest Africa and France and possibly expand quickly to include other Mediterranean basin countries concerned by these issues and which are developing these new approaches to research.

Innovation, expertise and public policy support for research impact

Driven by a desire to meet society's challenges with greater innovation and reactivity, to develop decision-making solutions and tools and initiate transition and transformation, in 2021 INRAE pursued its efforts to structure its expertise and public policy support activities such as typology, mapping and strategic foresight in order to develop national, European and international partnerships and strengthen its cooperation arrangements with socio-economic actors.

Patrick Flammarion

Deputy Director General of Expertise and Support for Public Policies

Expertise and support for public policies

Strengthened partnerships with public stakeholders

Recognition of facilities, centres and teams that provide a continuum of support for public policies (DPAPP)

In 2021, the French Ministry of Agriculture and INRAE jointly recognized 10 DPAPP and confirmed their continued funding for the next five years. These systems manage the data needed to implement policies supported by the ministry in conjunction with European and international regulatory obligations.
They are subject to strategic joint steering and monitoring.
The 10 recognised DPAPPs are:

- three epidemiological surveillance platforms for animal health, plant health and food chain safety,
- the French animal genetic database (BDZN),
- Plant innovation and plant and seed quality (GIP GEVES),
- Production, management and mapping of soil data (InfoSol),
- Reduction in pesticide use: Certificates for pesticide reductions (CEPPs),
- Rural Development Observatory service unit (ODR),
- Food Quality Observatory (OQALI),
- French Reference Centre for Animal Welfare (CNR BEA).

The same has been launched for schemes co-piloted with the Ministry of Ecological Transition and the Ministry of Solidarity and Health.

Certification for expertise quality

In February 2021, INRAE received ISO 9001 certification for its expertise quality system for the management of gravitational risks in mountain areas (avalanches, rockfall, mudslides, etc.) and hydraulic structures (dams, dykes, etc.), two key areas of public safety that are monitored via long-term programmes with the Ministry of Ecological Transition.

Agriculture, water and adapting to climate change: the Varenne ministerial meeting

The French ministries in charge of agriculture and environment met with stakeholders in 2021 to define the basis of a strategy for adapting agriculture to climate change and establish a common roadmap of priority action and tools. INRAE was involved throughout the process and provided structural scientific data. Over twenty experts contributed directly to the work, emphasizing the importance of mobilising levers to respond to this pressing problem, as well as the need for a global approach involving all actors while accommodating other environmental issues. The Research and Innovation Transfer (RIT) unit, created to help accelerate the agroecological transition and operated by INRAE, the Agricultural Technical Institutes (ACTA) Association and the French Chambers of Agriculture (APCA), was mobilised to develop a database of solutions for climate change adaptation shared with the ClimA Joint Technological Network (RMT). INRAE also signed the charter of commitments for the adaptation of agriculture to climate change together with ministers, interprofessional organisations and specialised committees of FranceAgriMer, APCA and ACTA.
Concluded by the Prime Minister on 1 February 2022, this consultation resulted in an action plan for existing government measures, to which INRAE and all its partners are fully committed.

©C. Saidou/agriculture.gouv.fr

Structuring national partnerships to include the regions

In order to develop expertise and support for public policies, INRAE signed five 5-year framework agreements.

The Institute works with three national public partners to enhance support provided for transitions:

- The French Environment and Energy Management Agency (ADEME), mobilising agricultural, food and forestry systems to provide solutions and decision-making tools.
- The national weather agency, Météo-France, to make available cross-referenced data on climate and weather forecasts and data on agriculture, forestry, the water cycle and biodiversity, their management and associated risks.
- The Centre for Studies on Risks, the Environment, Mobility and Urban Planning (Cerema), to produce scientific knowledge, methods and tools, along with expertise for regional environmental transitions.

INRAE also works with two regional actors serving as testing sites for transition:

- The French federation of regional natural parks (together with Institut Agro and AgroParisTech).
- The ANPP, a national association of French regions, via partnership and participatory approaches, on the issues of food and agricultural transition and the promotion of regions.

Cévennes National Park, looking north from Mount Aigoual.
©INRAE - J.M. Bossennec

Developing a culture of expertise and support for public policies

The first "Public Policy Support" research school

Held in October 2021, the event brought together around fifty participants to break down silos in practices and consolidate skills for the development of a common culture and to enrich projects.

The insights of 20 years of expertise, foresight and research

Over the last 20 years, the Directorate for Expertise, Foresight and Advanced Studies (DEPE) has conducted 17 collective scientific assessments, 11 advanced studies and 16 foresight studies.
A lexical analysis of this corpus of work highlights the need for a more systemic vision of problems involving agriculture, food and the environment, as well as to confront emerging challenges tied to risks, territories –urban in particular– and the bioeconomy, for example.
A catalogue of studies and evaluations conducted over 20 years was published in February 2021.
→ url.inrae.fr/3lET5g3

Updated guide to collective scientific expertise for the science-society relationship

The guide to collective scientific expertise, published by the Directorate for Expertise, Foresight and Advanced Studies (DEPE), explains the principles and modes of rigour and impartiality that govern the conduct of such evaluations with the aim of enhancing their impact. In November 2021, an updated version was published, including four new sections: objectivity, which is addressed by the Institute's collective approach; expertise and how it relates to society and citizens (with the creation of stakeholder advisory committees); the role of systematic review and meta-analysis, and the promotion of these initiatives.
→ url.inrae.fr/3lElD9l

Partnerships and innovation

Associated partnership laboratories (LPA) enrich innovation strategy at INRAE

In 2021, INRAE continued to forge new paths for innovation internally and externally by improving the visibility of the Institute's scientific and technological capacities in its innovation fields and the five Carnot Institutes; reinforcing partnerships with development stakeholders such as technology transfer accelerator companies (SATTs) and competitiveness clusters, and by supporting pre-maturation. New opportunities to work with socio-economic partners appeared with the creation of associated partnership laboratories.

These new facilities, which combine skills and equipment at a single site for a five-year period, aim to further steer science into areas of pertinence and accelerate knowledge transfer and its translation into innovation. Five LPAs were created in 2021, including LA PEPITE R&D. Based in Le Rheu (35), teams from INRAE and Terres Inovia, a technical institute specialised in plant-based oils and proteins, pooled their knowledge for the research and development of high-performance, innovative and low-input cropping systems. A sixty-member team of specialists in genetics, pathology, entomology and ecology is working together to improve yield consistency for rapeseed oil and legumes and to reduce the use of plant protection products.

> "The associated partnership laboratories allow us to launch a new way for our units to co-design and co-produce innovation with socio-economic partners."
>
> **Philippe Lénée**
> Director of Partnerships and Innovation Transfer

Launch of the Associated partnership laboratory involving teams from Terres Inovia and INRAE situated at the Institute for Genetics, Environment and Plant Protection in Rennes. ©INRAE E. Beaumont

Accelerating innovation by working more closely with competitiveness clusters

INRAE has signed its first tripartite framework agreement with two competitiveness clusters: AgriSudOuest Innovation and Valorial. This agreement aims to better understand market needs and promote knowledge transfer by connecting public and private actors in agriculture, agri-food and agro-industry at the regional, national and European level.

Regional innovation: TETRAE

Building on the achievements of the previous For and on Rural Development programme (PSDR), INRAE has launched TETRAE 2021-2027, an open innovation programme for regional transition in agriculture, food and the environment that works closely with regions to meet challenges in these areas. In 2021, the French regions of Auvergne-Rhône-Alpes and Occitanie signed agreements with INRAE on programmes in line with the INRAE 2030 strategic priorities.

