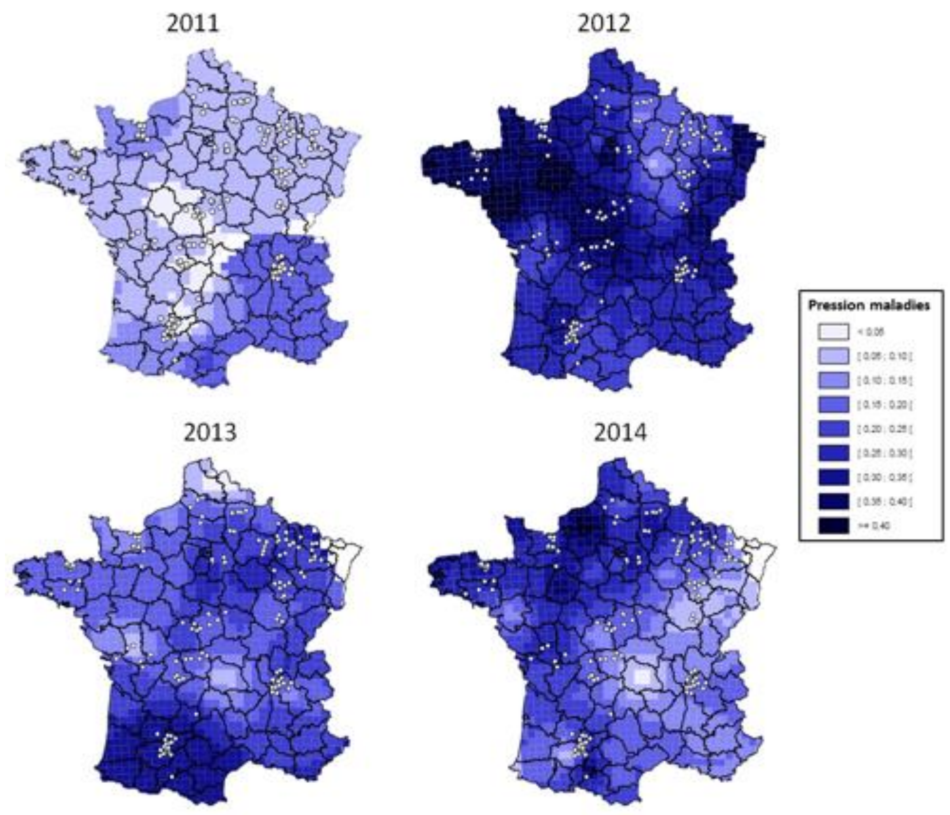
14 May 2024,
COST Training school
Bordeaux

Towards a productive pesticide-free agriculture in Europe: motivations, challenges and prospects

Christian HUYGHE, Scientific Director Agriculture, INRAE, France

Crop protection is compulsory to ensure safe and affordable food to all



Yield losses due to foliar diseases in bread wheat in absence of any protection
Urruty et al, 2016

- In absence of protection, losses may be high, are variable among sites and years and not predictable

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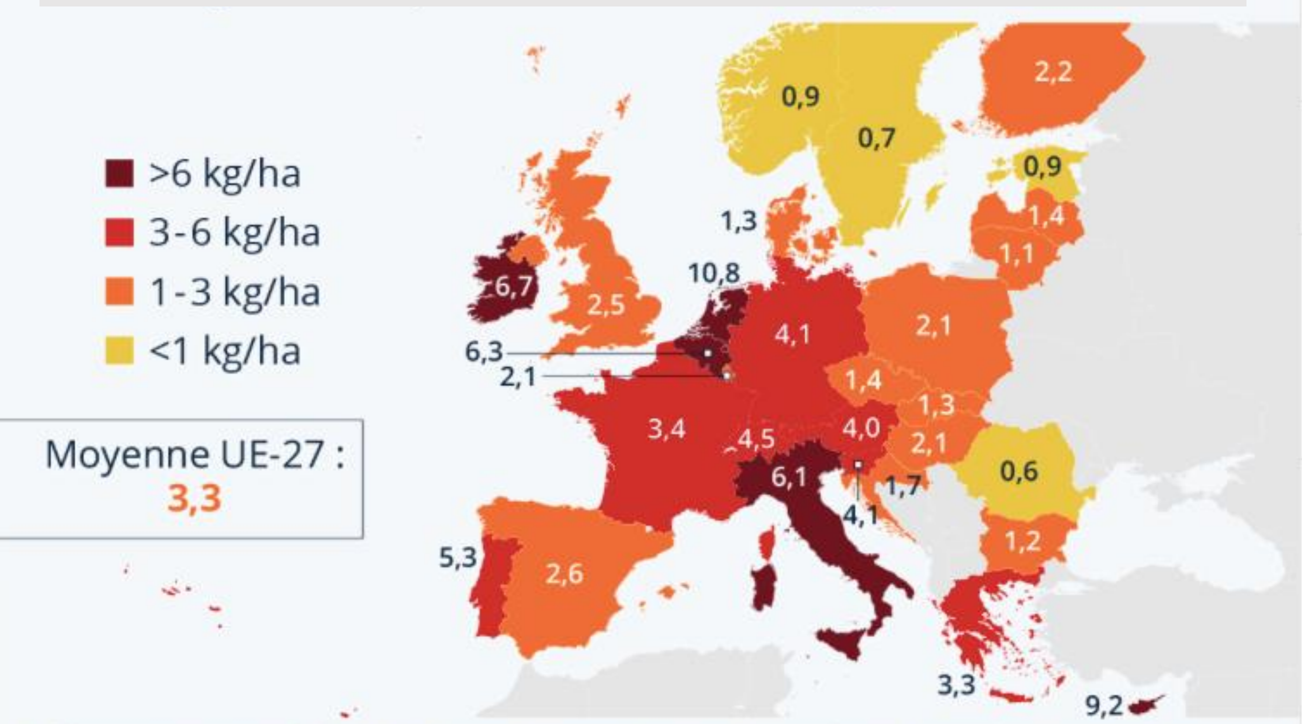
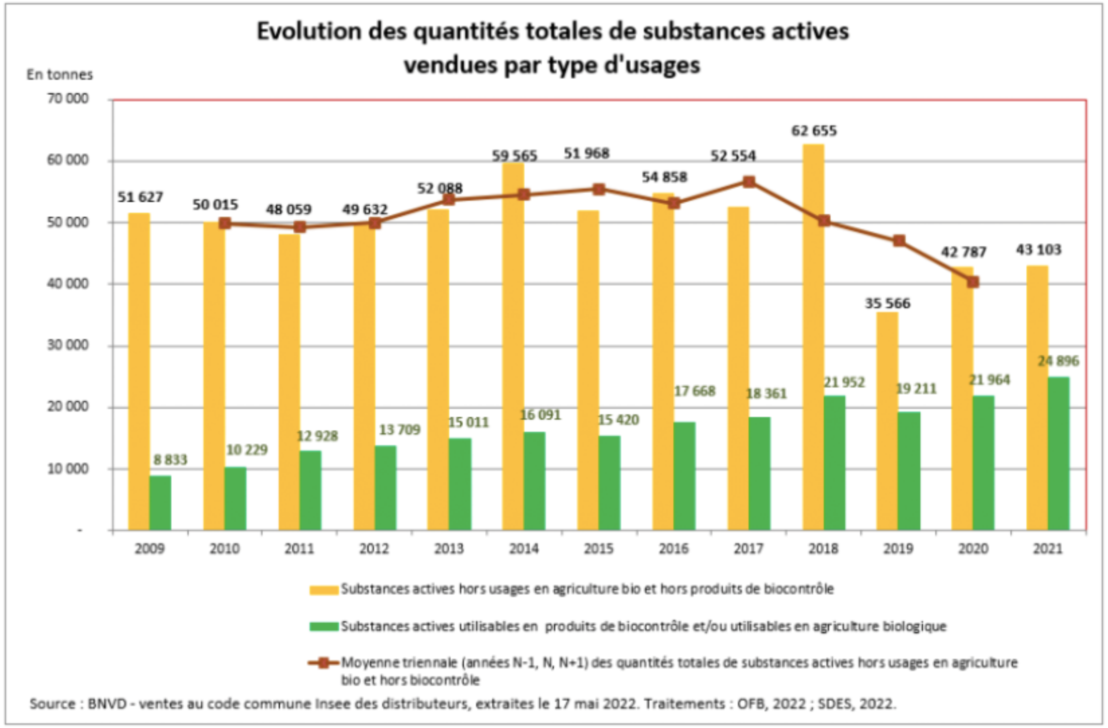
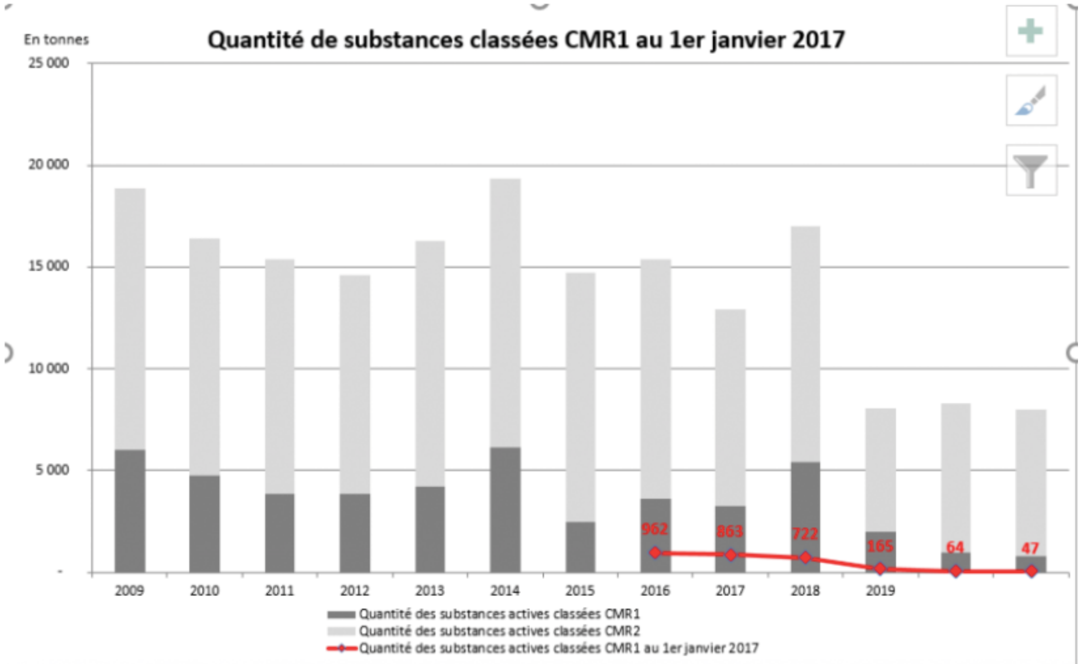
Crop protection is achieved today with massive use of chemical pesticides…

