Alternatives to stopping neonicotinoids: shedding light on the debate

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Summary:

Neonicotinoids are the symbol of agriculture built on chemistry. Despite their efficiency, neonicotinoids' effect have been judged disproportionately impactful, leading to the disappearance of biological regulations and weakening some useful functions of the agroecosystem. The withdrawal of neonicotinoids represents a real challenge, because in a context where the criteria used to assess agricultural performance struggles to go beyond the purely economic and short-term dimensions, there is no single alternative capable of replacing the plant protection products that have been withdrawn. Effectively, systems need to be rethought in their entirety and a new combination of tools envisioned. For example, the funding of a number of scientific projects in several sectors under a dedicated call for projects entitled "Ecophyto: Sustainable crop protection without neonicotinoids: improving the emerging and opening up innovative prospects" has enabled progress to be made in the management of arthropod pests and vectors by mobilising varietal characteristics, biocontrol solutions, and crop management itineraries to boost resilience or ensure an avoidance strategy for the most problematic situations. If we accept that the situation "with neonicotinoids" can no longer be considered as the benchmark, all these avenues can help to outline possible ways forward for agriculture that is open to an agroecological transition. The faster farmers are supported and trained to master these new approaches, the faster the upstream and downstream sectors of agriculture are mobilised to amplify the approach or take the effectiveness of the alternatives further than the 20-40% effectiveness of the individual alternative levers currently in use.

Key words: insecticide, alternative, preventive measure, agroecology, partial effect, environmental impact, Ecophyto

1. Introduction

1.1 Background

European Directive 2009/128 sets out a framework for the use of plant protection products (PPPs) that is compatible with sustainable development. In 2008 France initiated the implementation of the directive in the Ecophyto Plan. The initial plan aimed to reduce the use of PPPs by 50% within 10 years, if possible.

Although this first plan led to the launch of a number of structuring actions with dedicated experiments and pilot farms (DEPHY network[1]), it did not however achieve the results expected by the majority of

1 The FERME DEPHY network brings together 3,000 farms involved in a voluntary initiative to reduce pesticide use. The DEPHY EXPE network brings together 41 project leaders spread over some 200 experimental sites, and enables the design, testing and evaluation of cropping systems aimed at significantly reducing the use of plant protection products. https://agriculture.gouv.fr/les-fermes-dephy-partout-en-france-des-systemes-de-production-performants-et-economes-en-0

stakeholders. There was a slight increase in the tonnage of PPP sales until around 2019, even though a cautious reduction has been underway since[2] .

In 2014, the Ecophyto II plan was introduced, followed in 2018 by the Ecophyto II+ plan which maintains the objective of reducing the use of PPPs by 50% by 2025 and phasing out glyphosate The aim of these plans is to boost the promotion and deployment of agroecological techniques such as prophylactics, diversification, biocontrol solutions, etc. which have already proved their effectiveness with a small number of farmers to the largest possible number of farmers with the creation of the CEPP scheme[3] and the 30,000 farms[4] . Emphasis has also been placed on research and innovation, which we know to have many facets. In order to define, steer and implement the research and innovation strategy, the Research and Innovation Scientific Steering Committee (CSO R&I as the French acronym)[5] was established in 2016. To implement the strategy, the CSO R&I and the ministries (Agriculture and Food Sovereignty, Ecological Transition and Territorial Cohesion, Health and Prevention, Higher Education and Research) are developing and launching themed calls for projects funded by the Office Français de la Biodiversité (OFB) from the financial levy on diffuse pollution tax applied to pesticides.

In 2018 France enacted legislation for the widespread withdrawal of neonicotinoids (NNI), which accounted for 5.5% of the global PPP market and 24% of the global insecticide market in 2008; for seed treatment this share is even 80% (Jeschke *et al*., 2011). NNIs are neurotoxic substances with a marked insecticidal effect, but which are proving harmful to human health and the environment. Against this backdrop, the call for projects "*Sustainable crop protection* ***without neonicotinoids****: improving the emerging and opening up innovative prospects*"[6] was launched. The aim of this call was to improve, extend and make more reliable the existing solutions while also exploring and experimenting with new solutions. The projects selected were expected to identify (i) the progress of research and innovation on the subject at national and international level; (ii) the potential applicability of the solutions in different contexts; (iii) the exploration of innovative solutions whose feasibility is not yet certain; and (iv) the generalisability of the results thanks to multi-site and transdisciplinary projects.

