Moving beyond pesticides: exploring alternatives for a changing food system

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Reducing the use of pesticides is one of the main challenges facing the transition towards more sustainable agrifood systems (Carvalho 2006). Their negative impacts have been repeatedly highlighted, whether they affect human health (Inserm, 2022), biodiversity (Suryanarayanan and Kleinman 2013; Goulson et al. 2019.; Rigal et al, 2023) or natural resources (Pelosi et al. 2021). They entail huge hidden costs (Bourguet and Guillemaud 2016; Alliot et al. 2022), with dramatic medium-term consequences that question the possibility of life on earth (Goulson 2022). Critics against pesticides are not new. Mobilizations have taken place even before the Second World War, and they have been multiplying with their growing use since the 1960s, with more or less visibility depending on the time period and the local, national or international scales where they were taking place (Bosso, 1987; Bohme, 2015; Pellow, 2007). In the more recent period, scientific controversies (McHenry 2018), collective movements in rural areas (Arancibia 2013; Saxton, 2021), mobilization of victims (Jouzel and Prete 2015) and citizens' claims (Tosun and Varone 2021), as well as a growing number of reports of pesticide-related issues by the media, have increased the visibility of these problems.

Pesticides are a crucial component of contemporary agricultural systems (Shattuck 2021). A large body of literature has documented the variety of lock-in mechanisms that impede a reduction in pesticide use and even more eliminating them (Cowan and Gunby 1996; Vanloqueren and Baret 2009), as they are embedded in complex sociotechnical systems (Joly et al. 2022) and incumbant regimes (Turnheim and Geels 2013). Their widespread use has been and is still actively supported by public policies, and consequently discontinuing them is a problem of governance (Stegmaier et al. 2014) as well as a burning political issue (Tosun et al. 2019).

Despite these serious lock-ins and difficulties, increasing numbers of actors are calling for a withdrawal or a serious reduction in these technologies (Koretsky et al. 2022). The main challenge for the implementation of such a reduction is to identify levers to enable less chemistry-dependent agricultural systems (Wuepper et al. 2023). To reach this goal, the design of alternatives is crucial. Here, we define "alternatives" in a very broad sense, i.e. including a variety of political, social and technical options, encompassing a variety of framings of the problems associated with pesticides. As Joseph Gusfield underlined, any public problem corresponds to many possible representations of its causes and its solutions (Gusfield 1981), and both the lock-ins identified and the ways proposed to escape them and incentivise the transition are varied and contrasted. This special issue explores the variety of solutions and alternative ways to reduce or eliminate pesticides while ensuring agricultural production.

Our starting hypothesis is that these different solutions are competing alternatives, each one with its own promoters, each promoter having different types and amounts of resources available to promote his/her solutions. Our aim is to analyse this ongoing competition and its implications in terms of scientific and technological controversies, policy debates and the political strategies implemented by the different actors. Pesticide reduction/elimination initiatives embed contrasted visions of the future of agriculture, along with specific representations, values, imaginaries but also material cultures. The five articles that comprise this special issue plus this introductory article explore the sociotechnical processes and the politics behind the reduction/elimination of pesticides and behind the design/emergence of alternatives.

In the following section of this introductory article, we show that a huge diversity of sociotechnical and political processes shapes the policy debate on pesticide reduction, which may explain the emergence of one alternative or another as a politically legitimised option, or not. In section 2, we describe the two main technical alternatives most often discussed in academic and policy circles: the option of using biological alternatives as substitutes for synthetic pesticides on the one hand, and the option of farm re-design and a shift in agricultural practices on the other hand. We also explore their policy-related aspects. We then provide a more specific introduction to each of the five articles in this special issue.

1. Politics behind pesticide reduction/withdrawal

For many reasons that are well identified in the literature, pesticides are a key element in contemporary agricultural sociotechnical systems: together with synthetic fertilisers, they are the core condition for specialisation and enlargement of farms, the two main trends of agricultural industrialisation. Their relatively low prices enable a major reduction in the cost of labour. In some regions, they have become the keystone of entire value chains (Guthman, 2019). Calls for their drastic reduction or elimination threaten the very core of the system and hence provoke resistance from a variety of actors, from the farmers themselves to the pesticide manufacturers and their market partners (1.1). Since the post-World War II period, contemporary food systems have been shaped by public policies that have continuously promoted and supported pesticides as the best solution, incorporated in narratives of technical and social progress and modernisation. In the current context of increasing criticism of pesticides, these policies are themselves also deeply embedded in lock-ins. The ways the policy-makers suggest accompanying pesticide reduction are most often deeply path dependent. Depending on the types of instruments they implement, these policies provide more or less room for manoeuvre with respect to the possible options for reduction and/or elimination (1.2).

1.1 Resistance everywhere: withdrawing a key element of contemporary food systems is not an easy task

Reducing pesticides is a major challenge because they are deeply anchored in many practices and activities that are difficult to change. Resistance takes many forms. The frequently mentioned first category of resistance is individual farmers, who continue to use them. Despite the well-known negative sanitary and environmental externalities of pesticides and the risks to their own health, farmers keep using them because they save work while ensuring their production and income (Wilson and Tisdell 2001). However, some farmers are keen to adopt less pesticide intensive practices (and less intensive use of other chemical inputs) (Bakker et al. 2021; Gao and Arbuckle 2022; Young et al. 2022). Cognitive levers as well as economic ones have been studied, for example the effect of pesticide tax schemes (Skevas et al., 2013). However, pesticide use plays an important role in the identity of many farmers, shaped by notions of performance and high yields (Lamine 2011; Bell et al. 2015). Many farmers use pesticides intensively and tend to minimise their sanitary, agronomic and environmental impacts (Chèze et al. 2020; Müller 2021). Pesticides are also a key element in the relationship between farmers and their technical advisors; any reduction in pesticide use –not to mention withdrawal- would require a deep change in these relations (Compagnone and Simon 2018). The power of technical progress and modernisation narratives is not only widespread in Northern countries and their highly industrialised agricultural sector, but also causes lock-ins in countries with much less industrialised farming sectors, for example in Africa where many farmers think that obtaining good yields without pesticides is impossible (Luna 2020; Bendjebbar and Fouilleux 2022).

However, farmers' reluctance to reduce/stop using pesticides is not only individual; it often reflects or results from collective strategies and discourses. Trade unions and professional organisations actively resist and lobby against stricter regulations or reduction policies (Sherwood and Paredes 2014). Together with other actors, such as agrochemical firms, they refer to agricultural productivity and to the need to "produce more" to legitimise the use of pesticides and they stir up fears of food shortages if pesticides are reduced or withdrawn. The increasing world population along with growing food insecurity are also used as arguments to avoid making regulations and reduction policies stricter (Fouilleux et al. 2017; De Raymond and Goulet 2020).

The pesticide industry is particularly active in this political fight to avoid any destabilisation of the dominant agricultural regime based on chemical inputs (Jas 2021). As central actors of the global industrial complex of which pesticides are a core element, they seek to circumvent restrictions and to continue to sell products despite regulatory constraints. The "Circle of Poison", which was denounced decades ago (Weir and Shapiro 1981; Jansen and Dubois 2014) and consists in rebranding molecules banned in industrialised countries to sell them in the Global South, where pesticide regulations are more flexible (Galt 2008), still works today.