European use of pesticides (kg/ha of arable land in 2020



Sélection : pays de l'UE et Suisse, Royaume-Uni, Norvège. Données arrondies.
Source : FAO





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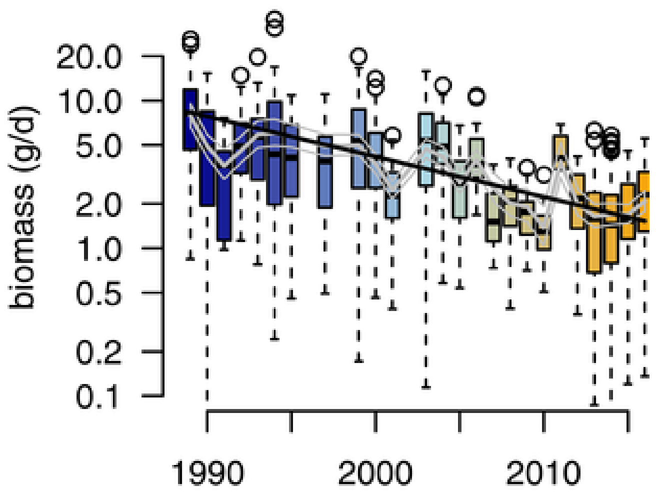
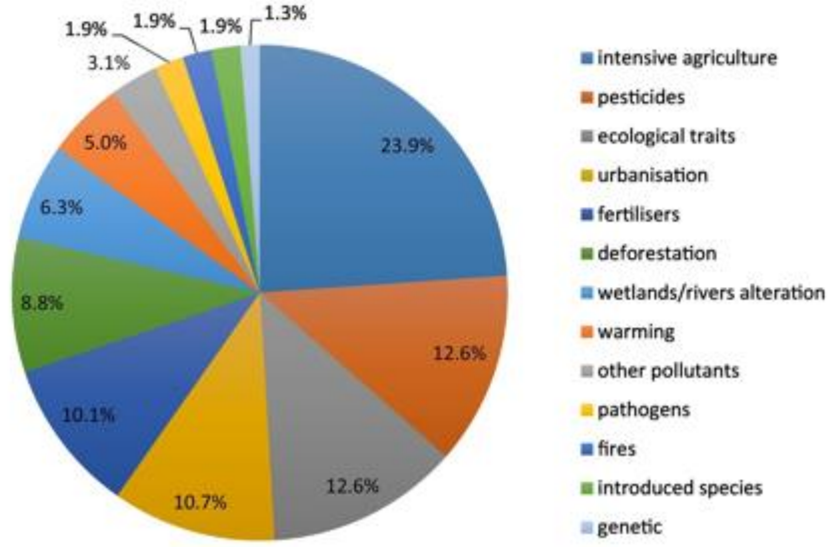
…generating an unsustainable pressure on environment and biodiversity, pesticides being a cornerstone of cropping systems



-75% of insects biomass in 26 years

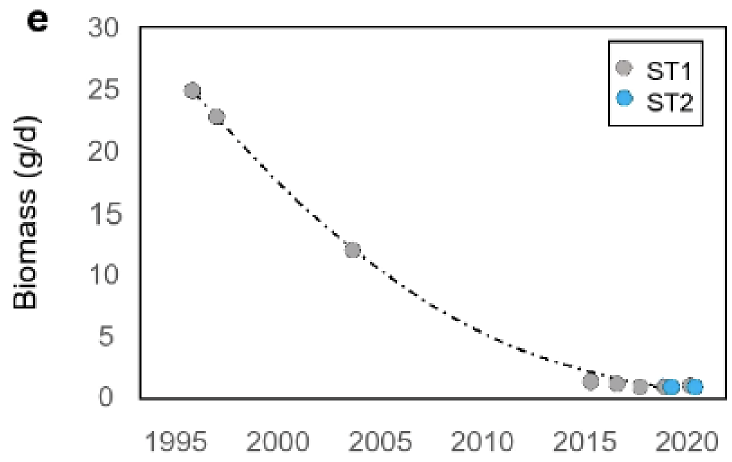
Hallmann CA et al. (2017) PLOS ONE 12(10): e0185809. https://doi.org/10.1371/journal.pone.0185809

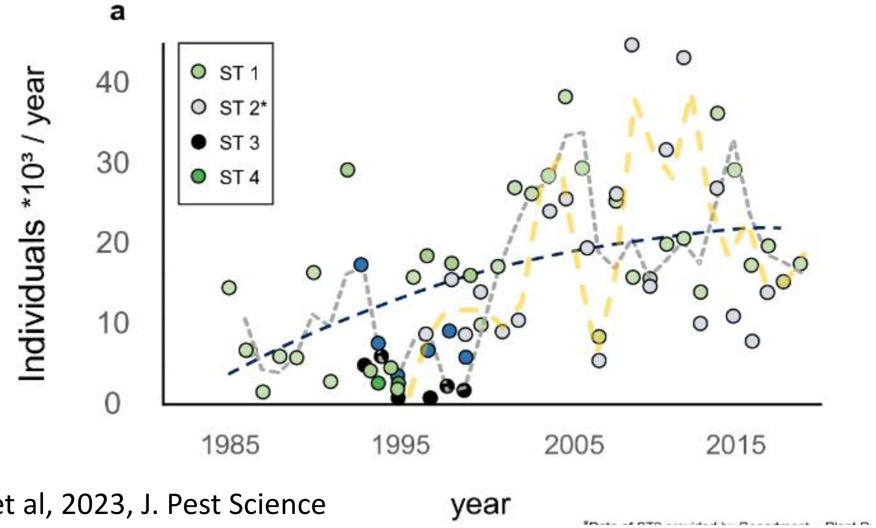


Sanchez-Bayo F et Wyckhuys KAG, 2019, Biological Conservation

In the areas of arable crops in Germany

- A 95% loss in insect biomass
- Populations of aphids are increasing (loss of biological regulations)