It should be noted, however, that this generalized withdrawal, imposed by regulations, did not leave time for coexistence between the use of NNI at reduced doses and alternative levers. This makes NNI a relatively atypical situation.

1.2 Findings

The success of NNIs began in the 90s and has grown rapidly (in 2008 they already accounted for 24% of the insecticide market) in crop protection use with widespread utilization in many sectors (viticulture, field

2 Growth in PPP sales tonnages from 2009 to 2021 (source: BNVD) https://www.ecologie.gouv.fr/publication-des-donnees-provisoires-des-ventes-produits-phytopharmaceutiques

3 CEPP is an innovative mechanism for promoting the use of practices that save plant protection products by farmers, while ensuring the economic performance of farms. https://ecophytopic.fr/cepp/concevoir-son-systeme/le-dispositif-cepp-en-details

4 This initiative to support 30,000 farms involves groups of farmers, known as "30,000" groups. In addition to farmers, these groups may involve non-farming partners (downstream sectors, local authorities, regional nature parks, research and training representatives, etc.). The aim is to disseminate the results obtained on the various farms in the DEPHY network and other networks, and to move from the experimental stage to large-scale practical application. https://agriculture.gouv.fr/ecophyto-objectif-30-000-exploitations-agricoles

5 The scientific composition of this committee is varied, bringing together expertise in health, the environment, agronomy, the ecological transition and integrated protection, as well as a wide range of players: researchers, practitioners, coaches, administrators, teachers, doctors, etc.

6 https://ecophytopic.fr/recherche-innovation/proteger/appel-projets-ecophyto-neonicotinoides-2017

crops, arboriculture, vegetable crops, seedlings, ornamental crops, forestry) against a broad spectrum of pests. Due to their systemic activity, neonicotinoids offer prolonged and undeniably effective protection against pests (up to 98% efficacy). Subsequently, they have rapidly become essential for short-term protection. As a result of their success, they have been used systematically, both as a curative and a preventive measure. Consequently, the risks of using NNIs may not be considered and the application may not be necessary.

Since the rise of NNIs popularity, research has focused on demonstrating and improving their efficacy (Ichinose *et al.*, 2010), and in rare cases even endorsing them by minimising the effects on non-target organisms and the environment in relation to insecticide sprays applied to the entire surface, both bare soil and vegetation (Jeschke *et al.*, 2011). A number of more recent studies, particularly on bees, show that the downside of this effectiveness is their high toxicity for the environment and humans. The discontinuation of NNIs is currently controversial, particularly among industry players, because it implicitly favours long-term systemic protection over short-term protection focused on a single crop and season. Added to this are inconsistencies in regulations, where NNIs are banned in agriculture but authorised for use in the treatment of livestock buildings, in veterinary products (anti-flea products), and have residues that may end up in the environment.

The decision to ban NNIs is often reduced solely to the deleterious effects on bees. In reality, the negative effects of NNI are probably much more widespread on a wide range of target and non-target organisms such as herbivorous pests and arthropod detritivores[7] (Mabubu *et al*., 2017; Panico *et al.*, 2022; Graciani *et al.*, 2023). The disappearance of certain useful arthropods results in a loss of services rendered not only in terms of pollination but also soil health. Detritivorous arthropods play an essential role in the physical, chemical and biological properties of the soil, particularly by incorporating organic matter. What's more, given NNIs long half-life, they persist in soils in turn leading to a cumulative effect of their concentration when applied in successive years (Goulson, 2013). Several successive generations of springtails living in the soil may therefore be exposed (Van Gestel *et al*., 2017; de Lima *et al.*, 2018). This contributes to geochemical cycles not being properly closed, due to an affected process of organic matter degradation. In conventional agricultural systems, the alteration of the organic matter cycle is easily compensated for by the addition of fertilisers and soil improvers, thereby masking the real impact of the decline in these arthropods. This raises the question; wouldn't the disappearance of this function be at least as negative on the functioning of the ecosystem and the contribution to climate change as the lack of pollination?.