Other marketing strategies have also emerged, for instance, pesticide producers moving into seed production. By developing GMO varieties that are resistant to glyphosate, agrochemical firms have succeeded in further locking in herbicides (Desquilbet et al, 2019; Clapp 2021). By using a variety of strategies to bind pesticides to farmers' practices, companies make their withdrawal even more arduous.

The power of the pesticide industry also resides in its market power. In 2022, the pesticide sector was dominated by only four firms that accounted for a 62% share of the world market, Syngenta alone controlling 25% of the market since its fusion with ChemChina. In the seed sector, two firms hold a 40% share of the global market, of which Bayer alone controls 23% (ETC group, 2022). Their dominant position allows them to fund active public relations campaigns as well as direct and indirect lobbying targeting governments and international organisations (Jansen 2017; Jas 2021). Paradoxically however, in particular contexts, competition with agrochemical firms producing generic products has also led to better enforcement of pesticides regulations (Jansen, 2017).

Beyond public authorities, agrochemical firms design all sorts of strategies with the aim of diluting, minimising or channeling criticism. Communication strategies directed at both agricultural stakeholders and the general public help them counter health and environmental criticism by greening the image of their products (Kroma and Butler Flora 2003). Furthermore, like other "merchants of doubt" on issues such as asbestos (McCulloch and Tweedale 2008), tobacco or global warming (Oreskes and Conway 2010), agrochemical firms act upstream of criticism, particularly in academic science, by creating ignorance concerning their products and nurturing doubts about the risks they present. Agrochemical companies have acted strategically to influence scientific evidence regarding the undesired impacts of pesticides (Fabbri et al. 2018; Goulson 2020). In particular regarding the extinction of biodiversity, they have actively funded academic research on other causes than pesticides to explain the decline of insects, pollinators and biodiversity. This has resulted in the literature giving too much weight to other causes like the varroa, the hornet or changes in rural landscapes and habitats that rendered the primary role of pesticides invisible (Foucart 2019). Boosting research on particular aspects is another way to ensure that "unaccomplished science" (Frickel et al. 2009) remains just that, meaning that some social or environmental justice issues that are deprived of the appropriate metrics and measurements are disregarded or considered to be non-existent (Navas 2022). The influence corporate actors have on scientific debates obviously results in the blurring and delaying of wider public debates. But when people criticise their products or claim justice for the environment, agrochemical firms deploy "soft" forms of repression in the framework of the civil justice system. For instance in Nicaragua, the pesticide industry promoted a narrative of corruption that was diffused through the media and legal system, which successfully discredited a move by banana farmworkers who wanted to take them to court because of the impact of pesticide use on their health (Bray et al. 2022).

Pesticides are therefore substances that lie at the heart of the agricultural sector and of the relationships between the actors of the sector. Their massive and continuous use is the result of numerous, diverse and lasting alliances and political pressures. This is why the calls to reduce these substances are particularly difficult to put into practice as they challenge stable socio-technical configurations and well-established economic interest groups with high political influence.

1.2 Pitfalls and shortcomings in public policies related to pesticides

Conventional farmers' unions and powerful corporate actors are not the only entities resisting change. Administrations, and more broadly the State, are sometimes themselves active elements in lock-in mechanisms: the way they govern and regulate pesticides can reinforce the omnipresence of the substances.

In the past, the main way for governments and public administrations to deal with pesticides has been to regulate their marketing based on the risks they pose. Like other chemical products, before they can be sold, pesticides must be authorised. For this purpose, the assessment of their impacts on humans, on non-target organisms and on the environment have been progressively added to the assessment of their agronomic efficacy. The importance given to efficacy or safety in the evaluation has varied upon time and varies greatly with the country concerned (Pelaez et al. 2013). Similarly, the process is organised differently depending on the national context (Hough 2003). Many authors call for stricter regulations to be adopted and implemented, in particular in developing countries (Bonvoisin et al. 2020; Phung et al. 2012). In comparison, European and North American regulatory systems may appear to be particularly sophisticated and rigorous. However, the design of these evaluation procedures has many shortcomings.

In European and North American countries, pesticide regulation is based on risk assessment using toxicological knowledge, which defines 'the conditions of use' for these substances (Davis 2014): maximum doses, detailed spraying conditions, use of personal protection equipment, etc. The main assumption of this risk assessment approach, which forms the core belief of pesticide regulation, is that pesticides *can* be safe if their instructions for use are respected. Various limitations to this approach, which is based on regulatory science (a field that develops tools, standards, and approaches targeted at assessing the safety, efficacy, quality, and performance of products) have been identified in the literature.

Firstly, "regulatory science" arises from important transnational activities controlled by a reduced number of actors in an opaque way. The rules and standards that govern regulatory science are defined by invisible colleges– loose transnational groups of prominent scientific experts who combine their practical experience of risk and control with advisory responsibility; these exerts circulate in different spheres including regulatory agencies, academic organisations, and private companies (Demortain 2011). Their activity gives rise to standards that may be based on personal and contingent initiatives, through multi-positioning strategies by the scientists involved that blur the frontier between the public and private domains – and are likely to lead to conflicts of interests – most often with no policy steering. Regulatory science is a privileged field for firms to exert their influence, notably through learned organisations. One example is the *International Life Science Institute*, a non-profit organisation established in 1978 in the United States and funded by major agri-food, agrochemical, chemical and oil companies, which promotes regulatory science that is advantageous to the industry (Demortain 2020). For decades, ILSI experts have played very influential roles in pesticide regulation worldwide. The way science is used in policy-making process for their authorization is also problematic because most of the studies are directly funded by or conducted by the pesticide industry or by its partners. In the EU, these studies are part of a complex legislative and "soft law" framework, which is sometimes ill-defined and not always aware of the most recent scientific developments. For example, in the case of glyphosate, a number of "scientific misconducts" have been reported over the years including selective use and omission of published data; invalid dismissal or denial of adverse side effects; misuse of past control data; misuse of statistical analytical tools to dismiss adverse effects based on alleged data inconsistency; misuse of the 'weight of evidence' approach; misrepresentation of research methodology plagiarism; failure to assess the toxicity of mixtures (Robinson et al., 2020). Similar issues have been reported for different products (e.g. Mie et al., 2018). A further limitation is that there may be strong long-lasting discrepancies between the elements taken into account in assessment procedures and farmers' real day-to-day practices, thus rendering regulations *de facto* inefficient. In particular, regulatory science tools used to monitor the effects of pesticides are efficient in spotting cases of acute poisoning but not in tracking the effects of long-term exposure; similarly, they do not assess the effects of mixtures of products although most farmers actually apply mixtures. The way assessment procedures are designed and organised, and in particular their toxicological focus, explains such discrepancies. As a matter of fact, institutionalised instruments and administrative routines tend to disqualify alternative knowledge. Other scientists -especially experts in epidemiology- identify hazards which cannot be assessed using a toxicological approach. Epidemiologists analyse the long-term or real-life effects of pesticides, whereas toxicology functions in laboratory conditions, and covers shorter time periods, and epidemiological knowledge is disregarded by the regulatory framework. For example, some French researchers in the fields of environmental epidemiology and ergonomics have shown that factors including the cost, availability, and physical discomfort involved may mean instructions on how to use personal protection equipment (PPE) are not respected by farmers; the same researchers also pointed out that nanotechnologies and low-dose effects are not taken into account in the assessment of the effectiveness of PPE, consequently questionning the protective role attributed to PPE in the marketing authorisation of pesticides (Garrigou et al., 2020). However, when in the mid 2000s, the same scientists raised the alarm and reported their results to the French administrative entity in charge, it turned a deaf ear. The alert did lead to some internal tensions, but not to any major change in existing French or EU regulation and authorisation procedures (Jouzel, 2019). Public authorities sometimes prefer to ignore what they actually do know, a situation that can be qualified as denial (Dedieu 2022a), or organised ignorance (Dedieu 2022b).