→ tetrae.fr

©INRAE

Seed'In Tech for more robust seeds

Following a maturation project funded by the Paris-Saclay SATT, the start-up Seed'In Tech was created in 2021. It offers a method of processing seeds that increases germination capacity and resistance to various stresses and maintains longevity.

→ seedintech.com

Internal webinars to strengthen entrepreneurship

Open to all researchers and support staff, online Share & Learn events are an opportunity to share experience and best practices on partnerships and on starting and developing a business. Ten Share & Learn events held in 2021 illustrated important topics such as social innovation with Opticourses®, financing research via research tax credits, or start-up studios with Technofounders, which served as an incubator for the start-up Bliss.

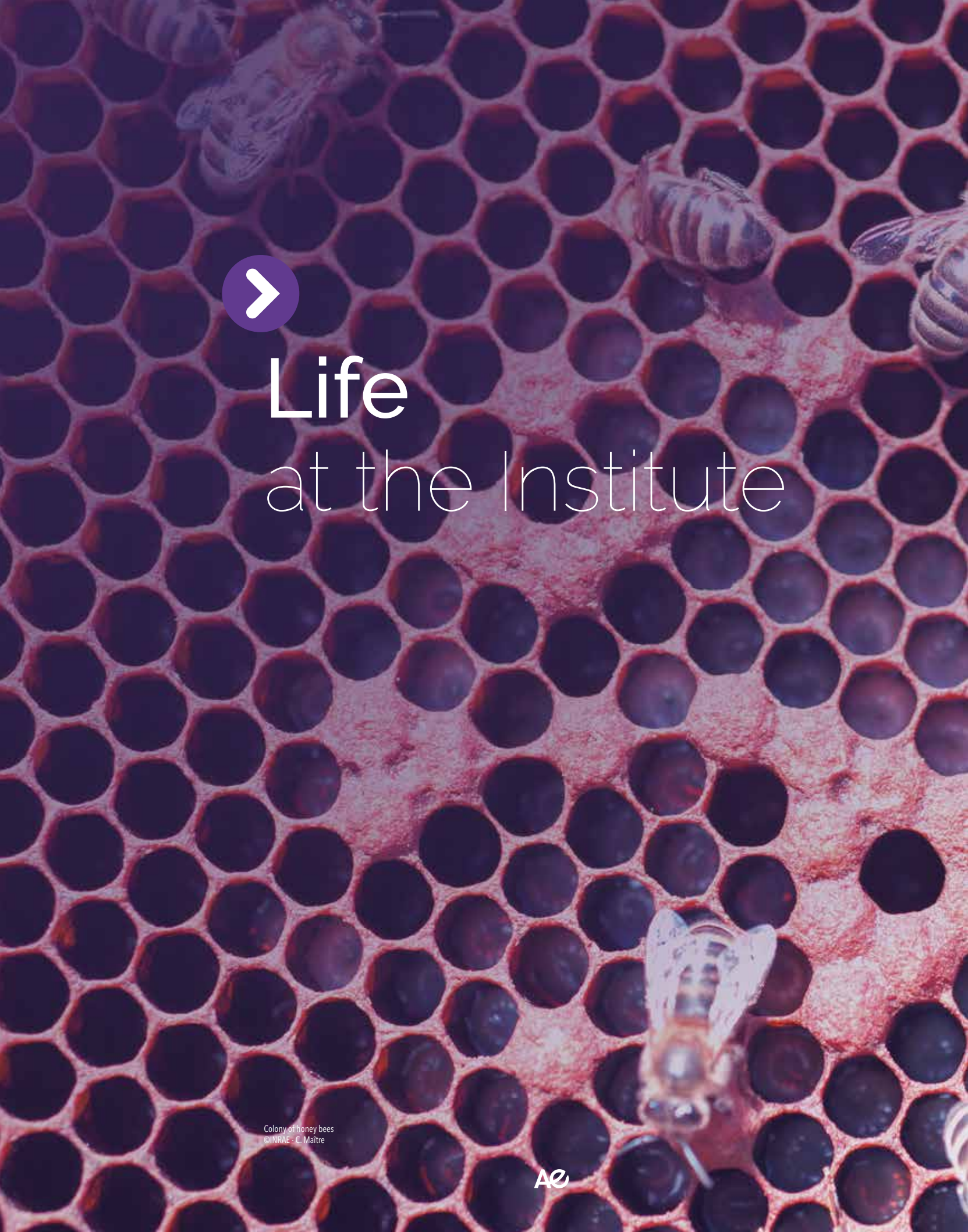
A focus on small and medium-sized enterprises

In order to foster innovation and facilitate transfer, small and medium-sized enterprises (SMEs) and intermediate-sized enterprises (IMEs) are a key focus area at INRAE. Forty-eight percent of CIFRE doctoral students co-supervised by INRAE are employed by SMEs or very small enterprises (VSEs). Targeted communications campaigns and dialogue via initiatives led by the ANRT, France's national technological research agency, and the competitiveness clusters have made companies more aware of opportunities. In 2021, VSEs and SMEs accounted for 21% of the Institute's contract-based revenues.

Pre-maturation: a key lever for the transfer of research results

INRAE supports pre-maturation as a means of multiplying knowledge transfer opportunities. In 2021, the Institute financed 12 'Coup de pouce technologique' projects, 2 'Coup de pouce start-up' projects and 2 'Coup de pouce Innovation sociale' projects for a total amount of €700,000. This pre-maturation scheme is designed to raise the technology readiness level (TRL)* of technological, societal, social or solidarity-based innovation produced by INRAE laboratories. Pre-maturation enables a threefold increase in transfer and development rates.

* The TRL scale assesses the level of maturity of a technology prior to its incorporation into a complete system and its industrialisation.



Life
at the Institute

Colony of honey bees
©INRAE - C. Maître

Continuously improving our support services

“

In 2021, still in the midst of the pandemic, INRAE proved resilient and continued moving forward, with the second half of the year finally showing signs of an easing crisis. The Institute began developing a second plan to modernise its support services (PMFS 2022–2025), designed based on a collaborative process involving the entire support services management team and the centre presidents. This plan echoes the ambitions of the INRAE2030 strategic plan and contributes to the UN's Sustainable Development Goals. The plan embraces a continuous improvement process and focuses on three priority areas:

• consolidating and modernising INRAE's activities in line with the needs of higher education and research by strengthening activities in the units and the Institute's resilience;
• supporting major societal transitions, namely the corporate social responsibility (CSR) and digital transitions;
• communicating on the Institute's strengths to recruit, develop and retain top talent.

”

Fabrice Marty
Deputy Director General of Resources

Shifting to a multi-year programme for projects and resources

INRAE has been working on several fronts to consolidate its business model and improve its budgeting process. Initiatives include new dialogue on financial management between the individual centres and the Finance Department, an overhaul of the simulation tool for payroll and staffing levels, a new rate-setting policy for activities, and the signing of a second objectives and resources agreement with the University of Angers.
The efforts undertaken in recent years have substantially improved the budget execution of the Institute's own resources from the units' research contracts and services: 98.6% of income projections in the provisional budget were achieved in 2021 versus 94.1% in 2020.
Moreover, to ensure continuous improvement in the Institute's support and management services, 250 unit and centre managers received finance training through a system first implemented in 2020 and which has now been made permanent. In addition to this training, a new employee handbook was created to share information on the existing networks, rules specific to different job positions, the main training tracks and more.