The disappearance of these pests also disrupts food webs. If there are no more pests, there are no more auxiliary beneficials. The natural system for regulating the dynamics of bio-aggressors is weakened, allowing for the appearance of poorly controlled outbreaks that can lead to the development of diseases at unprecedented levels, such as viral yellows affecting cereals (Barley Dwarf Yellows - BDY) or beets (*Beet Yellows Virus* - BYV).NNIs have a strong, visible, and immediate effect. The generic repercussions can have a lasting impact on all compartments (water, soil, air, living organisms) consequently affecting the functioning of natural ecosystems, the importance whom are not as clearly visible in an increasingly artificial system.

Neonicotinoids are also thought to be harmful to mammals, including humans. A review of the literature (Cimino et al., 2017) reports several studies showing a link between chronic exposure to this family of molecules and adverse developmental or neurological consequences. In its 2018 opinion[8] ,Anses is

[7] Lukas Jenni & Roman Graf, The decline of insectivores, Wogelwarte.ch https://bit.ly/declin_insectivores

[8] https://bit.ly/ansesthiaclopride

particularly concerned about the case of thiacloprid, suspected of being carcinogenic for humans, toxic for reproduction and classified as an endocrine disruptor by the European Commission.

If tomorrow farming systems are to meet the requirements of the Green Pact[9], they will need to achieve its objectives. One of which is to restore biodiversity to a more natural state. It is essential that farming practices (i) re-establish the natural regulation of pests via trophic relationships in order to limit the risk of disease outbreaks; (ii) improve the health of the soil and maintain its fertility, because a well-functioning soil releases more mineral elements for use in fertilisation and limits greenhouse gas emissions; (iii) enable biodiversity to flourish again (iiii) avoid harmful impacts on human health.

To safeguard the future, it is therefore vital to stop using NNIs, particularly when they are used as a preventive measure, sometimes unnecessarily, and to use alternative solutions.

2. Alternative solutions

There are currently five 'families' of alternatives to the use of insecticides (Grégoire *et al.*, 2017) and plant protection products in general:

- **Biomolecular** alternatives such as RNA interference, which can either inhibit the transmission of a bacterium that causes a plant disease by an insect vector, or reduce the survival rate of insects infected by this bacterium and therefore vectors of the disease;
- **physical** alternatives, such as the use of nets to prevent insect pests from attacking fruit trees, spraying white clay on the surface of leaves to isolate them from insect eggs, and destroying pests and pathogens using fire, frost, hot water and flashes of light. Agricultural equipment can help to mobilise these physical actions;
- **biocontrol solutions** such as the release of auxiliary insects, the addition of micro-organisms (bacteria, fungi, viruses), the diffusion of chemical mediators (pheromones), or the spraying of natural substances (paraffin oil, essential oils). These methods can act directly on pests and diseases or help to influence the kinetics of harmful organism's populations;
- **cultivation practices**, including tillage, co-cultivation with bait or service plants, the application of avoidance or repulsion strategies such as staggered sowing, crop combinations followed by sorting of harvested products, and landscaping;
- **genetic** leverage**,** to develop plant varieties that are less susceptible to pests.

The research work carried out to date under the calls for projects "*Sustainable crop protection without neonicotinoids: improving the emerging and opening up innovative prospects*"[4] and "*Towards operational solutions against sugar beet yellows*", launched in 2021 under the National Research and Innovation Plan (PNRI)[10] , has focused on studying a variety of levers among the alternative solutions to NNI. Some were tested alone, others in combination. These levers and their effectiveness are listed in Table 1 below.