This situation resulted in significant under-recognition of the impacts of pesticide use, on bees, other insects and on the rest of the ecosystems, as well as on the health of agricultural workers. In the latter case, under-recognition is reinforced by the fact that users are reluctant to declare pesticide-related health issues, because they feel guilty as their illness implies they did not do their job properly when they used the pesticides incorrectly. Hence, the farmers themselves are held responsible for stifling potential warnings about the difference between regulatory conditions and their practices on the ground (Dedieu et al. 2015).

There is no doubt that such mechanisms have delayed awareness of the consequences of pesticide use in many countries. Neither is there any doubt these mechanisms are still actively at work. However, in some cases, the scientific alerts did eventually lead to a ban on certain substances, for instance, the historic ban on DDT in 1972 (Maguire and Hardy 2009; Levain et al. 2015). More recently, this was the case of chlorpyrifos which was banned following an alert raised by scientists (Mie et al. 2018). Indeed, various cases show that the patient counter-expertise work conducted by scientists from various disciplines, sometimes through alliances with environmental activists, can, in certain contexts, lead to certain changes (Liévanos et al., 2011; Arancibia and Motta, 2019; Demortain, 2021).

Over the last two decades in various countries, a series of public policies have attempted to reduce the risks associated with pesticides in two main ways. First, pesticide registration procedures have been changing. They were originally focused on assessing a product's efficacy but gradually more importance has been given to evaluating the risks associated with their use (Brickman et al. 1985; Jas 2007). Assessment and authorisation procedures have progressively included new types of assessments, like cost-benefit analysis in the United States. Together with decisions by firms to no longer sell certain products, stricter regulation of pesticides by states and by institutions like the European Commission have contributed to a regular decrease in the number of authorised active ingredients, in particular following the adoption of Directive 91/414/EEC (Karabelas et al. 2009) and Regulation (EC) No 1107/2009 (Hillocks 2012). However, these developments clearly do not prevent new molecules from being approved, and despite a shift towards stricter regulations, major shortcomings persist, related - as mentioned above - to the regulatory standards used. Different stakeholders continue to denounce many specific substances as being dangerous despite their legal use, and criticise the approval systems that enable their authorisation. A controversy of this type arose in the EU concerning neonicotinoids and in particular, glyphosate, with two European citizen initiatives calling for a profound reform of current regulations having received official recognition (Alemanno 2013; Tosun et al. 2019). However, the path to stricter regulations is not equally smooth worldwide and can easily be interrupted by political upheavals. For example, the opposite movement i.e. to make registration procedures even more flexible, was reported in Brazil under the Bolsonaro government (Milhorance 2022). In many parts of the world (at least in South-East Asia and Africa), regulations are relatively recent (i.e. date back only two or three decades) and in reality, are not being applied. All the practical/anthropological surveys carried out in these regions confirm the continuing large-scale sale of illegal products (via both informal and formal channels) and/or their illegal use. Pesticide uses have even increased exponentially in some areas since the early 2000s, and, in addition, official statistics certainly substantially underestimate them (Shattuck, 2023).

Beyond improving their risk assessment procedures, some countries and regional communities have also designed policies aimed at reducing pesticide use. The European Union has played a pioneering role in this respect with the adoption of Directive 1107/2009 which requires EU member states to implement national action plans (NAPs). Several investigatory studies of the implementation of these NAPs (Barzman and Dachbrodt-Saaydeh 2011; Lee et al. 2019) revealed varying degrees of ambition across countries. Most countries rely primarily on incentive-based instruments that target farmers (Lefebvre et al. 2015; Möhring et al. 2020), and plan to disseminate integrated pest management approaches using different levers (Deguine et al. 2021). In France for example, instruments implemented so far include a network of pioneer farms, mandatory training for all farmers, newsletters informing farmers about the pests that threaten their crops, and specialised advisory services (Delière et al. 2015; Aulagnier 2020). To dtae, these instruments have had no visible effects, as pesticide sales continue to increase year after year. This complete failure can be explained by the fact the instruments are not constraining: they count on the farmers' good will (Guichard et al. 2017; Hossard et al. 2017). Some countries have also implemented more persuasive policy instruments. In France, Sweden, Denmark, and Norway specific taxes are levied on pesticides, with the aim of reducing their use or encouraging farmers to turn to alternatives (Böcker and Finger 2017; Finger et al. 2017). However, studies in Belgium, Switzerland and Germany point to the limited effectiveness of such policies, because the taxes would have to be extremely high for farmers to seriously reduce their consumption of the substances cited (Böcker and Finger 2017). And, most importantly, the policies do not combine increased taxation of pesticides with subsidies for alternative practices or technologies (Finger et al. 2017).

2. Politics and policies of alternatives: substitution *versus* redesign?

The design and identification of alternatives is a major problem in pesticide reduction/elimination practices and policies: it is a matter of "defining alternative passage points" (Goulet and Vinck 2012) to incumbent technologies that have become controversial. Two main alternatives to pesticides are most commonly discussed. The first is organised around technological alternatives/options, which consist in replacing chemical products by other technologies. The second one is the deep redesign option, which implies that farmers change their practices more radically to avoid being obliged to continue using pesticides (Hill and MacRae 1996; Hill 1998). A widely used illustration of the first approach is biocontrol: in France (Aulagnier and Goulet 2017; Villemaine et al. 2021) and in Latin America (Goulet et al. 2022), public policies attempting to reduce farmers' dependency on chemical inputs have opted for the development of biocontrol technologies. Historically, the most well-known illustration of the 'redesign' approach is organic farming, which forbids the use of any synthetic inputs in the production process and instead relies on agronomical practices aimed at reducing pest and disease pressure. Public policies supporting organic agriculture have generally been based on market regulation and market segmentation rather than on providing direct support for an alternative model of agriculture; this has contributed to the trend of conventionalisation of organic agriculture that has taken place since the 1990s (Fouilleux and Loconto 2017b).

Between these two alternatives (substitution *versus* redesign), a full continuum of solutions is called for on the ground and discussed in policy debates, and the boundaries between the two alternative paradigms can get blurred. Nevertheless, in the following two sub-sections, we consider the two options separately, in order to better distinguish their properties, their trajectories, their cognitive and technological anchors and related politics.

2.1 The substitution option, one among other technological promises

A first alternative to pesticides is to promote biological products/technologies that are substitutes for pesticides, i.e., that can be used instead of pesticides to perform similar functions. The term biological control, or biocontrol, is most commonly used to refer to these technologies, which may be auxiliary insects, micro-organisms, natural substances or biostimulants. Although they recently boomed, these technologies appeared in the mid nineteenth century (Sawyer, 1996) and they subsequently developed as an extension of IPM techniques since the 1960s (Kogan 1998). They were used early in certain crops including greenhouse vegetables, where they contributed to a boom in specific industrial crops like tomatoes (Bonnaud and Anzalone 2021). Since the 2000s, biocontrol technologies have undergone a microbiological turning point, with, for example in Latin America, considerable expansion of beneficial microorganisms (Goulet 2021a).