Ziesche TM et al, 2023, J. Pest Science

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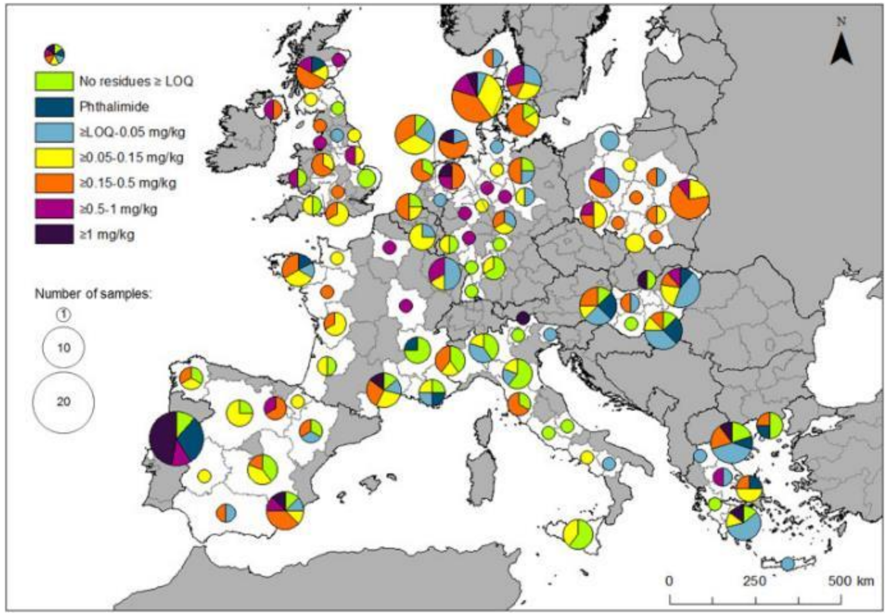
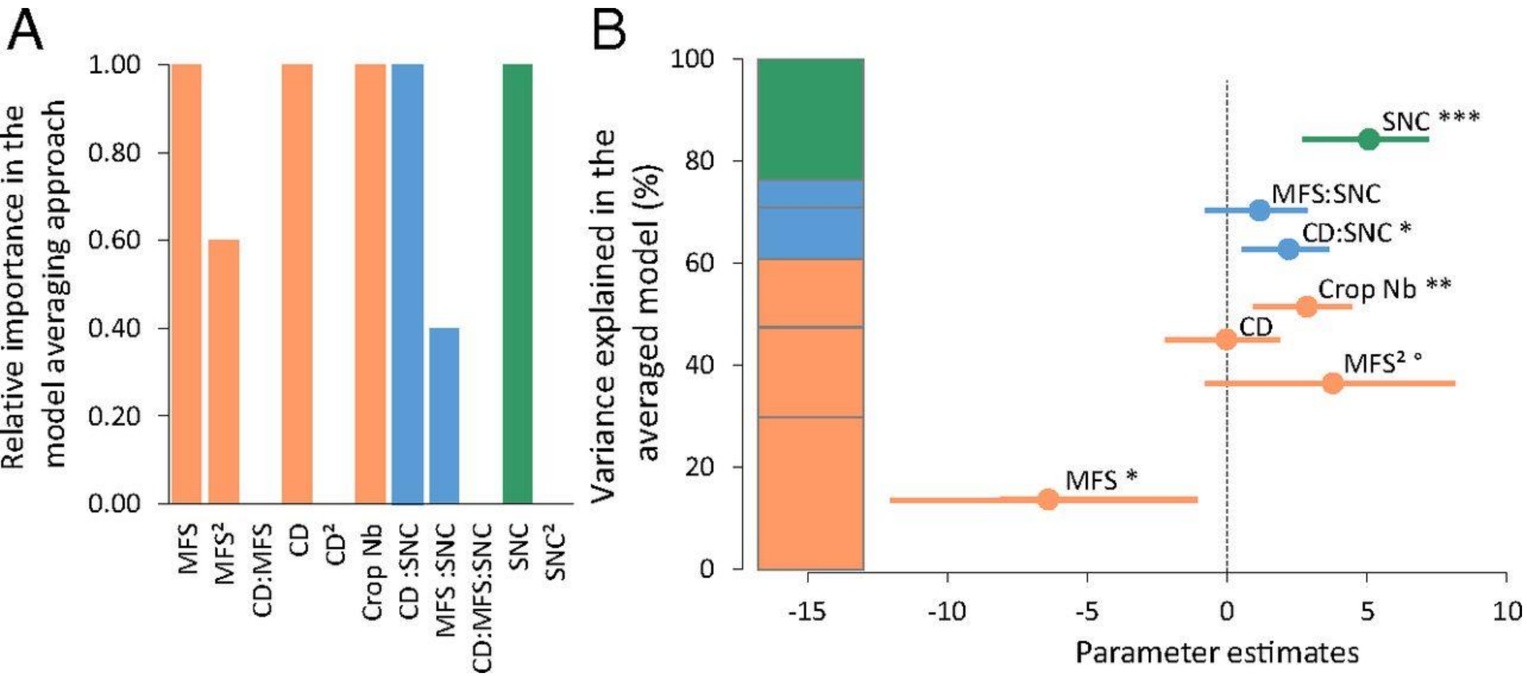
Agricultural practices, pesticide load and land use are the main sources of insect losses

…generating an unsustainable pressure on environment and biodiversity, pesticides being a cornerstone of cropping systems



Distribution of total pesticide contents in EU agricultural topsoils (according to Silva, 2019)

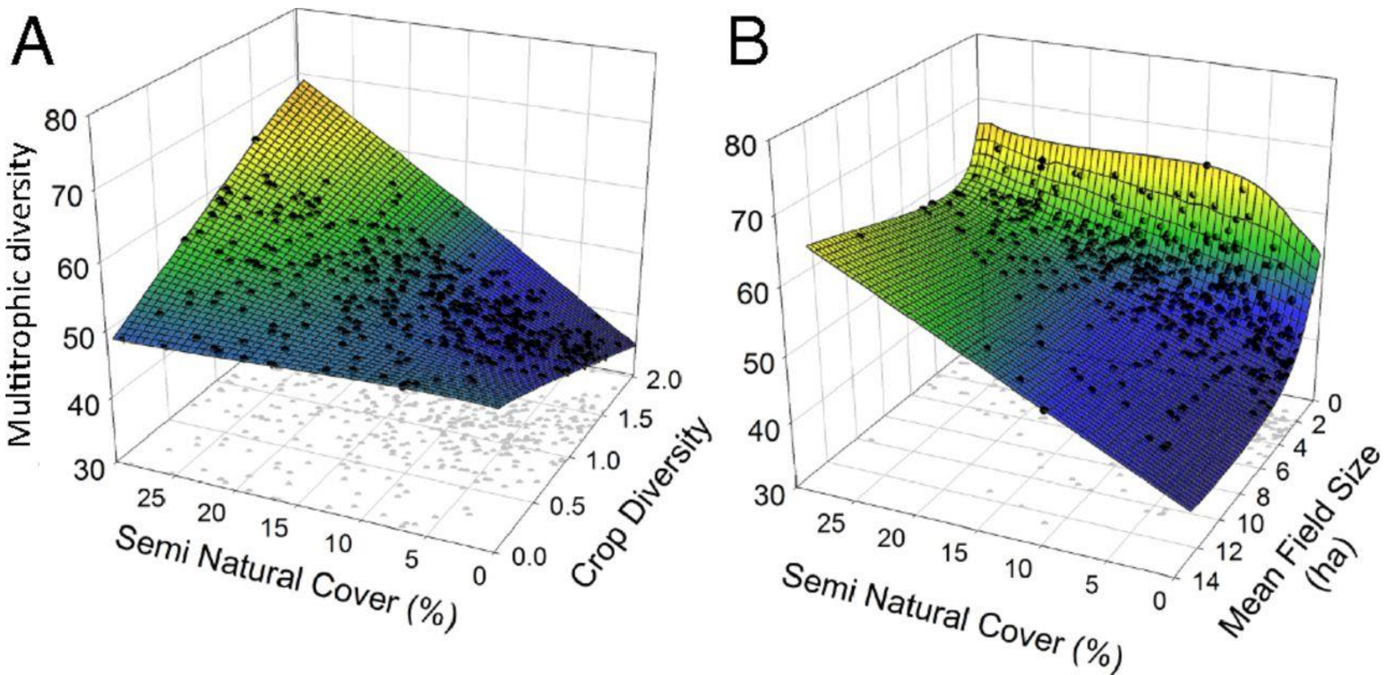
A worldwide review of soil contamination by pesticides has been recently proposed by Sabzevari and Hofman (2022, Science of the Total Environment)



Landscape heterogeneity (mean field size, crop diversity, semi-natural cover) are essential for biodiversity

According to Sirami et al, 2019, PNAS

What are the items on which innovation and public policies could play a role?



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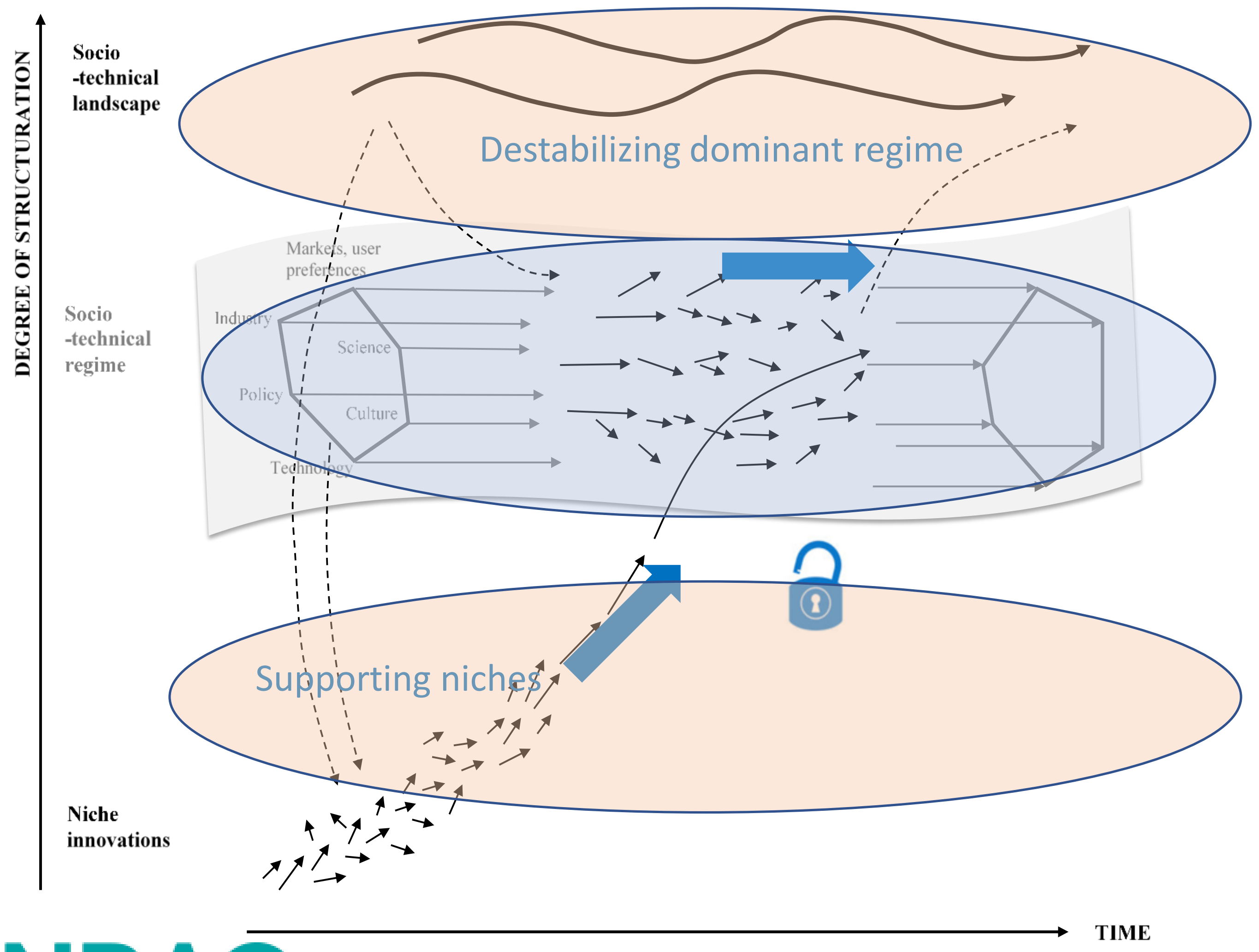
Crop protection is a typical lock-in situation