These projects have shown that all the levers studied are only partially effective, and that it is not always easy to quantify the extent of their proven effectiveness, particularly in the case of physical barriers. Furthermore, while their effectiveness has been demonstrated under controlled conditions, it cannot always be replicated under real conditions, and their use has economic or practical limitations. For example, the use of flower strips will be more effective if they are present in several farms borders, as

[9] The ambition of the European Green Deal is to become the first climate-neutral continent by reducing emissions, creating jobs, stimulating growth, combating fuel poverty, reducing external energy expenditure and improving health and well-being. https://bit.ly/pacteverteurope

[10] https://www.itbfr.org/pnri/projets/

they will be easier for beneficials to spot and colonise from one to the next. This requires agreement between the farmers in an area to reach a critical mass who will adopt the technique. This collective dimension of pest management remains underdeveloped, despite the fact that the benefits derived from the principle of "increasing adoption yield" are well known elsewhere[11] . What strategies could be put in place to facilitate acceptance of this lever? In the Netherlands, since 1970 a payment for environmental services (PES) and an agri-environmental and climate measure (MAEC) has been awarded to farmers who encourage changes in cultivation practices, the achievement of which entitles them to an additional premium.

In France, it was not until 2007 that MAECs were introduced, followed by the Biodiversity Plan, presented by the Prime Minister on 4 July 2018, where €150 million was earmarked for the introduction of PES. Since then, stakeholders (farmers, local authorities, non-governmental organizations, economic players, institutions, research) have been getting organised to deploy and manage PES. Implementing PES requires environmental engineering and coordination at different levels of the landscape. Territories and local authorities play an important role in this process (Duval *et al.*, 2019). The research results are promising and highlight factors that enhance the effectiveness of existing solutions. This is the case in the **AphidInnov** project[12], which has shown that the early introduction of biological control in crops grown under cover is favored by the early introduction of parasitoïds that are truly adapted to the target species. It also showed the combination of parasitoïds and lacewings, and the adoption of specific cultivation practices to be effective. (Postic *et al.*, 2021). This work has resulted in solutions that are already operational and being transferred to the field to control aphid populations on strawberry plants for producers affiliated to the AOPn Fraises de France. A great deal of research has emerged in the wake of these projects, which is representative of the innovation dynamic that is underway.

Moving away from chemical control requires a paradigm shift. The mode of action of a synthetic pesticide cannot be replaced by a single alternative that is just as effective: all systems must therefore be redesigned and combinations of solutions with partial or cumulative effects must be envisaged. Some research projects have taken full account of the need to find the most optimal combinations of levers. The **ABCD-B** project[13] , for example, is working on two fronts:

- **The genetic front** where varieties of each of the cultivated species are being compared in order to identify possible tolerance or resistance mechanisms to virus diseases;
- **The biocontrol front** to combat aphids and thus reduce the spread of viruses in cultivated plants and plots in a preventive manner.

This combination of levers has also been applied by the **AGROSEM** project[14] as part of DEPHY Expé, which aims to produce quality seeds without pesticides. Various levers were presented for weed management (rotations with several planting periods, sowing under cover, intercropping cover, false seeding, mechanical weeding and dense seeding on the row), disease management (non-susceptible varieties, crop associations, fertilisation, avoidance strategy, biocontrol and pest management (flower strips and grass strips, sowing on warm soil, fertilisation, avoidance strategy, biocontrol), all mobilised in a long and diversified rotation and in a favourable environment. Thanks to this orchestrated deployment of combined solutions no synthetic products were applied, although the results were still mixed in terms

[11] https://www.multitudes.net/Les-Rendements-croissants/

[12] Article published in this issue Le Ralec, A., Buchard, C., Floury, H., Hecker, C., Outreman, Y., Perennec, S., Postic, E., Souriau, R. (2023). AphidInnov - Biological solutions adapted to control aphid populations in protected crops

[13] Article published in this issue Thibord J-B., Robin N., Valade R., Jacquot E., Armand T., Pichon E., Souquet M., Ruck L., Maupas F., Guerle G., Vandeputte L., Lafleuriel P., Reveillere J., Herbach M., Gironde S., Gauthier C., Vernetti P., Mignot E. Protection of straw cereals, sugar beet and oilseed rape against virus diseases transmitted by aphids using biocontrol and varietal solutions

[14] https://ecophytopic.fr/dephy/concevoir-son-systeme/projet-agrosem

of the yield and germination capacity of the batches harvested. Therefore, being able to make the results more reliableremains an objective to be reinforced so that the approach can be more easily applied by those working in the field.