In Latin America in general, biological inputs as a whole - bioinputs, including biofertilisers - have been the object of strong political and industrial dynamics, through dedicated policies and reorganisation of the input sector (Goulet and Hubert 2020; Goulet 2021b). Specific public action programmes have been set up (Carvalho Vidal et al. 2021) aimed at stimulating either research and innovation, or the production of microorganisms by farmers in rural biofactories. The industrial sector has also witnessed important developments, with agrochemical companies investing in biological inputs, driven by a growing market, partly in response to the growing stringency of pesticides regulations in industrialized countries, making more difficult for them to get new market authorizations for synthetic products. The development of microbiological technologies, based on bacteria and fungi (Syed Ab Rahman et al. 2018), is thus seen as a promising technological front, with important challenges in terms of regulatory frameworks and/or technical guidance (Kvakkestad et al. 2020). Macro-organisms remain an integral part of the dynamics of technological innovation, with, for example the development of GMO insects (Schwindenhammer 2020) or sterile insect technologies (Dyck et al. 2021).

While Latin American agribusinesses offer a valuable window of opportunity to observe the boom in biocontrol, especially that of microorganisms, it also helps understand how these alternative technologies coexist with pesticides. In practice, farmers often use both types of technologies, based on a logic of complementarity. They take advantage of biocontrol technologies without abandoning the use of pesticides when necessary. These technologies allow to reduce the use of some pesticides, without calling into question technical systems overnight. Although biocontrol represents a technological break with pesticides (mode of production, action, conservation, etc.), it represents continuity at the scale of sociotechnical systems (Goulet 2022): industrial continuity as companies produce both technologies; continuity in use as farmers use both technologies; political continuity, as public policies defend the coexistence of technologies rather than one versus the other.

Numerous other technological innovations are being proposed to reduce pesticide use, relying on different mechanisms. They are not strictly substitutes, but they propose replacing other elements of the production process. Specific crop varieties are being developed that are less sensitive to diseases and consequently require less pesticide (Vanloqueren and Baret 2008). Improving pesticide application technologies is another possible lever to reduce the quantities applied (Wachenheim et al. 2021). Digital technologies for the recognition of plant pathologies are currently being tested, although their effects in terms of pesticides use are questionable (Heimstädt 2023). Alternating between seasons or crops with and without pesticide use on the same farm is another option that is implemented, with measurable positive environmental impacts (Koch et al., 2023).

Substitution is a convenient alternative because it functions as a technological promise (Joly, 2013). It creates a narrative in which pesticide reduction is approached via technological advances alone. This restrictive way of tackling withdrawal has often proved to be more convenient and less disruptive for policymakers than policies encompassing more systemic ambitions. In addition, in pesticide reduction policies, substitution can function as a boundary-object (Star and Griesemer 1989) that helps enrol actors who were originally opposed to any pesticide reduction/removal objective. Although some advocates of biocontrol defend the idea that the substitutes they promote must be accompanied by changes in practices in order to achieve their full potential, the idea of biocontrol as a miracle technology *per se* certainly remains the most diffused one. *De facto*, substitution can temporarily overshadow competing options such as systemic approaches (Aulagnier and Goulet, 2017).

2.2 Redesigning farms and shifting agricultural practices: the systemic option

Indeed, for many authors, the prioritisation of substitution as an alternative impedes the development of more ambitious and systemic approaches (Altieri et al. 1997; Rosset and Altieri 1997). Those contrasting alternatives rely upon the adoption of sets of practices excluding –or strongly reducing- reliance on pesticides by acting upstream through the redesign of farming systems, by combining various levers such as crop rotation or species diversification (Vialatte et al. 2022). This is a more complex approach, which necessitates significant disruption and getting all the actors of the farming system involved (Chantre et al. 2015; Lamine 2011). It offers a key role to agricultural extension actors (Compagnone and Simon 2018; Coquil et al. 2018). Historical organic farming (Bellon and Penvern 2014) or agroecology (Rosset and Altieri, 1997) are emblematic systemic options, requiring deep redesign of agricultural systems. However, their implementation is marked by conflicts over definitions, and the motives of the actors who promote these models and the way government officials frame them are very varied and may change over time. Indeed, the changes involved go far beyond the redesign of agricultural systems only, but also concern the value chains and, even more broadly, the entire the food systems in which those agricultural systems are embedded.

Organic agriculture has its roots in European social movements criticising the industrialisation of agriculture since the 1930s, with a radical political stance. However, in most countries, it has been institutionalised based on a simplified definition, restricted to the products used in the production process, i.e. no synthetic inputs can be used. This definition has been encapsulated in a standard format and advertised as a certified form of agriculture dedicated to a specific niche market rather than as an alternative production model (Fouilleux and Loconto 2017a). Thus, public policies have focused on the construction and regulation of this specific market (public or private voluntary standards, third-party certification, label), rather than on providing direct support for organic farms and practices, with some differences among countries however (Darnhofer et al. 2019). This market-based approach reveals a paradox in terms of pesticide use, as the very existence of organic agriculture depends directly on the continued use of pesticides in the conventional market. While the organic movement was initially grounded in a political criticism of chemistry-based industrial farming, its institutionalisation via simplified standards and the development of organic markets and profitability have changed the picture. For example, historical actors such as Nature&Progrès –the main historical actor in the French field of organic agriculture and a founder of the International Federation of Organic Agriculture Movements– are no longer allowed to claim they are "organic" because Nature&Progrès uses participatory guarantee systems instead of third-party certification. Most importantly, in many parts of the 'Northern' world, an increasing number of organic farms have adopted a more conventionalized and industrialised approach to organic agriculture, based on input substitution, including massive use of biocontrol technologies (Guthman 2004; Darnhofer et al. 2010).

Agroecology is another systemic alternative that has recently emerged from its previous political marginality. It is most often presented as a radical and nature-based systemic alternative to conventional farming, including an important social and political dimension (peasant to peasant modes of creation and sharing of knowledge, small scale family farms as the most concerned, etc.) (Rosset and Altieri, 1997; Wezel et al. 2009; Giraldo and McCune 2019). Agroecology has been recognised as a viable option at the international level since the 2010s (Loconto and Fouilleux 2019) and in many countries, including for example various Latin American countries (Altieri and Toledo 2011), France (Bosc and Arrignon 2020), and Senegal (Boillat et al. 2022). However, it is interpreted in many different ways depending on national and institutional contexts (Wezel et al. 2014), including more or less ambitious instruments designed to favour the adoption of agroecological practices. In the different approaches to agroecology, the importance given to the socio-political dimension in particular, as well as the intensity of pesticides withdrawal injunction made, may vary to a great extent. The approach of agroecology in France contrasts drastically to the strong socio-cultural-political dimension of agroecology in Brazil or Argentina for example. Since French policy makers launched the watchword 'agro-ecology', they have been actively promoting conservation/no-tillage agriculture as a major agroecological option, despite its dependence on glyphosate.