> "I'd like to thank all of our financial services staff – at the units, centres and headquarters – and recognise the co-construction process undertaken with the entire scientific leadership, and especially the project and infrastructure leaders, to develop an ambitious and balanced rate-setting policy. "Our scientific and support staff are all committed to strengthening our business model for the future."
>
> **Louis-Augustin Julien**
> Director of Finance and Procurement

The team at the French Plant Genomic Resources Center (CNRGV) at INRAE Occitanie-Toulouse..
©INRAE - C. Maître

Enhancing risk management

With regards to safety, INRAE shored up its information systems security to protect itself against the rising risk of cyberattacks by creating a general policy set to be rolled out in 2022. To comply with regulatory and partner requirements, the Institute is working towards getting all of its information systems accredited in accordance with risk analysis standards. Ten information systems were accredited in 2021 and the process is underway for another 30 of them. Accreditation is now a prerequisite to bringing any new information system online.

A map of strategic risks was updated. An action plan is being drawn up. Similarly, a map of major processes was created to identify the most serious emerging risks and implement improvement actions.

In terms of occupational and environmental risks, the Occupational Health and Safety Department, which was extremely active during the pandemic, continued providing support for employees. For example, it updated the "Workplace safety guidelines regarding the COVID-19 epidemic" guide several times (16 versions) to ensure employees had the latest information on the ever-changing situation and national recommendations. A free, confidential psychological support unit was created and will be made permanent.

New initiatives for the HR Department

The final 2021–2025 roadmap for INRAE's Human Resources Department focused on two main areas: consolidating and modernising HR activities with a view to ensuring continuous improvement and planning ahead for changes to come at INRAE. This new roadmap, approved in late 2021, is already being implemented. It is visible, for instance, in the reforms made to the job promotion process, and as part of the French law on research programming through increasing remunerations via the share of allowances. Finally, INRAE has also created a new Mediation and Dialogue Support Unit as part of its mediation process to manage internal conflicts.

> "We are constantly striving to support our colleagues and units."
>
> Camille Michon
> Director of Human Resources

A commitment to equality and diversity yields results

In January 2020, INRAE was the first public research establishment to obtain the dual Diversity and Professional Equality certification (known as Alliance) from AFNOR, the French national standards organisation, after monitoring at four pilot centres. The Institute's policy on diversity, non-discrimination and professional equality between women and men was thus recognised. A new audit carried out by AFNOR in 2021 confirmed the certification and extended it to all 18 centres. The first comparative review based on 2020 data shows that the percentages of women and men are nearly equal across the Institute and that, although differences remain with regards to certain corps and grades, the percentage of women holding the position of research director–exceptional class rose nearly fourfold in four years, from 6.9% in 2017 to 31.7% in 2020.

Awareness-raising and training are a key area for these action plans. Initiatives include several emblematic events (International Day of Women and Girls in Science, International Women's Day and the European Disability Employment Week) and a hiring kit for contractual employees that is full of tips, recommendations, decision support tools and videos. In terms of communication, a document on gender-inclusive writing was drawn up. INRAE's disability policy, which is a fully integrated part of the Institute's diversity-professional equality policy, is based on a convention signed with the Fund for the Integration of Disabled Persons in the Public Sector (FIPHFP) and set out in a 2021–2023 action plan.

> "Supporting diversity and equality consists in overcoming unconscious biases."
>
> Catherine Beaumont
> Head of Gender Equality and Anti-Discrimination

Esther Dzalé.
Research Support Award, 2021 INRAE Awards. Directorate for Open Science (DipSO).
©INRAE - C. Maître

IN BRIEF

An expanded T services catalogue

The catalogue of IT support services was expanded, with the addition of new collaborative services in response to the sharp rise in remote work.

A year on from the INRA-IRSTEA merger, focusing on connection

With the pandemic still weighing heavily on life at the Institute and remote work arrangements going strong, INRAE continued its efforts to unify its new community in 2021. The Institute sought to maintain a sense of connection through constant support at the units and for those who needed help adjusting to new tools and working methods. These efforts will continue as part of the merger oversight activities.

Lessons learned from managing the COVID-19 crisis

The feedback analysis conducted in late 2020 on the COVID-19 crisis management (see the 2020 Annual Report) was completed by a survey on employees' experiences, carried out in conjunction with the Central Committee on Hygiene, Safety and Working Conditions (CCHSWC) in 2021. The recommendations led to the creation of a "crisis management" action plan. Additionally, given the importance of the tools for completing work and managing teams remotely, the centres were surveyed on their audiovisual equipment needs. Plans are in the works to conduct another feedback analysis a few months after the crisis ends.

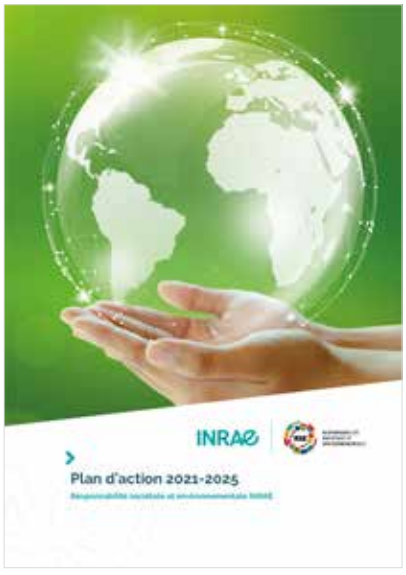
A responsible institute

INRAE is committed to being a responsible employer in terms of corporate social responsibility (CSR) as well as ethics and professional conduct.

Structuring the Institute's social and environmental responsibility

Widely endorsed during the internal consultations conducted when drawing up the INRAE 2030 strategic plan, corporate social responsibility at the Institute was structured in 2021, with the creation of the CSR department and a network of managers.

> "CSR is everyone's responsibility. It gives purpose to our activities and enhances the coherence between what we do and the meaning behind our research."
>
> Benoît Malpaux
> Director of CSR



RESPONSABILITÉ SOCIÉTALE ET ENVIRONNEMENTALE

A 2021–2025 action plan

As a leader among public scientific and technological research establishments, INRAE has developed its first CSR action plan for 2021–2025 based on the national reference framework for Sustainable Development and Social Responsibility in higher education and research.

The entire Institute is involved in implementing this plan, which identifies 70 actions rolled out locally and takes into account the site-specific strategies and centre-based measures. A network of CSR managers oversees the plan, supported by sustainable development specialists working to include these objectives at the unit project level, although the directorates and delegations remain responsible for the actions under their purview.

Half of the actions are now being implemented; others that are much larger in scope were operational in 2021:

- the cessation of the use of glyphosate in all INRAE experimental units;
- ISO 14001 certification (environmental management system) of the experimental units, with 25 out of 45 now certified;
- the creation of an eco-friendly communication guide for anyone in charge of communication or events.