Nevertheless, the combination of levers as an alternative solution to NNIs and, more generally, to plant protection products remains little-studied. While a number of research projects have produced a series of individual references, there is still often a lack of 'architects' who provide solution engineering through the aggregation of knowledge, global reasoning and risk assessment. They would be able to design optimal combinations of operational levers with partial effects and their dynamic management according to local contexts, as well as providing the methodological keys for assessing the coherence of their links. A call for projects has been launched by the CSO R&I specifically on this theme[15] to enhance current knowledge and develop tools and solutions that can be used by farmers. The challenge is to think in terms of assembly: How do we conceptualise the linkage and integration between the levers? How can we anticipate the best synergies? This analysis should make it possible to envisage the interactions between levers at a very early stage and predict their effectiveness in a given context. This should lead to the mobilisation of the upstream and downstream sectors of agriculture, resulting in business models that are sufficiently robust to justify the production of an offer. We can also expect the conceptualisation to lead to the production of a support tool to help farmers build the most robust system possible.

[15] https://bit.ly/combinerlesleviers

Table 1: Alternatives to pesticides studied in work resulting from the calls for projects "*Sustainable crop protection without neonicotinoids: improving the emerging and opening up innovative prospects*" and "*Towards operational solutions against sugar beet yellows*": a diversity of levers used alone or in combination. Projects marked with an asterisk are published in this special issue.

Research projects (name)	Levers studied	Tested alone	Efficiency	Jointly tested	Efficiency
ABCD_B* project	Genetics: varietal resistance	x	On wheat: some varieties are more resistant but none sufficiently so	x on wheat	Promising but partial effectiveness
	Biocontrol solutions: paraffin oil	x	50% on wheat		
	Biocontrol solutions: fungus	x	30% on sugarbeet		
Agronicoleg	Physical barrier: insect-proof tarpaulins	x	Unproven efficacy		
	Cultivation practices: beneficials via service plants	x	May be effective if colonised early		
	Genetics: cultigroup	x	No proven efficacy		
Aphidinnov*	Biocontrol solutions: parasitoids adapted to specific targets	x	30 to 60% for wild parasitoïds	x	Increased efficacy with certain leaf-stripping practices
	Cultivation practices: leaf thinning				
FAST*	Cultivation practices: untreated seeds	x	Promising efficacy: similar yield to treated seed (to be confirmed)		
PALPuF*	Farming practices: fertilisation regime Biocontrol solutions: defence stimulator Biocontrol solutions: paraffin oil	x x x	Not sufficiently effective	x	Not sufficiently effective
IAE Beetroot* (IAE)	Cultivation practices: flower strips	x	Beneficial effects on the crop		
PNRI Sugar beet	Cultivation practices: service plants	x	~ 39 to 55% on aphids, depending on the plant; ~ 19 to 34% on yellowing symptoms		

Plantserv*	Cultivation practices: flower strips	x	Up to 70% depending on region and year		
Startup	Farming practices: tillage	x	~ 45%	x	No conclusion possible at this stage
	Cultivation practices: tillage (plant cover)	x	~ 70%		
	Cultivation practices: bait plants (wheat)	x	~ 55%		
	Farming practices: landscape modelling	x	Reducing crop infestation by pests		
CRIOCERIS	Biocontrol solutions: bacteria (Saccharopolyspora spinosa)	x	~ 75%		
	Biocontrol solutions: fungus Insect-proof tarpaulin			x	Effectiveness difficult to demonstrate
DefolAltPC	Cultivation practices (defoliation) Physical barriers: oil, kaolin on leaves	x	57% on average for Golden	x	72 to 80% on average on Golden varieties
GRABT	Biocontrol solutions: essential oils	x	~ 50%		
Reguleg	Cultivation practices: service plants-bank plants	x	Proven efficacy on aubergine		
Stimulrav	Biocontrol solutions: defence stimulator	x	~ 35% (Bion 50WG and LBG01F34)		

3. A paradigm shift

3.1 Which reference?

When we try to change the paradigm in order to get out of the NNI, the new system logically does not yet have known and expected benchmarks (generally materialised by a monetary loss or gain). The unfinished nature of its coherence can be a stumbling block if it is judged only against the yardstick of what existed before. And yet, a priori, there are non-negligible "monetised" benefits. So how can they be made desirable or unavoidable?