In sum, both pesticide free (or less pesticide dependent) production systems and their corresponding policies are facing conflicts concerning the definition of their ambitions, the political levers they rely on and the technical alternatives they intend to promote.

3. Alternatives to pesticides worldwide: a variety of contexts and scopes

As we have shown above, the withdrawal or reduction in pesticide use does not only involve their replacement in the strict sense of the word, but also a multitude of other levers aimed at transforming farmers' practices as well as the behaviour of other actors in the food system. Whether they are based on the use of specific technologies, on more systemic transformations including social innovations, or on their combination, these alternative paths differ greatly in their cognitive anchoring. The diversity of alternatives contemplated is wide, implemented by a variety of actors, supported differently by states and/or governments, with different degrees of ambition and different levels of potential disruption. This diversity is confirmed and clarified by the various articles that compose this special issue.

The five articles cover various geographical contexts, objects and issues. The empirical material they are based on concerns three continents: Europe, Latin America and Asia. Three articles out of five address public policies and state action directly. Alexis Aulagnier describes how France has promoted substitution as a specific policy option since 2008 through the so-called Ecophyto plan. Fionna Kinniburgh analyses how the French government, in line with the same Ecophyto plan, relied on scientific expertise to select and evaluate alternatives to glyphosate. Carsten Daugbjerg looks at how Denmark and Sweden promoted organic farming in the 2010s by encouraging the purchase of organic products in public orders. In contrast, Cornelius Heimstädt explores a private sector initiative, a start-up that developed a mobile phone application for plant health diagnosis and which is used in India. One of the stated aims of this technology is to reduce pesticide use by Indian farmers, by giving them access to alternative products and advisory services. At a more micro level, Tomás Palmisano analyses how farmers are constructing alternatives to pesticides in Argentina and Chile, and the motivations that drive them to carry out these changes. States, private companies, agricultural advisory services, local authorities and farmers are the stakeholders at the core of these five contributions, all of which also mention the role of science and scientists in the processes at stake. All five articles provide useful elements for thinking more precisely about alternatives to pesticides, and the way in which these alternatives arise, or, on the contrary, do not arise.

First, several contributions reflect the distinction we made above between technologies that are direct substitutes for pesticides, technologies whose design and development indirectly reduce the consumption of pesticides, and more systemic approaches that require the redesign of farms and of the practices used on farms. Alexis Aulagnier examines exactly how the French state has contributed to shaping biocontrol as a category of alternative technologies to pesticides in rhetorical, statistical and regulatory terms. Using concepts drawn from the field of science and technology studies - boundary work, categories - he analyses the ways in which the French public administration forged the category of biocontrol by bringing together various technologies within it, and by emphasising the difference between this category and that of chemical pesticides. This work of constructing 'biocontrol' type alternatives through public action meets strategic goals on the part of the French administration. It can be understood in the light of the political, scientific and societal debates surrounding pesticides in France since the 2000s. In a context of spectacular failures of the Ecophyto plan illustrated by the constant increase in the sale of pesticides despite the plan’s objective of a sharp decrease, the official creation of the biocontrol category made it possible to differentiate biocontrol products from pesticides. This in turn, made it possible to exclude them from pesticide purchase statistics, the statistics whose lack of reduction was causing increasing discomfort among public authorities. Alexis Aulagnier shows that the definition by policy-makers of boundaries delimiting legitimate alternative technologies is not simply a matter of their effectiveness or their intrinsic characteristics, but also a highly political and strategic issue.

Fionna Kinniburgh also addresses the French Ecophyto plan, and also examines the boundary work of the French administration in its task of defining the perimeter of legitimate alternatives, by focusing on one particular pesticide, glyphosate, in a context of pressing political discourse with the aim of identifying alternatives. She shows how political choices made by the administration in terms of type of expert appraisals to evaluate alternatives to this famous herbicide - in particular economic evaluations - influence the type of alternatives retained as legitimate. She sheds light on the tensions between government officials and scientific experts regarding the various alternatives to pesticides and highlights the struggles between the advocates of systemic approaches focused on agricultural practices, and those focused on substitution technologies such as biocontrol. She also explains how difficult it is to compare alternatives. The definition of a stable comparison criterion is the result of political, economic, agronomic trade-offs and is subject to pressure from diverse stakeholder groups. Finally, she underlines that systemic approaches tend to be disqualified from the beginning, as comparison requires isolating the factors to be compared whereas systemic approaches rely primarily on interactions between factors.

By analysing the economic, social and political factors that push farmers in the Chilean and Argentinean Andes to reduce or stop using pesticides, Tomás Palmisano provides a contrasting reading. He shows that the abandonment of chemistry-based industrial farming does not entail a single path based on standard prescriptions but rather multiple possible pathways that depend on the socio-economic context, and on the material and symbolic resources available, as well as on personal experience built up over time. The decision to reduce pesticide use results from a readjustment of the balance between the available workforce, possible access to land, market conditions and needs that have to be covered. In practice, depending on the agronomic effectiveness of available technologies in their own local conditions, farmers most often use a combination. Some farmers do not refrain from using pesticides alongside other technological options, depending on criteria such as the state of their crops or the availability of technologies on the market. As illustrated by the use of sheep to help control weeds on both organic and conventional farms, hybridization and overlap of knowledge and technologies is the most common situation. Another common feature is the need for more labour to apply low pesticide-use production strategies, although the decision to reduce pesticide use is not always correlated with seeking specific markets with higher prices (e.g. through organic certification), but may be a question of reducing costs in a context of general rise in the price for inputs, for example. Paying attention to the reasons for farmers' choices and practices thus provides an alternative view on the debates and opposition between pesticides and their alternatives, but also between the alternatives themselves.

Many agents act as intermediaries between government action and farmers' practices and influence the transformation of agricultural systems and the use of pesticides. As mentioned for example by Tomás Palmisano, the intermediaries may be retailers or food processing companies, who push small commodity producers to standardise and control their use of pesticides in the context of “Good Agricultural Practices” (GAP). They may also be digital AgTech companies, in contact with agricultural extension services, who develop tools to guide farmers in their plant health management practices. In his article, Cornelius Heimstädt specifically examines one of these companies, who proposes a technology that is expected to support the use of virtuous, pesticide-saving practices. The application under scrutiny, developed by a German start-up and backed by international investors, aims to help farmers diagnose diseases or pests that affect crops. The diagnosis is made by taking a photo and sending it to a database where it is processed by an algorithm. Once the diagnosis is made, the application recommends a technical treatment to the farmer, accompanied by an invitation to apply optimal spraying practices to minimise the impact of the treatment on the farmer’s health and on the environment. The app was initially designed to favour the use of alternative products such as biocontrol. However, a close examination by Cornelius Heimstädt of the design of the application's algorithm and of its uses allowed him to show that the change generated by the app is limited. Indeed, remote diagnosis by the algorithm based on photos involves a reduction and an impoverishment of the information used for diagnosis. The application cannot capture the history and the soil and climatic environment of the cultivated plots, which are responsible for the complexity and the specificity of each situation. In practice, as underlined by Alexis Aulagnier, Fionna Kinniburg and Tomás Palmisano, freeing oneself from pesticide use is also and above all, a matter of complexity, observation and applying a systemic approach to problems. The paradigm shift in plant protection is not so easy. As they show in their papers, it is a matter of accounting for many different parameters to produce viable recommendations and innovations or to make choices adapted to specific situations. Cornelius Heimstädt also explains how the technological trajectory of the application and changes to its economic environment have reduced its power to transform agricultural practices. To pursue the development of its application, the start-up had to attract investors, who were looking for a return on their investment. To ensure this return, the application, which had gradually incorporated an interface that enabled direct purchase of inputs from local suppliers, then developed into a paying service based on a commission levied on the purchase/sale of products. This quest for profitability transformed the app into an asset and increased its dependence on input retailers. The channelling of technical recommendations tends to favour products whose effectiveness has already been proven, i.e. standard pesticides, rather than favouring alternative products and practices. This example demonstrates how difficult it is to develop alternatives to pesticides, in socio-technical systems that have been built for and shaped by pesticides. This invites us to take a detached look at the promises of digital technologies for the development of sustainable agriculture and suggests there is enormous scope for progress for algorithms to be able to grasp the multifactorial complexity associated with agroecological plant health management practices.