→ url.inrae.fr/39RIUC2

Ethics, scientific integrity and code of conduct for research projects

The Delegation on Ethics, Scientific Integrity and Code of Conduct for Research Projects received a new member in 2021 with the appointment of an Ethical Assessment of Research Projects adviser, alongside the Scientific Integrity advisers and the Code of Conduct adviser. Among the actions carried out in 2021, the delegation produced a memorandum on publication authorship in partnership with the Directorate for Open Science.
The main project of the year was on public expression. The project was co-managed by the delegation and the Communications Department, with support from Code of Conduct adviser. This project resulted in a charter on public expression being published in 2022
→ url.inrae.fr/38fDwrU

Charter on Public Expression

A CONVERSATION WITH

Françoise Simon-Plas
Head of Ethics, Scientific Integrity and Code of Conduct for Research Projects

Sandrine Vinzant
Director of Communications

What's the reason behind this charter?
F. Simon-Plas: Food, agriculture and the environment are all involved in major societal issues, and they are sometimes subject to debate. INRAE is expected to weigh in on these issues. Quality dialogue between scientists and citizens is essential but sometimes challenging. The COVID-19 crisis put a spotlight on these difficulties and revealed the risks, with the undermining of the basic tenets of the scientific process – rigour, honesty, reliability and transparency regarding the methods used, a lack of conflicts of interest and peer review. We wanted to support our scientists and other personnel when engaging in this dialogue and to give them the tools they need to communicate with the public while not restricting their right to freedom of expression. The goal is to provide shared points of reference in terms of ethics, professional conduct and integrity by integrating the fundamental values of the scientific process into public expression.

> "We wanted to support our scientists and other personnel [...], and to give them the tools they need to communicate with the public while not restricting their right to freedom of expression.
> Françoise Simon-Plas

How did you approach the process?
S. Vinzant: We created a working group with members from our directorates and delegations and then interviewed scientists, centre presidents and division heads, who frequently face these issues, to develop a charter and best practices. The charter, which was presented to the Scientific Advisory Board and aligns with the French National Charter for Research Integrity and the INRAE Ethics, Scientific Integrity and Code of Conduct Charter, provides a framework and principles to be followed in matters of public expression. The best practices offer advice depending on the situation, illustrated with case studies, definitions and source reference documents. They are an excellent resource, with questions to help users be ready for anything as they prepare to engage with the public.

> The best practices [...] are an excellent resource, with questions to help users be ready for anything as they prepare to engage with the public.
> Sandrine Vinzant

Joint INRAE-CIRAD-IFREMER-IRD Ethics Advisory Committee

The INRAE-CIRAD-IFREMER-IRD Ethics Advisory Committee has 13 members hailing from around the world who are appointed for their expertise and interest in ethical issues. The committee provides an external perspective of the ethical issues raised by research to encourage dialogue. Chaired by Axel Kahn since 2016, the committee recently appointed **Michel Badré** and **Bernadette Bensaude-Vincent** as president and vice president following Axel Kahn's death in July 2021.

Michel Badré
©INRAE - C. Maître

Bernadette Bensaude-Vincent
©B. Martinez

The committee, which has full control over the issues it wants to tackle, has issued three opinions since 2019 on human needs, natural resources and preservation of the biosphere; on conflicts related to water management in coastal areas; and on land management.
These opinions will be published together in late 2022 with a foreword written by Axel Kahn.

Ethical considerations for the use of animals in science

'The use of animals in science is still necessary in human and animal health research as well as in agricultural, species conservation and environmental research. To minimise the use of animals and their potential stress, European and French regulations seek the application of the so-called Three Rs principle: replacement, reduction, refinement.

To support the application of the Three Rs regulation, a specialised centre called France Centre 3R (FC3R), structured as a scientific interest group, was created in 2021 at the request of the French Ministry of Research. INRAE is a founding member alongside other major French public research stakeholders. FC3R, located at the Alfort national veterinary school, strives to foster training and communication about the Three Rs, and support the development of methods that respect animal integrity (noninvasive methods, cellular models, etc.)

Additionally, to communicate with the public about the reasons why and conditions under which animals are used in experiments, INRAE and some 40 public and private stakeholders in French research signed a transparency charter in February 2021. The signatories committed to improve their sharing of information, to better engage with the public and to report on those efforts through an annual report. Statistics on the use of animals in science and nontechnical summaries of experiments are also published on the Ministry of Research's website.

> “These initiatives are part of a proactive approach by the Institute to support research units working in animal and human biology as they adopt new approaches to obtain reliable results while taking into account the continuous evolution of the place of animals in our society.”

Françoise Médale
Head of the Animal Physiology and Livestock Systems Division

2021 INRAE Awards. Science with an Impact Award, Animal Welfare Team
Animal Physiology and Livestock Systems (PHASE)
©INRAE - C. Maître

les Lauriers

NOVEMBRE 2021
GROUND CONTROL
PARIS

Seven awards were presented on 29 November 2021 during a ceremony held in the presence of the Minister in charge of Research and introduced by a video of the Minister of Agriculture. The international jury honoured five remarkable careers and two units for the impact of their work on society.

Hervé Vaucheret

Lifetime Achievement Award

Exploring the unexpected, such as "abnormal" transgenic plants practically fished out of the rubbish bin, can shed light on how plants silence outside genes, including those of invading viruses. Behind the remarkable advances in plant immunity and nonself recognition mechanisms in plants are 135 publications, over 28,000 citations, and numerous scientific awards. "Researchers give their best in a climate of trust, not scrutiny," says Hervé.

Research Director at the Institut Jean-Pierre Bourgin, Île-de-France–Versailles-Grignon Centre.

Animal Welfare Team

Science with an Impact Award

From cows to sheep, pigs and chickens, "animals have a psychology – they feel emotions and are capable of interpreting and even communicating them." For more than 20 years, INRAE's research has contributed to better understanding livestock animals to improve their living conditions. "Today, all sectors have integrated these ideas into their production models."

The eight researchers who were recognised represent a network with around a hundred ethologists, veterinarians, geneticists, zootechnicians, animal care technicians and students from several INRAE centres.

InfoSol Team

Science with an Impact Award

Revealing the hidden side of the soil... The InfoSol unit, created in 2000, acquires and exploits data on French soils. It manages a collection of over 70,000 soil samples and a national information system on their status and evolution. This information is precious when it comes to developing health policies on decontamination as well as agricultural policies. This programme is one of ten extended by the Ministry of Agriculture (see p. 67). "We have gone from viewing the soil as a simple production medium to seeing it as a living, complex environment." It is one of the long-term public policy support programmes.

INRAE Val de Loire Centre

Esther Dzalé

Research Support Award

She makes all the products of INRAE's research – data, software, publications and more – accessible online to the world.

IT research engineer, head of the digital technology for science team of the Directorate for Open Science at INRAE's Île-de-France–Versailles-Grignon Centre

Jeanne-Marie Membré

Innovation Award

Passionate about scientific modelling, she has developed many methods and tools to quantitatively evaluate the risks and benefits of food.

Research engineer, Food Safety and Microbiology Joint Research Unit, INRAE Pays de la Loire Centre

Laurent Philippot

Scientific Breakthrough Award

When asked why he chose to become a researcher, he mentions curiosity, a thirst for knowledge and wanting to share knowledge. He works in the field of microbial ecology.

Research director, Agroecology Joint Research Unit, INRAE Burgundy-Franche-Comté Centre

Lucie Marandel

Promising Researcher Award

"Without basic research, there would be no applications." Lucie studies new nutrients to develop more sustainable food for farmed fish.

Research scientist, Nutrition, Metabolism, Aquaculture Joint Research Unit, INRAE Nouvelle-Aquitaine Bordeaux Centre

Our distinguished scientists

L'Oréal-UNESCO French Young Talents Award: "For Women in Science"

Young-Kyoung Park (Joint Research Unit for Food and Gut Microbiology for Human Health) is one of the 2021 winners of this award, which aims to recognise promising young women researchers. Her work focuses on the development of yeast using metabolic engineering to produce microbial oils as an alternative to fossil fuels.