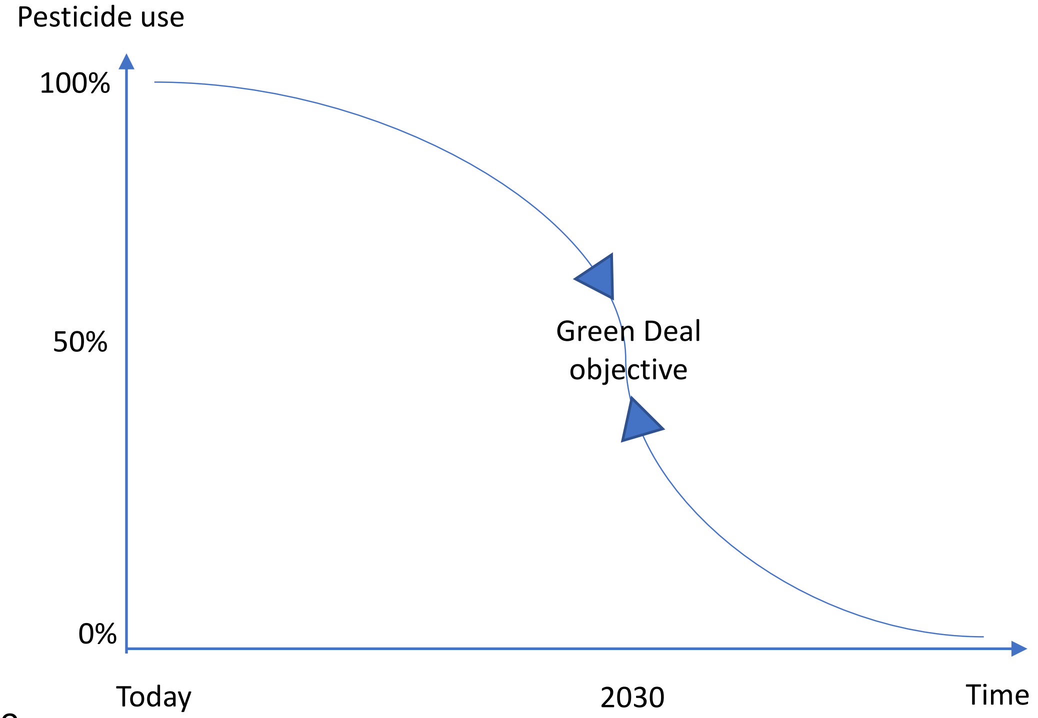
(adapted from Ollivier et al., 2018 (Ecology and Society) who adapted from Geels, 2002 (Research Policy))

How to achieve the -50% reduction objectives?

- Incremental innovations into the existing cropping systems (**E** and **S** according to Hill and Mc Rae)

OR

- Disruptive innovations based upon paradigm shifts (**S** and **R** according to Hill and Mc Rae)



Options for future sustainable crop protection

- Avoiding an *a priori* attitude that a trade-off between production and environment has to be accepted

- Levers already exist (genetics, biocontrol) but are not sufficient for a 0-pesticide agriculture. Innovations are required and prophylaxis must be first
- What are the possible knowledge and innovation breakthroughs, in the coming decade *(under the hypothesis of absence of limitations due to regulations and societal acceptance)* ?

- *A EU proposition for a revised version of the **Directive** 2009/128 (Sustainable Use of pesticides) towards a **Regulation** was released on 22 June 2022 and rejected in Dec 2023*
- *A foresight 'Pesticide-free agriculture in Europe in 2050', released on March 21rst 2023 in Paris and discussed at the European Parliament in Brussels on April 27th 2023*

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Scenario 1 (S1) : **Global Market**: World and European food chains based on digital technologies and plant immunity for a food market without pesticides

Food supply chains	Supplying pesticide-free foods as a sanitary security standard	Supplying safe foods for safe diets with lower animal products	Supplying foods preserving human and environment health (much lower proportion of animal products) and providing diversified landscapes
Farm structures	Specialization and financiarisation of farms with residual family farms	Local diversity of farm structures	Site-dependent and diversification of farm structures
Cropping systems	Renforcing immunity defences of crops	Using holobiont of cultivated species with more interactions between host plants and microorganisms	Conceiving complex and diversified landscapes adated to local conditions
Digital technologies and machinery	Autonomous robos acting on each plant	Sharing equipments sensors and data)	Modula equipments adapted to practice peculiarities

- Scenario 2 (S2) : European food chains based on plant holobionts, soil and food microbiota, for healthy food and diets
- Scenario 3 (S3) : Complex and diversified landscapes and local food chains for a One Health European food system

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The knowledge and innovation breakthroughs in the coming decade

- Crop and practice diversification to maximize the ecosystem services (R)

According to a synthesis of 98 meta-analyses, gathering 6160 original studies (Tamburini et al, 2020, Science Advances **6** : eaba1715): **Increasing diversity of practices and of crops massively increases environmental services while preserving production**

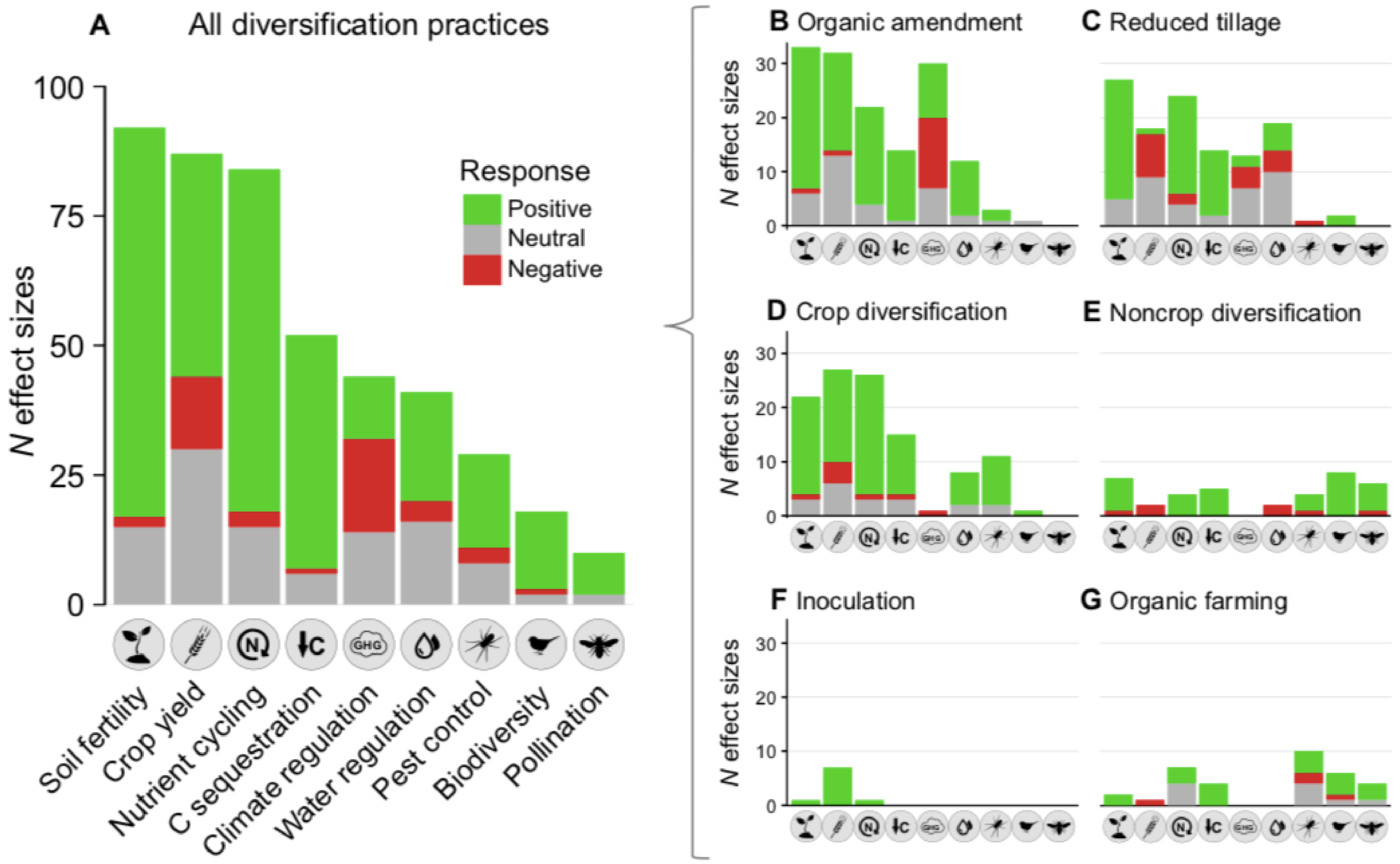
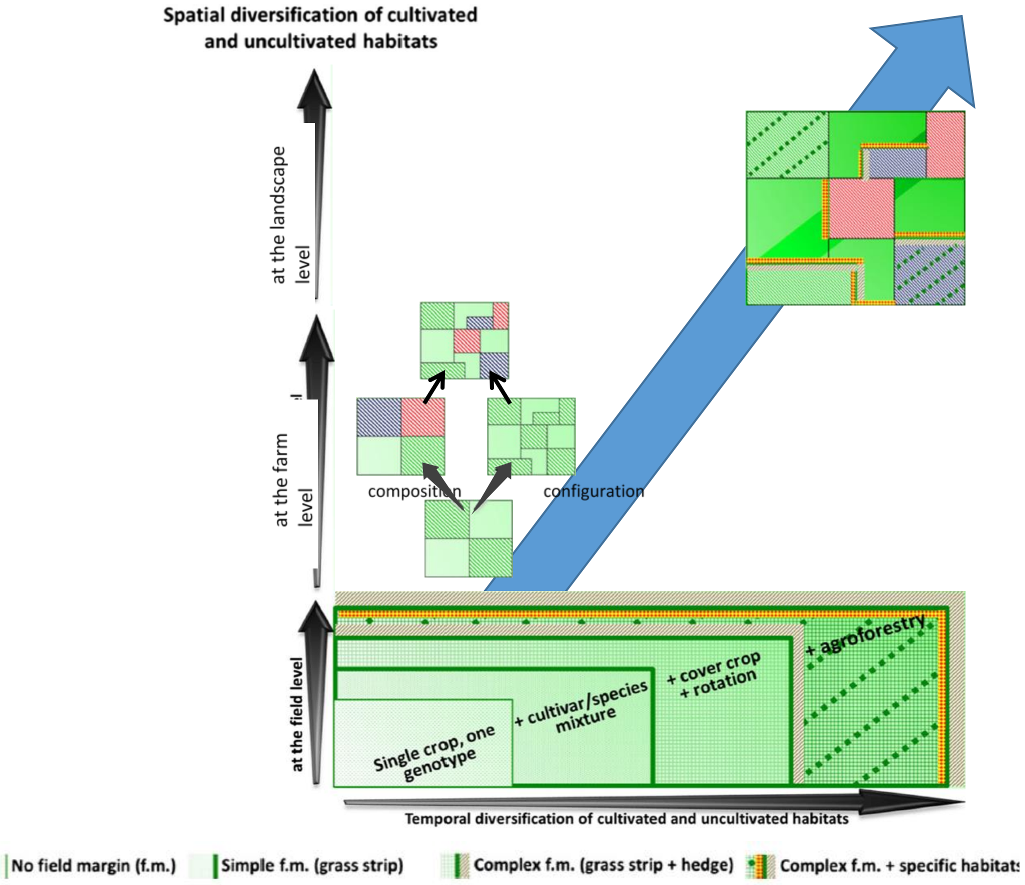