As long as NNI remains the reference implicitly adopted by a majority of players, the debate will remain biased. Practitioners will always be waiting for an alternative recipe that provides the same efficacy as NNI, at the same price, with the same ease of use... But there will be nothing equivalent. As indicated *above*, research shows that alternative solutions are only partially effective (Table 1) and that it is necessary to combine up to 3 or 4 types of levers to achieve a correct level of effectiveness. Practitioners are therefore unsatisfied with the effectiveness, cost and practicality of these solutions.

If we now looked at these solutions from the point of view of a world where NNIs are not authorised, would practitioners accept them? Wouldn't it always be better to have partial-effect solutions than nothing at all?

As a result, the ban of the NNI is causing controversy, even though this ban should be the model for what agroecological systems should be: resilient, sober systems with associated benefits (soil fertility, pollination, etc.). We could therefore seize this opportunity to increase recognition of alternative solutions non-directly commercial performance (reducing pollution and disease, preserving ecosystems and biodiversity). A qualification followed by a quantification of the degree of "*agroecologisation*" would be welcome, as this recognition could then be part of a regulatory and/or labelling framework. However, the multiplicity of labels (Label Rouge, AB, HVE, PDO, PGI) should not be allowed to confuse consumers by creating controversy, as is currently the case with the HVE label[16] . Already, more than one in two French people are sceptical about the control practices implemented by labelling bodies and say they do not have enough information about the environmental and health impact, regulations, control and origin of products[17] . Yet confidence, even before knowledge, is crucial in consumers' decision to buy organic products (Hvarregaard Thorsøe *et al*., 2016; Nuttavuthisit and Thøgersen, 2017). In addition, international studies show that the use of information on food labels depends on consumers' socio-economic level, level of education, professional activity, gender and eating behaviour (Sousa *et al.*, 2020).

Today, there is a lack of products that are backed by a set of specifications that consumers can identify as products that respect a production method in line with the ambitions of the European Green Deal. However, under the current system, these products would undoubtedly be sold at a higher price. There are two primary reasons for this, the production method does not yet allow sufficient volume to be achieved to reduce production costs, particularly the fixed costs, and achieve economies of scale; or because competition is not sufficient. These products will therefore find niche markets that are not accessible to the whole population.

[16] https://www.lsa-conso.fr/agriculture-le-label-hve-remis-en-cause,430984

[17] https://www.agencebio.org/wp-content/uploads/2019/02/AgenceBio-DossierdePresse-Barometre2019.pdf

3.2 Mobilising stakeholders

This paradigm shift towards a conscious phase-out of NNIs must lead to societal choices that are the responsibility not just of farmers but of all stakeholders, with a global approach to reducing the use of plant protection products. The CSO R&I has launched a call for research projects along these lines[18] . For example, how can we encourage farmers to use preventive methods, which are still largely lacking, rather than curative ones? If we were to apply European Directive 2009/128 to the letter, curative (chemical) measures should only be used as a last resort. How can this approach be recognised by consumers? What compromises need to be found in terms of production performance? How can we cover a (temporary) drop in profitability for farmers? How can we share the responsibility for taking risks? The global approach is therefore an approach that links farmers through their farming practices, citizens, regions and sectors through their acts of support and their purchases.

We know that not all households are equal when it comes to the price of food, and this has implications for human health (Combris, 2006; Cavaillet *al.*, 2014). It should also be noted that part of the water bill is specifically aimed at combating the pollution caused by certain agricultural practices. So, there are both ramifications in terms of consumption patterns and others in terms of possible deferrals of expenditure. Situations where what costs more on the one hand can be partially saved on the other by funding healthcare or maintaining resources in their current state.

Research is also a lever for this change, with projects aimed at studying these global approaches[19] and strengthening epidemiosurveillance[20] to tip the balance towards more preventive actions, or finding solutions to compensate farmers for taking risks.
Research can also help assess and develop public policies. Policies which are responsible for defining collective strategies and deciding whether or not to implement alternative solutions for phasing out the use of pesticides. Policies which are currently considered insufficient[18].