Young-Kyoung Park

French Academy of Agriculture Awards

Ten INRAE researchers received awards in 2021 from the French Academy of Agriculture.

Among them, Béatrice Denoyes **(Joint Research Unit for Fruit Biology and Pathology) won the Researcher Award from the Xavier Bernard Foundation.** The award recognises her skilful management of a research programme for strawberries and the production of the fruit in a context of climate change in conjunction with industry professionals.

The Academy granted two silver-gilt awards in recognition of outstanding research careers: Dominique Desbois (Joint Research Unit for Public Economics), whose work deals with the microeconomics of agricultural production, and Marie-Hélène Wagner, an INRAE engineer for the Variety and Seed Study and Control Group (GEVES), whose work focuses on the development of methods to analyse the physiological quality of seeds and a seed and seedling phenotyping service.

The Academy also granted five Dufrenoy silver awards for the best theses defended the previous year.
Anne-Lise Boixel (Research Unit for Biology and Risk Management in Agriculture – Plant Pathogenic Fungi) studies the effects of thermal heterogeneity on the adaptation of plant pathogen populations. Margot Leclère (Joint Research Unit for Agronomy) was honoured for her multi-stakeholder methodological approach to support the agroecological transition through species diversification of a territory, and Hélène Fargeon (Ecology of Mediterranean Forests Unit) for her work on the changing risks of forest fires in France in the context of climate change. The work of Laëtitia Cardona (Research Unit for Environmental Biotechnology Processes) contributes to a better understanding of the microorganisms involved in anaerobic bioreactors, which are sources of renewable energy production. The thesis by Loïc Mazenc (Joint Research Unit for Agroecology, Innovations and Territories) provides new knowledge on crop managers.

Béatrice
Denoyes

Dominique
Desbois

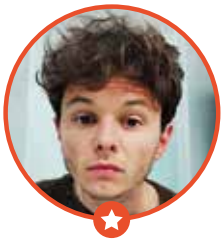
Marie-Hélène
Wagner

Anne-Lise
Boixel

Margot
Leclère

Hélène
Fargeon

Laëtitia
Cardona



Loïc
Mazenc

Communication activities pick up the pace

In 2021, INRAE's communication activities gained momentum as health restrictions lifted and a flurry of new formats emerged (newsletter, podcast series, magazine). All areas at INRAE were covered, consolidating the Institute's status as a leader in its speciality fields of agriculture, food and environment.

Nurturing a shared INRAE culture through internal communication

One year after the INRA-IRSTEA merger, the new arrivals week was held in person for nearly 300 staff throughout France to bring them up to speed on the organisational, scientific and historical basics of our public scientific and technological research establishment and help nurture a shared organisational culture. Additionally, in a show of support for INRAE's CSR actions, staff were incredibly enthusiastic about the national and local events held as part of the European Week for Waste Reduction (EWWR).

External communication and events get back on track

After an involuntary pause, event activities began resuming mid-year in 2021. After an all-digital participation in the French Agriculture Week in May, INRAE returned to in-person activities in June for the National Agriculture Days, opening six of its experimental sites to the public. In September, researchers presented their work to the public under the "biodiversity dome" at the World Conservation Congress in Marseille, organised by the International Union for Conservation of Nature (IUCN) and the French government. In November, the Banquet exhibition, for which INRAE is a key scientific partner, opened its doors for a year-long show at the Cité des sciences in Paris. Finally, 2021 was marked by a successful first attendance at the Pollutec trade fair in Lyon, which showcased research on water management and natural risks.

INRAE also had the chance to show its commitment and love for Earth with a short film shared on social media, reaching a remarkable audience of more than one million Twitter users, thanks to the retweeting by French astronaut Thomas Pesquet from the international space station.

Maintaining strong media relations during the pandemic

INRAE continued its ongoing relations with the press, shifting to a digital press conference format (eight held during the year) adapted to the pandemic context, in coordination with partners for two of them (acclimation of white truffle cultivation in France with the nursery Robin pépinières and preclinical results of the COVID-19 vaccine via nasal administration with the University of Tours).
In a year dominated by COVID-19-related subjects, a large proportion of INRAE's 20,000 press mentions dealt with the areas of food, human health and environmental health. Overall, INRAE's media visibility rose by 15%, thanks in particular to involvement by researchers, who were in high demand among audiovisual media players (+80%) to provide details on current events.

A newsletter, a magazine and a podcast series

INRAE developed three new formats in 2021 to communicate about life at the Institute. The first is a monthly digital newsletter packed with scientific and institutional news aimed at INRAE's business, political, social and scientific partners. The second is *Ressources*, a magazine (three issues per year) designed to provide benchmarks and scientific solutions for societal issues. The magazine is freely accessible on the website and in a limited print edition. Finally, the podcast series *La boucle est bouclée* ("the loop is closed") was created to give listeners a chance to take a deep dive into scientific issues with INRAE researchers.

Governance and key figures

Experiment in a level 3 lab at the Molecular Virology and Immunology Unit in Jouy-en-Josas.
Île-de-France–Jouy-en-Josas–Antony research centre.
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Governance

Board of Directors

Composition as of 31 December 2021

President

Philippe MAUGUIN, Chair and CEO of INRAE

State Representatives

- Valérie BADUEL, , Director General for Higher Education and Research, Ministry of Agriculture and Food
- Bénédicte HERBINET, Deputy Director of Research, Innovation and International Cooperation, Directorate-General for Education and Research, Ministry of Agriculture and Food (alternate)
- Cyril MOULIN, Deputy Director of the Research and Innovation Strategy Department, Ministry of Higher Education, Research and Innovation
- Lise FECHNER, Research and Innovation Strategy Department, Deputy Scientific Director for the "Environment and Universe Sciences, Agronomy, Ecology and Earth System Science – Directorate-General for Research and Innovation – Ministry of Higher Education, Research and Innovation (alternate)
- Diane SIMIU, Deputy Director to the General Commissioner for Sustainable Development, General Commission for Sustainable Development
- Thierry COURTINE, Deputy Director of Research and Innovation, Ministry for the Ecological Transition (alternate)
- Agathe ROLLAND, Head of the Office of Research and Higher Education at the Directorate of the Budget, Ministry of Public Action and Accounts

Representatives of public higher education or research institutions

- Elisabeth CLAVERIE DE SAINT-MARTIN, CEO of CIRAD
- François ROCHE-BRUYN, Director General of AgroSup Dijon

Members chosen for their knowledge in the agriculture, environment and food sectors

- Paul-Joël DERIAN, Director General Innovation, Research and Sustainable Development
- François ENGUEHARD, Director of Research Centres, Véolia
- Anne-Claire VIAL, President of ACTA, Agricultural Technical Institutes

Labour and Economic Sector Representatives

- Dominique CHARGE, President, Coopération agricole
- Annabel FOURY, National Secretary, FGA-CFDT

Members representing approved consumer protection associations and approved environmental protection associations

- Marie-Claude FOURRIER, Head of the Consumer Affairs Office, French national association for consumer and user rights
- François LETOURNEUX, Honorary President, French Committee of the International Union for the Conservation of Nature

Elected Staff Representatives

Full Members

Dominique DESBOIS, CFDT
Elisabeth TABONE, CFDT
Pascale MAILLARD, CGT
Eric LATRILLE, CGT
Baptiste HAUTDIDIER, SUD Recherche EPST

Alternate Members

Anne DE LA FOYE, CFDT
Jean-Marc BONNEFOND, CFDT
Michel BERTRAND, CGT
Laurence ARTIGE, CGT
Fabrice GUIZIOU, SUD Recherche EPST