Fig. 1. Vote count reveals that agricultural diversification practices generally have a positive impact on biodiversity and ecosystem services. Number of reported effect sizes with a significant positive (green), negative (red), or neutral (gray) response to agricultural diversification, overall (**A**) and to each category of diversification practice separately (**B** to **G**). The systematic review comprises 456 effect sizes from 98 meta-analyses based on 6167 original studies (fig. S1). Diversification practice and ecosystem service categories were based on classifications following (*8*, *9*) and (*13*, *14*, *27*), respectively (tables S1 and S2).

Fully consolidated by the paper of Beillouin et al, 2021: **Positive but variable effects of crop diversification on biodiversity and ecosystem services**. *Global Change Biology*

The collective scientific expertise on the natural regulations obtained from increasing functional diversity (Oct 2022)



	Adventices	Insectes aériens	Insectes telluriques	Maladies vectorisées	Pathogènes aériens	Pathogènes telluriques	Nématodes	Autres bioagresseurs
Mélanges variétaux	* Effet attendu positif	**	?	* Effet faible	*** Amplitude très variable	* Effet faible	?	?
Cultures associées	***	*** Effet fort	*	?	*** Effet fort	* Amplitude variable	?	?
Agroforesterie	** Effet assez fort	*** Amplitude variable	?	?	** Effet plus faible que pour les insectes	?	*	striga : * — gastéropodes : * Effet lié à l'absence de travail du sol
↗ diversité rotations	*** Effet fort lié au travail du sol	* Effet à l'échelle du paysage	* Effet potentiellement fort	?	* Efficace lorsque l'inoculum est local	* Effet potentiellement fort	** Effet potentiellement très fort	?
↘ part d'une culture dans le paysage	?	*	?	* Effet attendu positif		? Effet attendu nul ou très faible	?	rats taupiers : *
↗ diversité de l'assolement	0*	*	?	* Effet attendu positif		? Effet attendu nul ou très faible	?	araignées : 0* — chauves-souris : * — oiseaux : *
↘ taille des parcelles	*	*	?	* Effet attendu peu clair			* Effet attendu peu clair	?
↗ distance d'isolement entre cultures	* Effet attendu variable	*	* Effet attendu positif	* Effet attendu positif			* Effet attendu positif	?
↗ diversité des ESN dans le paysage	* Effet attendu positif	** Effet faible	?	*			?	Acariens : * Effet attendu positif

NB : La **non-additivité des effets** synthétisés dans ce tableau interdit toute lecture transversale entre lignes mais aussi entre colonnes. Cette règle est d'autant plus fondamentale que l'analyse des effets multiples de chaque modalité de diversification sur des cortèges de bioagresseurs, ainsi que des effets combinés de plusieurs modalités de diversification constitue un champ de recherche à développer.

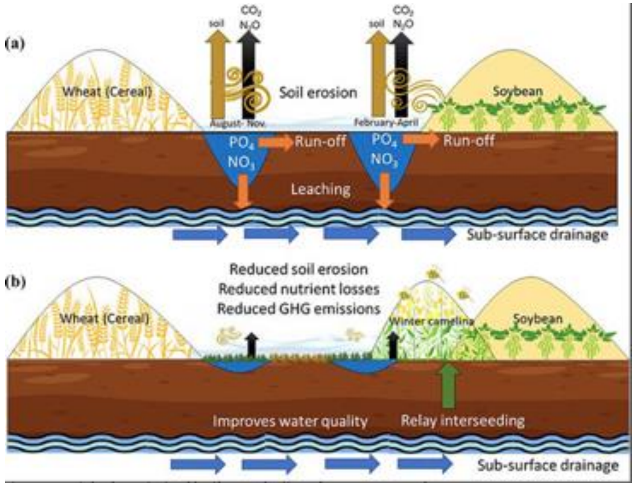
In practice

New species and new swards to produce ecosystem services

- New species
  - Crops for new food and non food demands: meeting dietary transitions
  - Crops adapted to climate change
  - Cover crops and intercrops to preserve environment (e.g. soil conservation, biodiversité): Towards multi-services intercrops
  - Species for living mulchs

- New cropping systems
  - Growing mixtures of species, with different functional traits (LER >1)
  - Relay-cropping (crop n+1 sown long before the harvest of crop n, LER >>1).
  - Agroforestry
  - Strip-cropping

Relay-copping with soybean sown in winter wheat



Gesch et al, 2023

The knowledge and innovation breakthroughs in the coming decade

- Crop and practice diversification to maximize the ecosystem services
- Digital, machinery and robotics (E, S and R)

- Drilling multi-species swards

- Efficient alternative for weed control

- Leading to reconception of agronomic practices

The knowledge and innovation breakthroughs in the coming decade

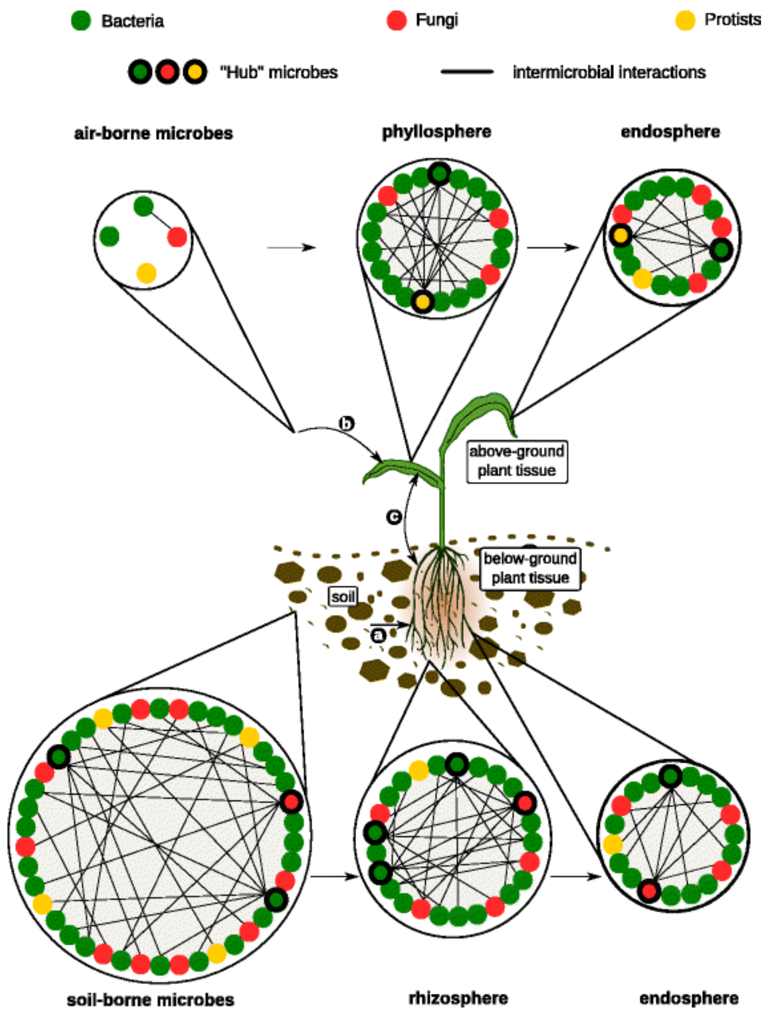
- Crop and practice diversification to maximize the ecosystem services
- Digital, machinery and robotics
- Odorscape and chemical ecology (R)

- Insect behavior is highly driven by odors in the environment: presence of volatile organic compounds
    - Sexual confusion (pheromons)
    - Detection of host plants
        - Tagetes and protection against flies (in gardens)
        - Mixtures of rapeseed and annual forage legumes to control cabbage-stem flea beetle *Psylliodes chrysocephalus*
    - Attracting predators against aphids/pests (Verheggen et al, 2020)

- Emergence of the concept of odorscape
    - For screening substances or plant species
    - For setting new survey systems (trapping odors of pests)
    - Creating new agricultural landscapes with odor gradients?