If the transformation of agricultural practices and the development of technological alternatives are essential levers for developing production models that are pesticide free, many other types of levers linked to other dimensions of the food system can also be mobilised. In his paper, Carsten Daugbjerg suggests broadening the focus on production and on farmers that usually characterises policies aimed at reducing pesticides, by analysing public organic procurement policies, which target the demand side. Through public purchases, those policies promote market demand for organic products. They aim to enable organic producers to sell their products as organic as much as possible (rather than sometimes being forced to sell their organic products on the conventional market) and to make organic production more attractive and, consequently, the use of pesticides relatively less attractive. More specifically, Carsten Daugbjerg examines two different national pathways, one in Sweden the other in Denmark, aimed at increasing the supply of organic food in public collective catering. These two countries have been particularly ambitious in this field, by setting national policy goals for organic food public procurements up to 60% (with concrete results showing 39% of organic meals were served in public catering in Sweden and 27% in Denmark in 2019). The two countries, which have different political and administrative cultures and policy styles, applied different governance modes to their organic public procurement policy. A centralised mode in Denmark, with the national government designing and implementing incentives and capacity building programmes and local governments as policy takers, and in Sweden, simply a clear national policy target set-up with local governments as voluntary policy-makers, plus some ranking/benchmarking systems assessing the share of organic procurement by the diverse municipalities as additional incentives for local governments. In both cases, the successful implementation of these policies relied on close collaboration with the actors of the organic food system, who appear to be key intermediaries in the success of these plans.

By referring to public procurement policies, Carsten Daugbjerg reminds us that in order to have a chance of success, any approach aimed at reducing pesticides in agriculture must take the whole food system into account, i.e. the entire set of public policies that direct and indirectly shape the food system. We have mentioned regulatory policies aimed at controlling the type of products allowed on the market and their environmental and sanitary effects, which could be far stricter. Policies that control the conditions of use, disposal and elimination of obsolete pesticides, including chemical waste produced by the manufacture of pesticides and resulting from their use, must not be forgotten. Absolute priority should be given to agricultural policies - be they of a redistributive nature or not - which should be tightly linked to pesticide-free modes of production and very explicitly target their budgets to reward those types of practices. As suggested by the Swedish and Danish cases, demand-side policies could more explicitly differentiate between products and their modes of production (in particular between organic and conventional agriculture) and give priority to pesticide free products; even more generally, all types of policies that would promote and support organic and/or pesticide-free products and processes should be strengthened.

4. Conclusion

Despite the fact that pesticides have become central in most agrifood systems in the space of a century, their fate is not yet sealed. For decades, warnings, criticisms and controversies have followed one another, while lock-ins and resistance to critics have grown stronger. Nevertheless, in all their diversity and in the degree of change they imply, the alternatives are now more than ever the focus of political, scientific and industrial agendas. This special issue and the articles it contain invite us to pay closer attention to the conditions of their emergence and development. They are a key element in understanding the future of agrifood systems and the way they will be able–or not- to escape from their chemical dependence, at both local and global scales. The dynamics of pesticide reduction/removal analysed in this special issue will also feed broader reflection on the mechanisms of identification and promotion of alternatives. In this respect, the dynamics surrounding alternatives to pesticides shed light on the tensions at work in other technological domains including energy, transportation and consumption. Alternatives emerge at the interfaces between science, society and politics, where the magnitude and speed of change are also the subject of debate. Two key findings emerge.

First, the five contributions invite us to question a mechanistic perspective in which alternatives only emerge in response to the clear problematization of pesticides by different publics, and instead to consider withdrawal or reduction injunctions and the emergence of alternatives as part of one and the same movement. The temporalities of the former differ from those of the latter, and the actors associated with one are not necessarily those associated with others. Social pressure may be strong in support of the withdrawal of pesticides, placing them at the crossroads of political, societal, scientific and industrial issues. Yet alternatives emerge in a variety of environments, and these are not always linked to the social spaces in which pesticides are construed as a problem. Some are developed by groups of farmers through bottom-up dynamics; others basically remain a matter for experts, industrialists and scientists, among which alternative framings of pesticides problems and solutions also compete. These alternatives do not involve other types of actors, such as citizens or social movements and activists calling for pesticide reduction in the same way. The time frames required by scientists to uncover problems and identify solutions are obviously not the same as those of political actors, industrialists, citizens or users, although alliances among them can also emerge and lead to policy changes linked to one or the other possible alternative.

Problematic technologies do not disappear simply because they are proven to be bad or because citizens no longer want them. Just like any technology, alternatives do not take over simply because they are efficient or because it has been shown that they can do better than existing technologies. The movement from one technology to another is the result of complex entanglements. The dynamics of problem construction/definition and of the identification of alternatives also needs to be analysed in interaction with one another. Alternatives can be put under the spotlight by political actors to justify ambitions in terms of pesticide reduction: this is precisely the case when these actors argue that few or no alternatives are available and/or technologically mature to explain why total or partial bans on certain products are impossible. The politics of the alternatives – or the absence of an alternative – can therefore be both a policy of action and of inaction, in order to meet or, on the contrary, to dismiss societal demands for problematic technologies.

Second, the case of pesticide reduction demonstrates that the issue of alternatives cannot be reduced to a technological problem. Alternatives are never 'only' technical objects, isolated from the rest of the social reality, as a technologist framing would assume. The articles in this special issue show that such a technological framing, which is the most common type, can have major political consequences by rendering alternatives not based on that technology invisible. Like in many other areas of ecological transition, the case of pesticide reduction or removal underlines the importance of considering the notion of alternative (or innovation) as broadly as possible. The withdrawal of pesticides can be achieved through technological replacement, but also through a number of more profound transformations and social innovations, including market reconfigurations, transforming agricultural labour, changing how farms are organized, redefining the relations between farmers and their advisors, changing the metrics and methods of assessment used, etc. Approaching the notion of alternative in a broad sense has strong implications for both policymaking and expertise. It invites public authorities to rethink their need for expertise when it comes to considering the reduction or withdrawal of controversial substances or objects. In this perspective, the knowledge produced on the social and political transformations linked to the dissemination of one alternative or another is as important as the technical knowledge related to these alternatives. A broader understanding of the very notion of alternative thus appears necessary in the governance of ecological transitions and in the definition of the scientific knowledge that should be produced and mobilized in this respect as well as the appropriate use of this knowledge.