Scientific Advisory Board

Composition as of 31 December 2021

President

Philippe GILLET, Professor at the École polytechnique fédérale in Lausanne (EPFL), Switzerland

INRAE Members

- Philippe MAUGUIN, Chair and CEO of INRAE
- Carole CARANTA, Deputy Director General of Science and Innovation

Ex-Officio Members

- Ministry of Higher Education, Research and Innovation: Lise FECHNER, full member, or Alain LAGRANGE, alternate
- Ministry of Agriculture: Marion BARDY, Deputy Director for Research, Innovation and International Cooperation, full member, or Sofia MLALA, alternate
- Ministry for the Environment: Gwenaelle HELLO, Deputy Director for Research, full member, or Céline COUDERC-OBERT, alternate

Nominated Members

By ministerial order of 9 November 2020, the Ministers for Agriculture and Research appointed the following persons:

- Philippe GILLET, Professor at EPFL (Switzerland), President of the Scientific Advisory Board
- Valérie ARCHAMBAULT, Deputy Director for Research in charge of industrial partnerships, MINES ParisTech – PSL
- Sylvie BAUDINO-CAISSARD, Director of the Plant Biotechnologies Laboratory, University of Saint-Etienne
- Antoine BAULE, CEO of Lesaffre
- Patrick CARON, Vice President of International Relations at the University of Montpellier
- Jérôme CHAVE, Deputy Director of the Evolution and Biodiversity Joint Research Unit at CNRS/Paul Sabatier University
- Cécile CLAVEIROLE, Policy Officer for agricultural issues at France Nature Environnement
- Anne-Charlotte DOCKES, Head of the Livestock Trades and Society Department at the French Livestock Institute (Idele)
- Thierry DORE, Head of research policy at Paris-Saclay University
- Sophie DUBUISSON-QUELLIER, CNRS Research Director, Deputy Director of the Centre for the Sociology of Organisations (CSO)
- Teresa FERREIRA, Professor at the Department of Natural Resources of the University of Lisbon, Portugal
- Elisabeth GRAF-PANNATIER, Member of the management staff of the Swiss Federal Institute for Forest Snow and Landscape Research WSL in Birmensdorf, Switzerland
- Sophien KAMOUN, Professor at The Sainsbury Laboratory, Norwich University, UK
- Thierry LEFRANÇOIS, Director of the Biological Systems Department (BIOS), CIRAD
- Xavier LITRICO, Research and Scientific Director, SUEZ Group
- Eveline VOLCKE, Professor of process engineering at Ghent University, Belgium

Elected INRAE Members

Sector 1: Agroecosystems, Mathematics and Digital Technologies
Wolfram LIEBERMEISTER (full member)
Marie-Anne LAUNAY (alternate)
Sector 2: Ecology and Biodiversity, Aquatic Ecosystems, Water Resources and Risks
Philippe ROZENBERG (full member)
Christelle GRAMAGLIA (alternate)
Sector 3: Plant Biology and Breeding, Variety and Seed Study and Control Group (GEVES)
Juliette SALVAING (full member)
Denis LECLERCQ (alternate)
Sector 4: Plant Health and Environment
Benoit FACON (full member)
Louise VAN OUDENHOVE (alternate)
Sector 5: Food, Bioproducts and Waste
Nathalie GONTARD (full member)
Thierry BENEZECH (alternate)
Sector 6: Animal Physiology and Livestock Systems
Denise AUBERT (full member)
Christophe GAUTHIER (alternate)
Sector 7: Animal Genetics, Animal Health
Claude CHARVET (full member)
Sandrine TRUCHET (alternate)
Sector 8: Human Nutrition and Food Safety; Microbiology and the Food Chain
Jean-Paul LALLES (full member)
Emmanuelle MAGUIN (alternate)
Sector 9: Economics and Social Sciences, Action and Transitions
Marie THIOLLET-SCHOLTUS (full member)
Vincent MARTINET (alternate)
Sector 10: Research Support Services
Christine CHARLOT (full member)
Bruno COTTE (alternate)

Union Observers
Each union organisation represented on the Institute's technical committee can designate a representative to attend Scientific Advisory Board meetings as an observer.

CFDT: Dominique DESBOIS
CFTC: Bruno PONTOIRE
CGT: Jean-Louis DURAND
SUD: Cyril DUTECH

Specialised Scientific Commissions (CSS) and their presidents

CSS N°1 - Agronomy, Livestock, Forestry
Eric MALEZIEUX

CSS N°2 - Biology of Host-Pest Interactions, Symbionts and Commensals
Daniel BARTHELEMY

CSS N°3 - Integrative Plant Biology
Emmanuel GUIDERDONI

CSS N°4 - Ecology, Population Biology and Ecosystem Dynamics
Philippe USSEGLIO-POLATERA

CSS N°5 - Plant and Animal Genetics
Pierre BOUDRY

CSS N°6 - Mathematics, Informatics, Digital Science and Technology, Artificial Intelligence and Robotics
Etienne BIRMELÉ

CSS N°7 - Microbiology, Microbial Ecosystems, Agri-Food Systems, Biotechnologies
Christophe JUNOT

CSS N°8 - Nutrition and Toxicology
Christophe MAGNAN

CSS N°9 - Animal Biology
Claude DUCHAMP

CSS N°10 - Environmental Sciences: Earth, Water and Atmosphere
Anne-Catherine FAVRE

CSS N°11 - Food Science and Engineering, Materials Science, Biobased Products and Waste-to-Resource
Etienne PAUL

CSS N°12 - Economic, Social and Management Sciences
Jean-Philippe TROPEANO

CSS N°13 - Research Support and Steering
Philippe MAUGUIN

Joint INRAE-CIRAD-IFREMER-IRD Ethics Advisory Committee

Joint Ethics Advisory Committee Members

Michel BADRÉ, President of the Committee
Graduate engineer from the École Polytechnique – École nationale du Génie rural, des Eaux et des Forêts. Member of the Economic, Social and Environmental Council, in the group of environmental associations.

Bernadette BENSAUDE-VINCENT, Professor emeritus at the University of Paris 1 Pantheon-Sorbonne, Associate Professor of Philosophy and Doctor of Arts and Humanities.

Madeleine AKRICH, Research director and graduate engineer at MINES ParisTech (Center for the Sociology of Innovation – CSI) and Doctor of Socioeconomics of Innovation.

Céline BOUDET, Ineris, scientific coordinator, risk assessment specialist in health and environment (epidemiology, toxicology, biostatistics).

Catherine BOYEN, CNRS research director, Doctor in Plant Biology, Director of the Roscoff Marine Station, research and training centre in marine ecology, Sorbonne University-CNRS (marine biology, algae, genomics, evolution, microbiomes, marine biodiversity and marine biotechnology).

Denis COUVET, Professor at the Muséum National d'Histoire Naturelle (MNHN), president of the French Foundation for Biodiversity Research (FRB), associate professor at the University of Lausanne and at SciencesPo Paris, graduate engineer in agricultural sciences, Doctor in evolutionary science and ecology.

Mireille DOSSO, Director of the Pasteur Institute of the Ivory Coast, professor of Microbiology.

Mark HUNYADI, Professor of Social Philosophy and Politics at the Catholic University of Louvain, associate professor at the Institut Mines-Télécom Business School and at EHESS–School for Advanced Studies in the Social Sciences, member of the Ethics Committee at Orange, member of the strategy committee and of the steering committee of the Forum Vies Mobiles.