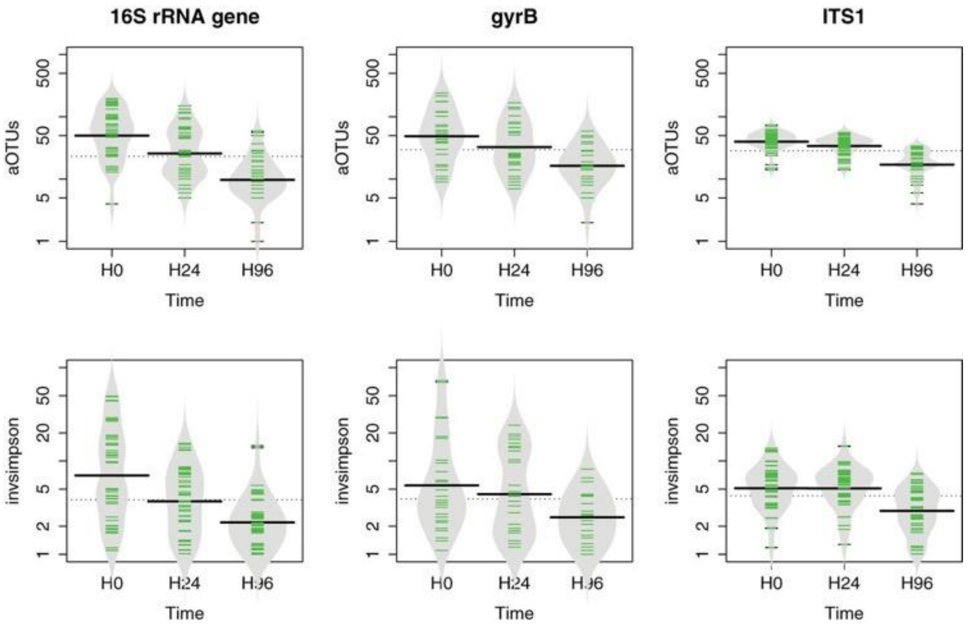
The knowledge and innovation breakthroughs in the coming decade

- Crop and practice diversification to maximize the ecosystem services
- Digital, machinery and robotics
- Odorscape and chemical ecology
- Microbiota, including endophytes: a key role for plant protection and plant nutrition (R)



Hassani et al, 2018, Microbiome 6, Art 58

Complexity of microbial networks in the various plant compartments.



Matthieu Barret et al. Appl. Environ. Microbiol. 2015

Horizontal transmission through seeds and screening during seedling emergence

Challenges

- Towards the concept of holobiont
- Screening plant microbiota and understanding the functions
- Defining complex and stable microbiota communities
- Applying them to seeds and fields
- *Adapting the regulations*

The knowledge and innovation breakthroughs in the coming decade

- Crop and practice diversification to maximize the ecosystem services
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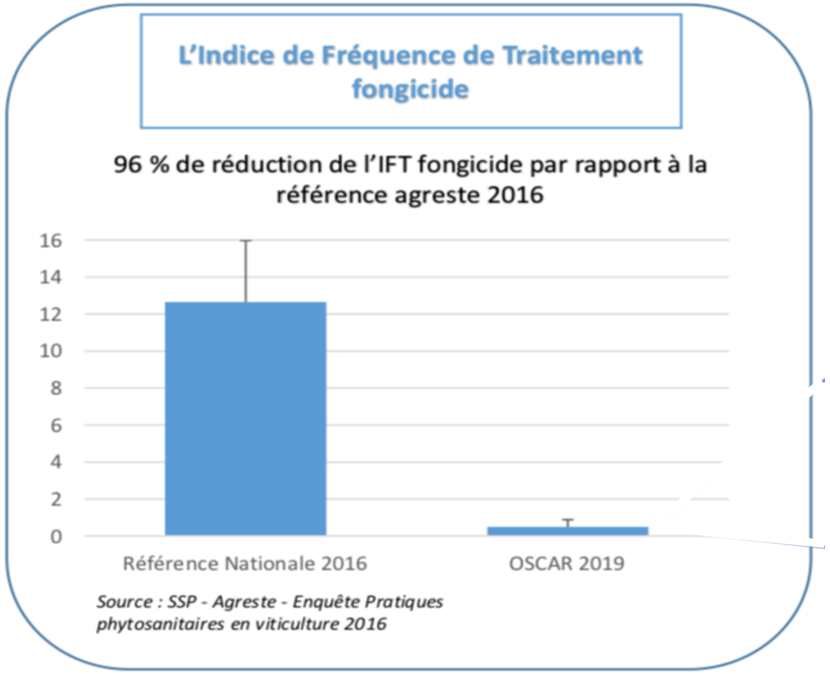
- Microbiota, including endophytes: a key role for plant protection and plant nutrition
- Varieties (E, S)

Genetics and plant breeding for resistance to pests and diseases



Oustanding successes already exist such as in grape, with resistance to downy and powdery mildews

-96% FTI in farm conditions !

Genetics and plant breeding for other traits related to agroecology and crop protection

Many new challenges

- Diversification is only possible if a sufficient variety resource does exist for ‘minor’ species
- Crop competition against weeds is partly due to plant architecture at early stages
- Plant genotype determines the selection of the microbiome: how to endorse this in breeding?
- Plant volatile organic compounds: is it possible to breed for that? Interesting example in *Tagetes*

How to make achieve this **for many/all species**?

- Genetic resources
- High throughput phenotyping infrastructures
- Breeding technologies
  - *Genomic selection (that requires full length sequences)*
  - *New Breeding Technologies and genome editing*

The regulatory issues that are applicable to varieties

- For access to markets in Europe, varieties must be registered on one national catalog
- This implies
  - DUS
  - VCUS (for arable crops, forage crops, vines)
- VCUS includes
  - Production
  - Quality
  - Tolerance to biotic stress

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The knowledge and innovation breakthroughs in the coming decade

- Crop and practice diversification to maximize the ecosystem services
- Digital, machinery and robotics
- Odorscape and chemical ecology
- Microbiota, including endophytes: a key role for plant protection and plant nutrition
- Varieties
- In social sciences, unlocking the sociotechnic systems (R)

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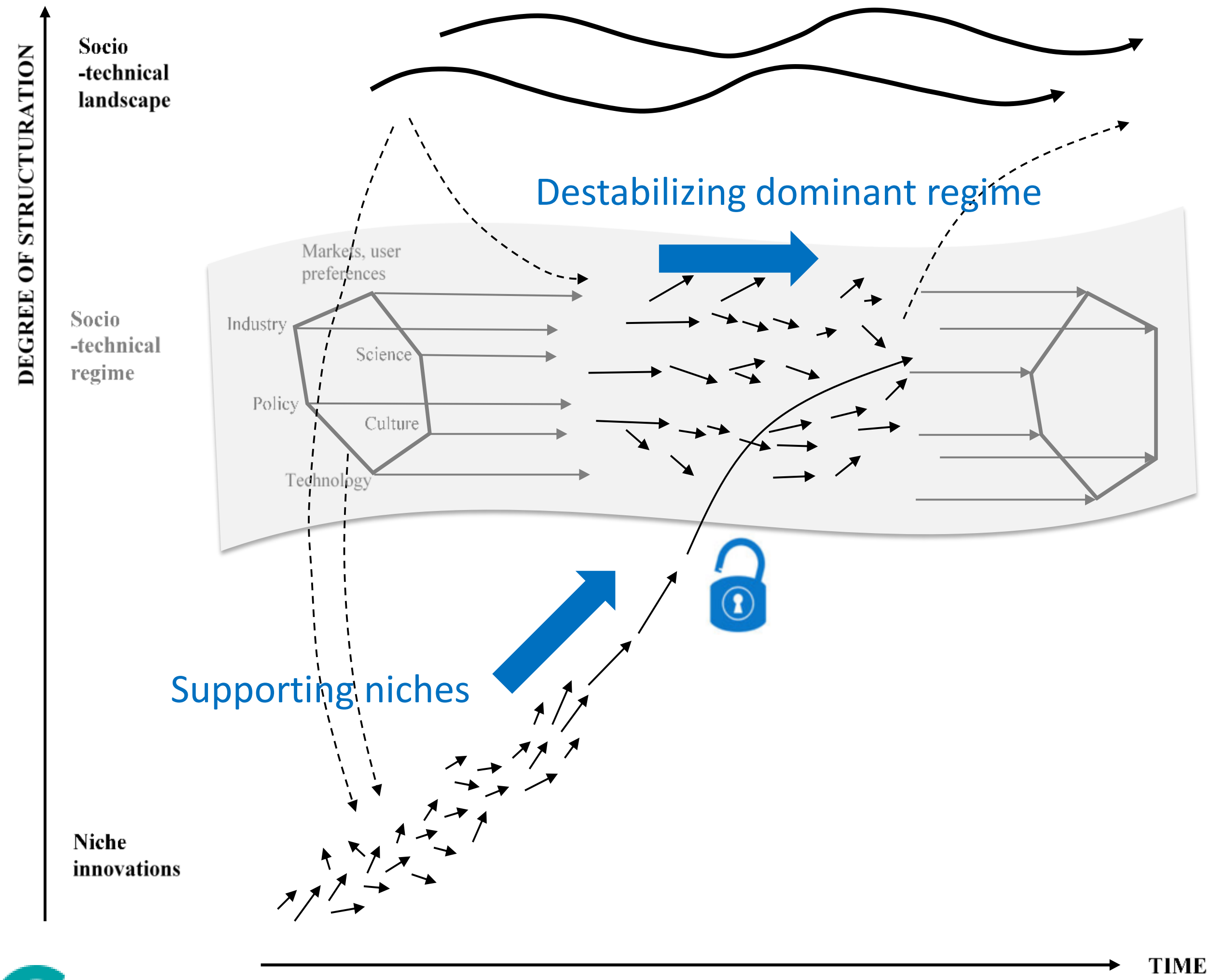
How to unlock locked-in systems?