5. References

Alemanno, Alberto. 2013. The Science, Law and Policy of Neonicotinoids and Bees: A New Test Case for the Precautionary Principle. *European Journal of Risk Regulation* 4 (2):191-207. doi:10.1017/S1867299X00003342.

Alliot, Christophe, Delphine Mc Adams-Marin, Diana Borniotto, and Philippe V. Baret. 2022. The social costs of pesticide use in France. *Frontiers in Sustainable Food Systems* 6. doi:10.3389/fsufs.2022.1027583.

Altieri, Miguel A., Peter M. Rosset, and Clara I. Nicholls. 1997. Biological control and agricultural modernization: Towards resolution of some contradictions. *Agriculture and Human Values* 14 (3):303-310. doi:10.1023/A:1007499401616.

Altieri, Miguel A., and Victor Manuel Toledo. 2011. The agroecological revolution in Latin America: rescuing nature, ensuring food sovereignty and empowering peasants. *The Journal of Peasant Studies* 38 (3):587-612. doi:10.1080/03066150.2011.582947.

Arancibia, F. 2013. Challenging the bioeconomy: The dynamics of collective action in Argentina. *Technology in Society* 35:79-92.

Aulagnier, A., and F. Goulet. 2017. Des technologies problématiques et de leurs alternatives. Le cas des pesticides agricoles en France. *Sociologie du travail* 59 (3). doi:https://doi.org/10.4000/sdt.840.

Aulagnier, Alexis. 2020. éduire sans contraindre. Le gouvernement des pratiques agricoles à l'épreuve des pesticides. Sciences Po, Paris.

Bajwa, U., and K. S. Sandhu. 2014. Effect of handling and processing on pesticide residues in food- a review. *J Food Sci Technol* 51 (2):201-220. doi:10.1007/s13197-011-0499-5.

Bakker, L., J. Sok, W. van der Werf, and F. J. J. A. Bianchi. 2021. Kicking the Habit: What Makes and Breaks Farmers' Intentions to Reduce Pesticide Use? *Ecological Economics* 180:106868. doi:https://doi.org/10.1016/j.ecolecon.2020.106868.

Barzman, M., and S. Dachbrodt-Saaydeh. 2011. Comparative analysis of pesticide action plans in five European countries. *Pest Manag Sci* 67 (12):1481-1485. doi:10.1002/ps.2283.

Bell, Shannon Elizabeth, Alicia Hullinger, and Lilian Brislen. 2015. Manipulated Masculinities: Agribusiness, Deskilling, and the Rise of the Businessman-Farmer in the United States. *Rural sociology* 80 (3):285-313. doi:https://doi.org/10.1111/ruso.12066.

Bellon, Stéphane, and Servane Penvern. 2014. Organic Food and Farming as a Prototype for Sustainable Agricultures. In *Organic Farming, Prototype for Sustainable Agricultures: Prototype for Sustainable Agricultures*, eds. Stéphane Bellon, and Servane Penvern, 1-19. Dordrecht: Springer Netherlands.

Bendjebbar, Pauline, and Eve Fouilleux. 2022. Exploring national trajectories of organic agriculture in Africa. Comparing Benin and Uganda. *Journal of Rural Studies* 89:110-121. doi:https://doi.org/10.1016/j.jrurstud.2021.11.012.

Böcker, Thomas G., and Robert Finger. 2017. A Meta-Analysis on the Elasticity of Demand for Pesticides. *Journal of Agricultural Economics* 68 (2):518-533. doi:https://doi.org/10.1111/1477-9552.12198.

Bohme, S. R. (2015). *Toxic Injustice: a transnational history of exposure and struggle*. Univ of California Press.

Boillat, Sébastien, Raphaël Belmin, and Patrick Bottazzi. 2022. The agroecological transition in Senegal: transnational links and uneven empowerment. *Agriculture and Human Values* 39 (1):281-300. doi:10.1007/s10460-021-10247-5.

Bonnaud, Laure, and Guilhem Anzalone. 2021. A perfect match? The co-creation of the tomato and beneficial insects markets. *Journal of Rural Studies* 83:11-20. doi:https://doi.org/10.1016/j.jrurstud.2021.02.002.

Bonvoisin, Toby, Leah Utyasheva, Duleeka Knipe, David Gunnell, and Michael Eddleston. 2020. Suicide by pesticide poisoning in India: a review of pesticide regulations and their impact on suicide trends. *BMC Public Health* 20 (1):251. doi:10.1186/s12889-020-8339-z.

Bosc, Christel, and Mehdi Arrignon. 2020. Les transitions agroécologiques en France. Clermont-Ferrand: Presses universitaores Blaise Pascal.

Bosso, Christopher J. 1987. *Pesticides and Politics: The Life Cycle of a Public Issue*. Pittsburgh: University of Pittsburgh Press

Bourguet, Denis, and Thomas Guillemaud. 2016. The Hidden and External Costs of Pesticide Use. In *Sustainable Agriculture Reviews: Volume 19*, ed. Eric Lichtfouse, 35-120. Cham: Springer International Publishing.

Bray, Laura A., Nicholas J. Membrez-Weiler, and Thomas E. Shriver. 2022. Agrochemical Exposure & Environmental Illness: Legal Repression of Latin American Banana Workers. *The Sociological Quarterly* 63 (2):359-378. doi:10.1080/00380253.2020.1841585.

Brickman, Ronald , Sheila Jasanoff, and Thomas Ilgen. 1985. *The politics of regulation in Europe and the United States*. Ithaca, NY: Cornell University Press.

Carvalho, Fernando P. 2006. Agriculture, pesticides, food security and food safety. *Environmental Science & Policy* 9 (7):685-692. doi:https://doi.org/10.1016/j.envsci.2006.08.002.

Carvalho Vidal, Mariane, Daniela Firmino Santana Amaral, Joaquim Dias Nogueira, Marcio Antônio Teixeira Mazzaro, and Virginia Mendes Cipriano Lira. 2021. Bioinsumos: a Construção de um Programa Nacional pela Sustentabilidade do Agro Brasileiro. *Economic Analysis of Law Review* 12 (3):557-574. doi:https://doi.org/10.31501/ealr.v12i3.12811.

Chantre, E., M. Cerf, and M. Le Bail. 2015. Transitional pathways towards input reduction on French field crop farms. *International Journal of Agricultural Sustainability* 13 (1):69-86. doi:10.1080/14735903.2014.945316.

Chèze, Benoît, Maia David, and Vincent Martinet. 2020. Understanding farmers' reluctance to reduce pesticide use: A choice experiment. *Ecological Economics* 167:106349. doi:https://doi.org/10.1016/j.ecolecon.2019.06.004.

Clapp, Jennifer. 2021. Explaining Growing Glyphosate Use: The Political Economy of Herbicide-Dependent Agriculture. *Global Environmental Change* 67:102239. doi:https://doi.org/10.1016/j.gloenvcha.2021.102239.

Compagnone, Claude, and Béatrice Simon. 2018. Cooperation and competition among agricultural advisory service providers. The case of pesticides use. *Journal of Rural Studies* 59:10-20. doi:https://doi.org/10.1016/j.jrurstud.2018.01.006.