3.3 Education

We have just seen that we all have to make choices. In order to make informed choices, education plays an essential role. It must intervene and reinforce itself at several levels:

- **In agricultural education**, from secondary school onwards, to enable learners to tackle the issue of exiting PPPs with possible solutions. However, this raises a number of questions, both on the part of the teachers, about their training and approach to teaching, in order to create a learning situation adapted to the audience they are working with, and on the part of the learners about their representations and conceptions. This is well documented in Peltier's article in this issue[21] .
- **With agricultural professionals**. The role of support is central. It is vital that time is set aside for training and exchanges between peers on the "new" references to be produced in the context of a reduction in PPPs, by also involving agricultural colleges and higher education. Change management must be put in place to support and equip those involved in the field.
- **Supporters** who provide advice to agricultural professionals.

[18] Call for research projects "For and on the commitment of stakeholders in the sectors and territories to support and enhance the reduction in the use and impact of plant protection products". https://bit.ly/ecophytopartiesprenantes

[19] https://bit.ly/approchesglobales

[20] https://bit.ly/epidemiosurveillance

[21] Peltier, C. (2023) Teaching and learning how to reduce the use of synthetic plant protection products

- **Among the population as a whole**. The growth of urbanisation has had the corollary of distancing consumers from what they eat. Starting from a very young age, everyone could be taught how and where our food is produced, the basics of agriculture and our food. In fact, this is becoming essential. Indeed, according to the definition of the proxemic law established by two French psychologists, Abraham Moles and Elisabeth Rohmer in 1973, man has a natural tendency to attach more importance to what is close to him than to what is further away[22] . So, the closer we feel to what we ingest, the more attention we will pay to the way it is produced. Teaching should help to overcome this distancing. Particular attention could be paid to people with a low level of education, which is often correlated with a low level of income, itself correlated with food choices.

Research can help to develop new teaching tools and new forms of learning, to understand the various obstacles and barriers, to identify the levers on which to base the deployment of technological solutions. This is why it is essential to promote interdisciplinarity between the biological sciences, the Human and Social Sciences (SHS) and the educational sciences; and, break down the barriers even further by also involving psychology or political science.

4. Conclusion

To make the transition from NNI and other pesticides a success, all the players must be involved.

Research has a role to play in producing knowledge, benchmarks and tools for use by public decision-makers, and in communicating this knowledge to professionals and the general public. We also need to mobilise more systematically the knowledge that can be used directly. The ASIRPA approach - Analysis of the Societal Impacts of Research - shows that it takes an average of 20 years between the start of research and the production of the first impacts[23] , in particular by involving engineering players (technical institutes, companies, etc.). Further progress needs to be made in the study of alternative solutions, in particular the combination of levers that would be satisfactorily applied by practitioners in terms of effectiveness, cost and practicality, when this is not yet the case. This is their individual feeling, and it differs from the general interest, which considers that the shortcomings of NNIs far outweigh the benefits of using them. Therefore, we also need to innovate in the public approach to ensure that the individual interests of producers and sectors are aligned with the general interest. Although the situation is urgent, we have to accept that it will take time to restore biological equilibrium or adapt markets before we see any tangible results. This time, which is difficult to compress, can be put to good use in the preparation and consultation phase between stakeholders, using a participative and supportive approach.

It should also be emphasised that stepping up inter- and trans-disciplinary research would provide a better understanding of the complexity of the interactions between the phenomena at play in the use of pesticides (agricultural practices, business models, education, social representations, regulations, environmental, human and animal health, public policies, consumer habits, etc.).

[22]Definition of the proxemic law by Abraham Moles and Elisabeth Rohmer: "Fundamentally, axiomatically, what is near is, all things being equal, more important than what is far, whether it be an event, an object, a phenomenon or a being".

[23] https://www.inrae.fr/dossiers/evaluer-limpact-societal-recherches-dinrae-methode-asirpa/ouvrir-boite-noire-limpact-societal-recherches-methode-asirpa

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