(adapted from Ollivier et al., 2018 (Ecology and Society) who adapted from Geels, 2002 (Research Policy))

Forcing changes of the socio-technic landscape: public policies including CAP, regulations, listening societal demands

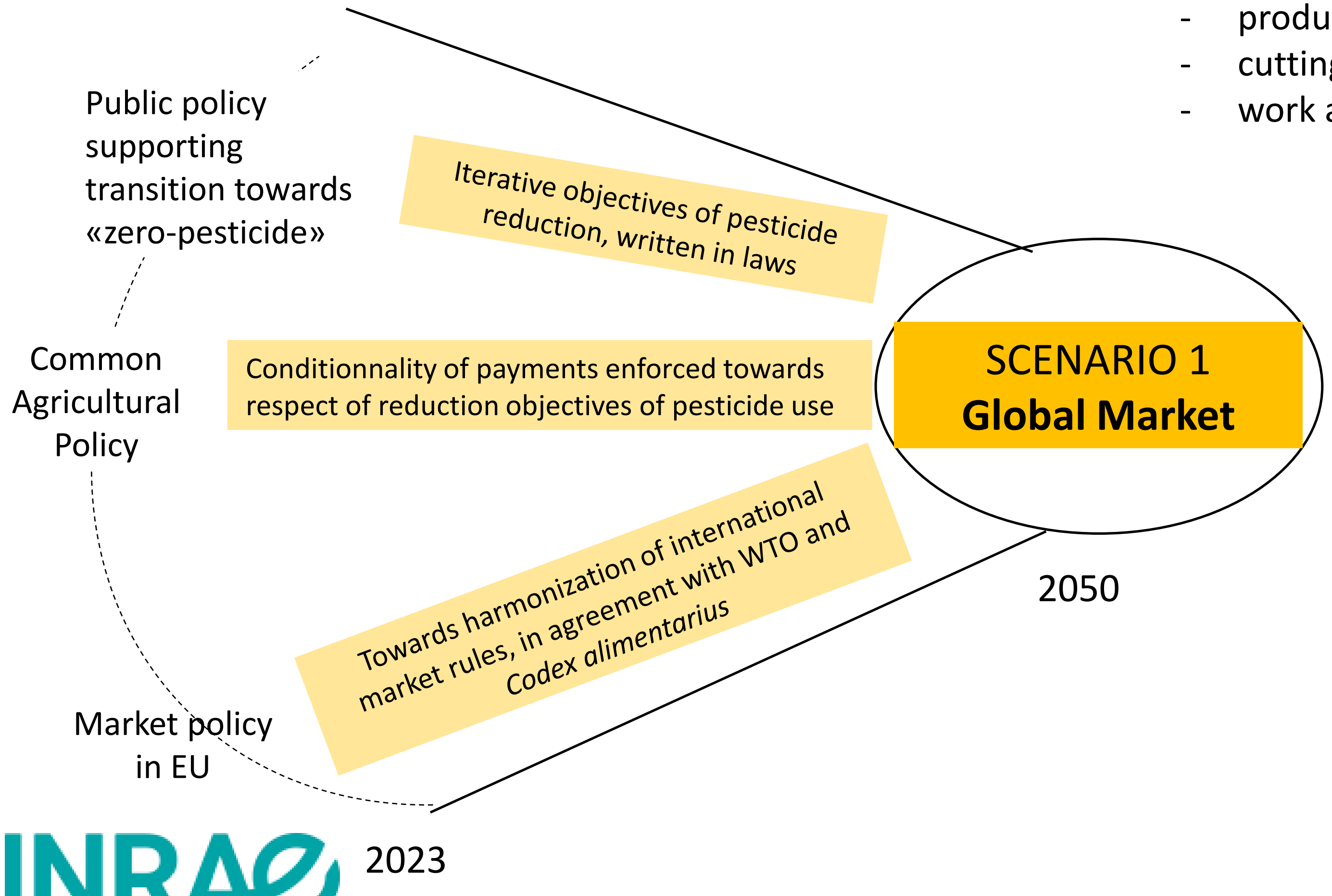
How to go beyond?

- Setting non prescriptive extreme scenarios: 0-pesticides (*PPR, European Research Alliance)*
- Participatory approaches and living labs: involving new players (Klerkx et al, 2020)

Supporting rupture innovation. R&I is essential

The foresight analysis ‘Pesticide-free agriculture in Europe in 2050 for supporting transition

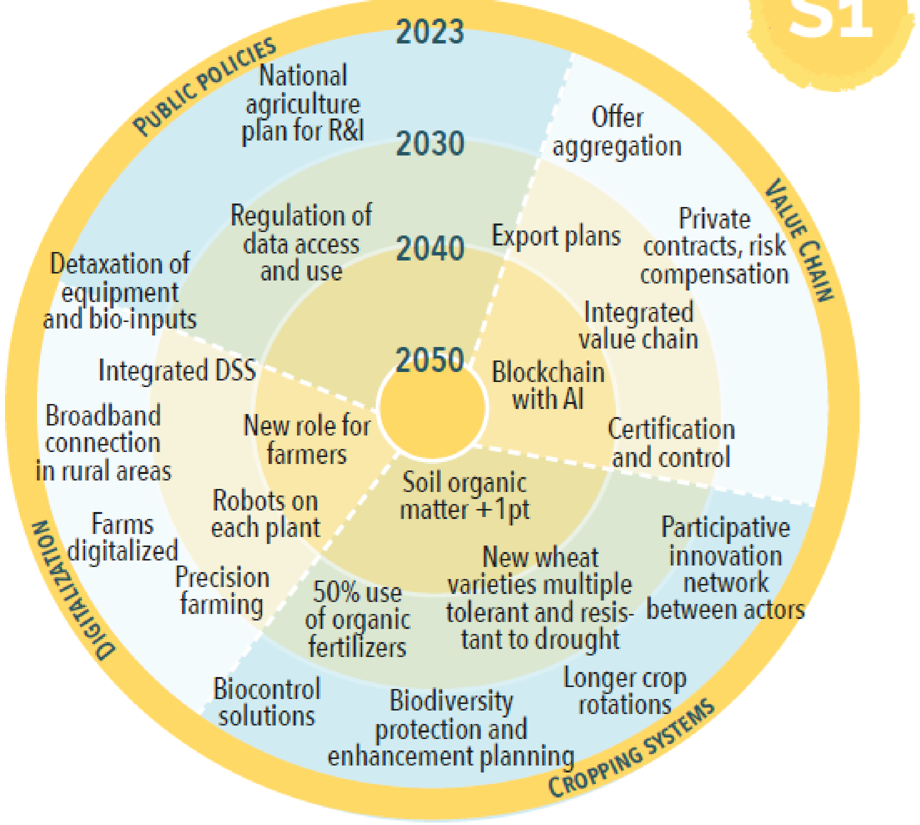
Hypotheses of public policies for a transition towards scenario 1



Regional case study

2050 scenario for durum wheat production without chemical pesticides in Tuscany (Italy)

- **compliance with global market standard**,
- production in **large and specialised farms in Tuscan plains**,
- cutting-edge technologies (precision farming, satellite-guided)
- work at **very large scale with little labour force**.