Youba SOKONA, Professor, 40 years of experience in the field of water, energy, environment and sustainable development in Africa. Has participated in the IPCC's work since1990 and elected Vice-Chair of the IPCC in October 2015. Has since been the co-founder of the ENDA-TM energy programme, executive secretary of the Sahara and Sahel Observatory (OSS) and coordinator of the African Climate Policy Centre (ACPC). Until 2020, was the principal advisor for sustainable development at the South Centre. Member of the African Academy of Sciences.

Marie-Geneviève PINSART, Philosopher, professor in Applied Ethics at the Université Libre de Bruxelles. Member of the Ethics Advisory Committee for research in partnership (CCERP) of the IRD.

Louis-Etienne PIGEON, Philosopher specialising in environmental ethics, Doctor of Philosophy from Laval University (Canada), assistant professor at Laval University.

Pere PUIGDOMÈNECH, Research professor at the Spanish National Research Council (CSIC) at the Molecular Biology Institute of Barcelona, specialist in the molecular biology of plants, Doctor in Biological Sciences.

Hervé THÉRY, Geographer, associate professor at the University of Sao Paulo (Brazil), research director emeritus at the CNRS.

Joint Administrative Staff

INRAE: Christine CHARLOT, Secretary General, with the support of Nathalie HERMET
CIRAD: Philippe FELDMANN, Marie DE LATTRE-GASQUET
IFREMER: Philippe GOULLETQUER, Marianne ALUNNO-BRUSCIA
IRD: Chloé DESMOTS

Staff and budget

8,197
permanent staff
(FTE)*

50.4%
4,128 women

49.6%
4,069 men

2,005 researchers
3,175 engineers
3,017 technicians

3,005
staff with contracts
(FTE)

787
PhD candidates (200 of whom are foreign nationals)

132
post-doctoral fellows (78 of whom are foreign nationals)

2,443
trainees (329 of whom are foreign nationals)

**FTE: full-time equivalent. Takes into account the percentage of time (part-time or not) and the working period (one year or less).*

Subsidy for public service expenses
€812.6m

INRAE resources
€235.9m

INRAE resources (from research contracts)
€164.3m

ANR	41.1
PIA	18.7
Other public institutions	15.0
Local and regional authorities	18.1
Europe	28.1
Ministries	9.0
Research & higher education institutions	6.8
Socio-economic partners	27.7

INRAE resources (non-contractual)
€71.5m

Allocated grants	6.0
Donations and bequests	0.1
Royalties for patents, licences	5.2
Services rendered	17.9
Product sales	17.4
Other subsidies	8.5
Other operating income	7.5
Financial and exceptional income	9.0

2021 resources
€1,048.5m

77.53%
Subsidy for public service expenses

22.47%
INRAE resources

Partnerships and innovation

Socio-economic partnerships

New partnership contracts signed with socio-economic partners	408
Number of partnership arrangements with socio-economic partners	**29** Joint Technology Units **5** Carnot Institutes **5** Labcom **5** LPA

Intellectual property

Declarations of inventions & exploitable research results	140
Patents submitted	30
Patent families held	405
Applications for plant variety rights	20
Plant varieties listed in an official catalogue and/or held	425

Creating value

New exploitation agreements (licences, options, etc.) on patents, know-how, software, trademarks, models	46
Licences held	640
New plant variety rights licences	19
Plant variety rights licences held	1 128

Pre-maturation

Funding divided among 16 projects	€700k

Creating new companies

New companies set up based on INRAE results	6

Revenues

Research contracts signed with socio-economic partners	€27.7m
Licences for plant variety rights	€3,029k
Licences for patents and know-know	€1,966k

Subsidiaries

Éditions Quæ

The Éditions Quæ publishing house was founded in 2006 by four French research institutes: INRA and IRSTEA (which later merged to form INRAE), CIRAD, and IFREMER. It is now the leading French public scientific publisher. It boasts a catalogue of more than 1,000 titles in French and English aimed at scientists and industry professionals, as well as readers interested in societal issues related to the work of the abovementioned research institutes. Éditions Quæ has strengthened its commitment to open access since 2018, working to expand its readership to an international French and English-speaking community. Its catalogue includes open-access titles as well as books for purchase in print form, with some available in both formats as part of its freemium offer.

INRAE Transfert

Working together to transform innovations for the well-being of the planet and people.

As a subsidiary, INRAE Transfert develops activities to support INRAE in implementing its technology transfer policy and European projects.

It is specialised in managing complex project engineering and technology transfers in the fields of agriculture, food and the environment in the following areas:

- transferring research results to companies;
- supporting the creation of innovative businesses;
- managing the Carnot Institutes;
- setting up, negotiating and managing European projects;
- handling RDI activities for demonstrators and platforms;
- providing technological and business intelligence services for third parties.

Château Couhins

Château Couhins, located in the Bordeaux winegrowing region and owned by INRAE, has been committed to producing high-quality grapes and wine in an environmentally friendly way for more than 20 years. It is deepening those efforts by converting its operations to organic. The winery's first 100% organic vintage will be available in 2022. The estate is also still working towards its ambitious development objective to deploy INRAE agroecology research results *in situ* at the full vineyard scale.

Agri Obtentions

Agri Obtentions, a subsidiary of INRAE founded in 1983, is a French multi-species seed producer whose core business is varietal innovation. Agri Obtentions is strongly committed to the agroecological transition and strives to develop new solutions for farmers that work with their practices.
As a pioneer in offering varieties adapted to organic farming, Agri Obtentions produces a wide range of seeds for cereals, protein crops, buckwheat, lentils and forage crops.
It also has a range of varieties adapted to crop associations and intercropping mixtures and is involved in developing vegetable crop innovations.

Key figures:
- €15m in turnover generated in France and in Europe
- 30% of turnover invested in Research & Development
- More than 400 licences
- 10 species groups and more than 450 varieties distributed

INRAE Organisation

(As of 31 December 2021)

BOARD OF DIRECTORS
President
Philippe MAUGUIN

SCIENTIFIC ADVISORY BOARD
President
Philippe GILLET

ETHICS COMMITTEE
President
Michel BADRÉ

MANAGEMENT BOARD

CEO – DIRECTORS GENERAL

Philippe MAUGUIN
Chair and CEO

Jean-François SOUSSANA
Vice President of International Policy

Carole CARANTA
Deputy Director General of Science & Innovation

Fabrice MARTY
Deputy Director General of Resources

Patrick FLAMMARION
Deputy Director General of Expertise & Support for Public Policies

Christian LANNOU
Associate Deputy Director General of Science & Innovation

Cyril KAO
Director of Academic Partnerships, Regional and European Affairs

Camille MICHON
Director of Human Resources

SCIENTIFIC DIRECTORS

Monique AXELOS
Scientific Director of Food and the Bioeconomy

Christian HUYGHE
Scientific Director of Agriculture

Thierry CAQUET
Scientific Director of Environment

Ségolène HALLEY DES FONTAINES
Director of International Relations

Sandrine VINZANT
Director of Communications

Édith LEGOUY
Scientific Advisor

Pauline SOUVIGNER
Secretary General of the Management Board

RESEARCH SUPPORT DIRECTORS

- **Benoît MALPAUX** — *Corporate Social Responsibility*
- **Guy RICHARD** — *Expertise, Foresight and Advanced Studies*
- **Nicolas de MENTHIÈRE** — *Support for Public Policies*
- **Philippe LÉNÉE** — *Partnerships and Innovation Transfer*
- **Odile HOLOGNE** — *Open Science*
- **Frédéric GAYMARD** — *Evaluation*
- **Louis-Augustin JULIEN** — *Finance and Procurement*
- **Guillaume PINGET** — *Assets and Property*
- **Françoise ROUDAUT** — *Information Systems*
- **Pierre-Yves SAINT** — *Support for Scientific Management and Administration (DIAGONAL)*
- **Cécile JANET** — *Legal Affairs*
- **Marie-Claude PAULIEN** — *Coordination of Research Support Services*