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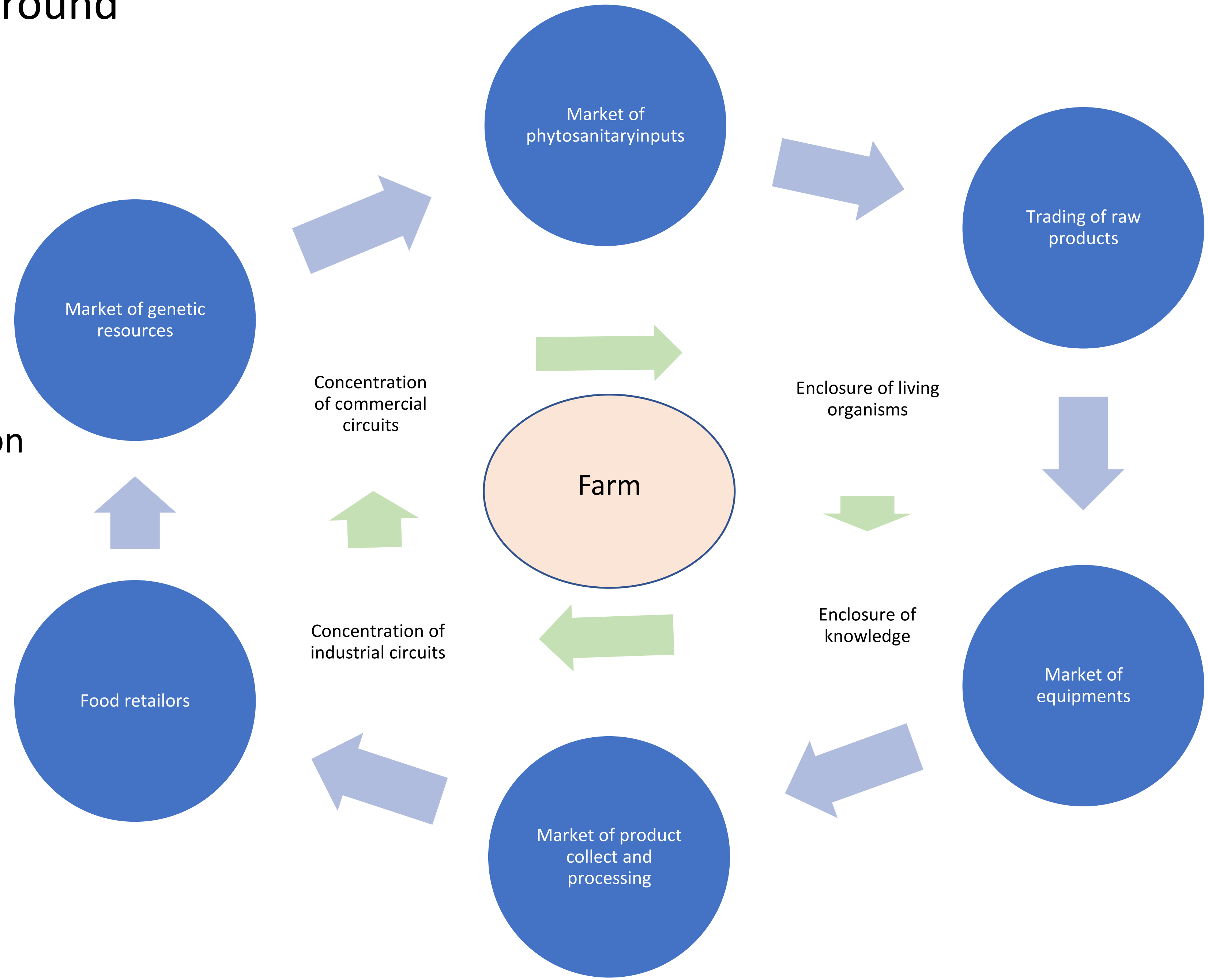
Strong socio-technic lock-in around farms (Geels, 2002)

Adapted from Valiorgue (2020)

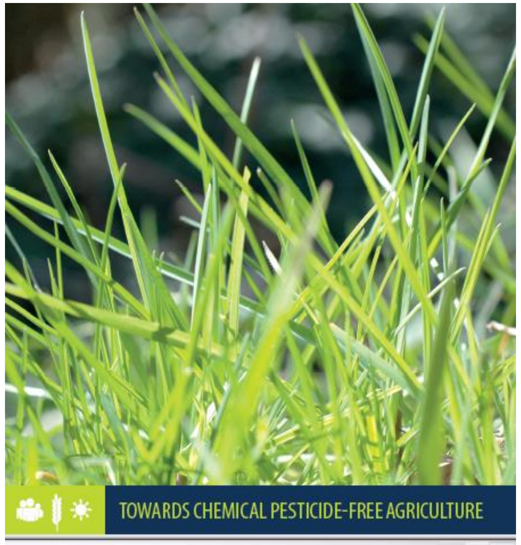


Two major issues to foster transition

- The enclosure patterns
- The weight of specific investments

European Research Alliance

Towards Chemical Pesticide-free Agriculture



- 3 preparatory workshops organized at
  - Inra, Paris, October 2018
  - JKI, Berlin, May 2019
  - Luke, Helsinki, October 2019
- Signature of the MoU
  - SIA, Paris, February 2020
- Annual General Assembly
  - Next: 22 May 2024, Zagreb

A unique context with emerging fronts of science

- Microbiota and its impact on plant health
- Plant-plant interactions and their impacts on crop diversification
- Chemical ecology, insect and plant odorscapes
- Ecological immunology and plant immunity

Today

- 37 organisations
- 21 countries

Achievements

- An increasing scientific community
- Contribution to a foresight study published in March 2023
- A Cost project approved (CA 21134)
- A CSA approved (Fortuna)
- A Life-PLP approved (Agrowise)

COST ACTION 21134

Towards zer0 Pesticide AGRIculture : European Network for sustainability (TOP-AGRI-Network)

Action Chair: Christian Huyghe (France)

Action Vice-Chair: Renata Bazok (Croatia)

WG1 leader: Mugur Jitea (Romania)

WG2 leader: Danilo Christen (Switzerland)/Christian Andreasen (Denmark)

WG3 leader: Dimitris Tsitsigiannis (Greece)/Sevgi Marakli (Turkey)

WG4 leaders: Riccardo Bommarco (Sweden)/Kathrin Grahmann (Germany)

WG5 leader: Silke Dachbrodt (Germany)/Federic Leoni (Italy)

Grant Awarding Coordinator: Elisabete Figueiredo (Portugal)

Starting 1rst November 2022
Now: 330 participants

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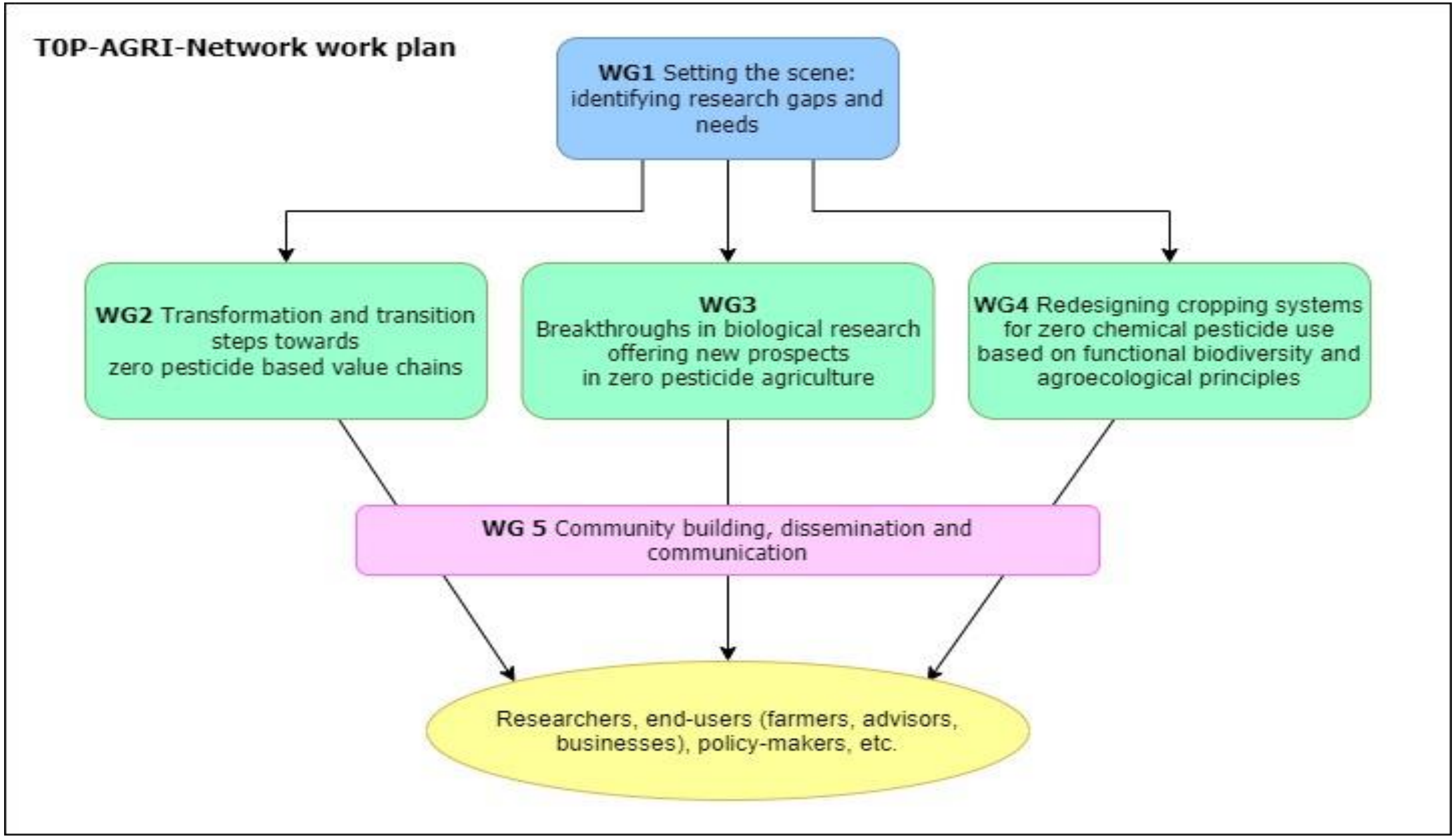
COST Action Structure



You are invited to join the WGs!

INRAE https://www.cost.eu/actions/CA21134/#tabs+Name:Working%20Groups%20and%20Membership


Thank you for your attention …