- **Karine GUERITAT** — *Head Office Administrator*
- **Philippe MARTIN** — *Head Accountant*

DELEGATIONS

- **Françoise SIMON-PLAS** — *Professional Conduct, Scientific Integrity, and Research Project Ethics*
- **Catherine BEAUMONT** — *Gender Equality and Anti-Discrimination*
- **Nathalie GANDON** — *Data Protection*
- **Stéphane AYMERICH** — *Research Infrastructure*
- **Christophe ROTURIER** — *Science in Society*
- **David CAFFIER** — *Biosafety*

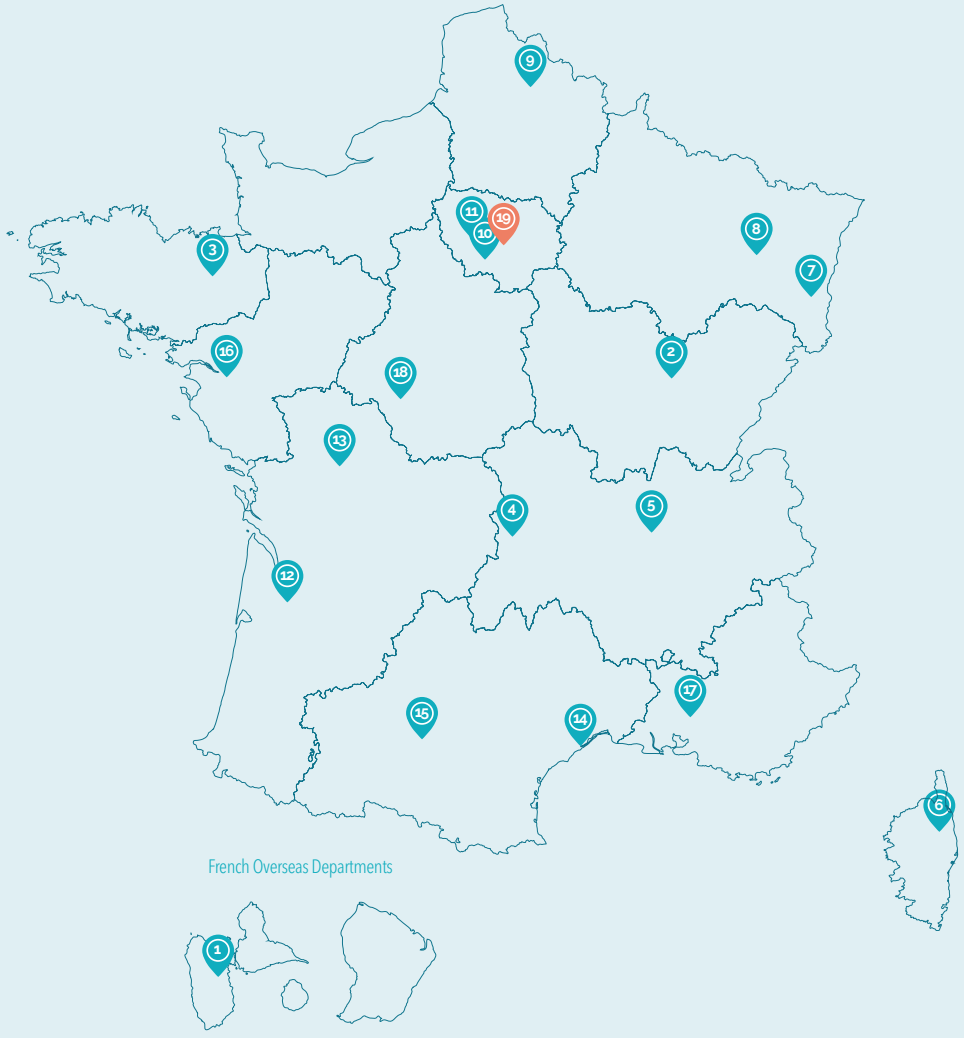
MISSIONS

- **Nicolas BÉCARD** — *Security and Defence*
- **Sylvie NUGIER** — *Information Systems Security*
- **Michaël CHELLE** — *Digital Transition*
- **Hadi QUESNEVILLE** — *Chief Data Officer*

INRAE's 18 centres

(As of 31 December 2021)

18 research centres reflect INRAE's involvement in key regional dynamics.
The Institute also has two head offices.



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1. French West Indies and Guiana
   President: Harry Archimède
2. Burgundy-Franche-Comté
   President: Nathalie Munier-Jolain
3. Brittany-Normandy
   President: Hélène Lucas
4. Clermont-Auvergne-Rhône-Alpes
   President: Emmanuel Hugo
5. Lyon-Grenoble-Auvergne-Rhône-Alpes
   President: Pascal Boistard
6. Corsica
   President: André Torre
7. Grand Est-Colmar
   President: Serge Kauffmann
8. Grand Est-Nancy
   President: Meriem Fournier
9. Hauts-de-France
   President: Jean Tayeb
10. Île-de-France-Jouy-en-Josas-Antony
    President: Nathalie Touze
11. Île-de-France-Versailles-Grignon
    President: Egizio Valceschini
12. Nouvelle-Aquitaine-Bordeaux
    President: Olivier Lavialle
13. Nouvelle-Aquitaine-Poitiers
    President: Abraham Escobar-Gutierrez
14. Occitanie-Montpellier
    President: Sylvain Labbé
15. Occitanie-Toulouse
    President: Pierre-Benoit Joly
16. Pays de la Loire
    President: Emmanuelle Chevassus-Lozza
17. Provence-Alpes-Côte d'Azur
    President: Jean-Philippe Nabot
18. Val de Loire
    President: Marc Guérin
19. **Paris-Antony Head Office**
    Administrator: Karine Gueritat

INRAE'S 14 research divisions

(As of 31 December 2021)

- Action and Transitions
  Christophe SOULARD
- Agroecosystems
  Philippe HINSINGER
- Human Nutrition and Food Safety
  Lionel BRETILLON
- Aquatic Ecosystems, Water Resources and Risks
  Mohamed NAAIM
- Plant Biology and Breeding
  Isabelle LITRICO-CHIARELLI
- Ecology and Biodiversity
  Catherine BASTIEN
- Economics and Social Sciences
  Pierre DUPRAZ
- Animal Genetics
  Edwige QUILLET
- Mathematics and Digital Technologies
  Hervé MONOD
- Microbiology and the Food Chain
  Sylvie DEQUIN
- Animal Physiology and Livestock Systems
  Françoise MÉDALE
- Animal Health
  Muriel VAYSSIER-TAUSSAT
- Plant Health and Environment
  Marie-Hélène OGLIASTRO
- Food, Bioproducts and Waste
  Michael O'DONOHUE

INRAE'S Units

204 research units

43 experimental units

24 support service units


INRAE

Annual report

2021

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Join us on:

www.inrae.fr/en

French national research institute for agriculture, food and environment

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

INRAE