Coquil, Xavier, Marianne Cerf, Caroline Auricoste, Alexandre Joannon, Flore Barcellini, Patrice Cayre, Marie Chizallet et al. 2018. Questioning the work of farmers, advisors, teachers and researchers in agro-ecological transition. A review. *Agronomy for Sustainable Development* 38 (5):47. doi:10.1007/s13593-018-0524-4.

Cowan, Robin, and Philip Gunby. 1996. Sprayed to Death: Path Dependence, Lock-in and Pest Control Strategies. *The Economic Journal* 106 (436):521-542. doi:10.2307/2235561.

Darnhofer, Ika, Simona D'Amico, and Eve Fouilleux. 2019. A relational perspective on the dynamics of the organic sector in Austria, Italy, and France. *Journal of Rural Studies* 68:200-212. doi:https://doi.org/10.1016/j.jrurstud.2018.12.002.

Darnhofer, Ika, Thomas Lindenthal, Ruth Bartel-Kratochvil, and Werner Zollitsch. 2010. Conventionalisation of organic farming practices: from structural criteria towards an assessment based on organic principles. A review. *Agronomy for Sustainable Development* 30 (1):67-81. doi:10.1051/agro/2009011.

Davis, Frederick Rowe 2014. *Banned: A History of Pesticides and the Science of Toxicology*. New Haven, CT: Yale University Press.

De Raymond, Antoine Bernard, and Frédéric Goulet. 2020. Science, Technology and Food Security: An Introduction. *Science, Technology and Society* 25 (1):7-18. doi:10.1177/0971721819889916.

Dedieu, François. 2022a. Organized denial at work: The difficult search for consistencies in French pesticide regulation. *Regulation & Governance* 16 (3):951-973. doi:https://doi.org/10.1111/rego.12381.

Dedieu, François. 2022b. Secrecies as Organized Ignorance: The Illusion of Knowledge in French Pesticide Regulation. *Science as Culture* 31 (4):455-479. doi:10.1080/09505431.2022.2090328.

Dedieu, François, Jean-Noël Jouzel, and Giovanni Prete. 2015. Governing by ignoring. The production and the function of the under-reporting of farm-workers' pesticide poisoning in French and Californian regulations. In *Routledge International Handbook of Ignorance Studies*, eds. Matthias Gross, and Linsey McGoey. Routledge.

Deguine, Jean-Philippe, Jean-Noël Aubertot, Rica Joy Flor, Françoise Lescourret, Kris A. G. Wyckhuys, and Alain Ratnadass. 2021. Integrated pest management: good intentions, hard realities. A review. *Agronomy for Sustainable Development* 41 (3):38. doi:10.1007/s13593-021-00689-w.

Delière, Laurent, Philippe Cartolaro, Bertrand Léger, and Olivier Naud. 2015. Field evaluation of an expertise-based formal decision system for fungicide management of grapevine downy and powdery mildews. *Pest Management Science* 71 (9):1247-1257. doi:https://doi.org/10.1002/ps.3917.

Demortain, David. 2011. Scientists and the Regulation of Risk: Standardising Control. Cheltenham: Edward Elgar, 288 p.

Demortain, David. 2020. Le lobbying par la science : l'enrôlement des scientifiques et de la connaissance scientifique dans la représentation des intérêts, dans Kerléo J.F., Le Lobbying: influence, contrôle et légitimité des représentants d'intérêts, LGDJ, Paris, 439 p.

Demortain, D. (2021). The science behind the ban: The outstanding impact of ecotoxicological research on the regulation of neonicotinoids. *Current Opinion in Insect Science, 46*, 78-82.

Desquilbet, Marion, David S. Bullock & Filippo Maria D'Arcangelo. 2019. A discussion of the market and policy failures associated with the adoption of herbicide-tolerant crops, International Journal of Agricultural Sustainability, 17:5, 326-337

Dereumeaux, C., C. Fillol, P. Quenel, and S. Denys. 2020. Pesticide exposures for residents living close to agricultural lands: A review. *Environ Int* 134:105210. doi:10.1016/j.envint.2019.105210.

Dyck, V.A., J. Hendrichs, and A.S. Robinson. 2021. Sterile Insect Technique: Principles And Practice In Area-Wide Integrated Pest Management. Boca raton, London, New York: CRC Press.

Evangelakaki, Georgia, Christos Karelakis, and Konstantinos Galanopoulos. 2020. Farmers' health and social insurance perceptions – A case study from a remote rural region in

Greece. *Journal of Rural Studies* 80:337-349. doi:https://doi.org/10.1016/j.jrurstud.2020.10.009.
Fabbri, A., A. Lai, Q. Grundy, and L. A. Bero. 2018. The Influence of Industry Sponsorship on the Research Agenda: A Scoping Review. *Am J Public Health* 108 (11):e9-e16. doi:10.2105/ajph.2018.304677.
T. Skevas, A.G.J.M. Oude Lansink & S.E. Stefanou. 2013. Designing the emerging EU pesticide policy: A literature review, NJAS: Wageningen Journal of Life Sciences, 64-65:1, 95-103.
Finger, Robert, Niklas Möhring, Tobias Dalhaus, and Thomas Böcker. 2017. Revisiting Pesticide Taxation Schemes. *Ecological Economics* 134:263-266. doi:https://doi.org/10.1016/j.ecolecon.2016.12.001.
Foucart, Stéphane. 2019. *Et le monde devint silencieux. Comment l'agrochimie a détruit les insectes*. Paris: Seuil.
Fouilleux, E., N. Bricas, and A. Alpha. 2017. 'Feeding 9 billion people': Global food security debates and the productionist trap. *Journal of European Public Policy* 24 (7):1658-1677.
Fouilleux, Eve, and Allison Loconto. 2017a. Behind the scenes of quality labels: Tripartite regulation and layered markets. From the Europeanization to the globalization of organic agriculture. *Revue Française de Sociologie* 58 (3):501-531.
Fouilleux, Eve, and Allison Loconto. 2017b. Voluntary standards, certification, and accreditation in the global organic agriculture field: a tripartite model of techno-politics. *Agriculture and Human Values* 34 (1):1-14. doi:10.1007/s10460-016-9686-3.
Frickel, Scott, Sahra Gibbon, Jeff Howard, Joanna Kempner, Gwen Ottinger, and David J. Hess. 2009. Undone Science: Charting Social Movement and Civil Society Challenges to Research Agenda Setting. *Science, Technology, & Human Values* 35 (4):444-473. doi:10.1177/0162243909345836.
Garrigou, A., Laurent, C., Berthet, A., Colosio, C., Jas, N., Daubas-Letourneux, V., ... & Judon, N. (2020). Critical review of the role of PPE in the prevention of risks related to agricultural pesticide use. *Safety science*, *123*, 104527.
Galt, Ryan E. 2008. Beyond the circle of poison: Significant shifts in the global pesticide complex, 1976–2008. *Global Environmental Change* 18 (4):786-799. doi:https://doi.org/10.1016/j.gloenvcha.2008.07.003.
Gao, Lijing, and J. Arbuckle. 2022. Examining farmers' adoption of nutrient management best management practices: a social cognitive framework. *Agriculture and Human Values* 39 (2):535-553. doi:10.1007/s10460-021-10266-2.
Giraldo, Omar Felipe, and Nils McCune. 2019. Can the state take agroecology to scale? Public policy experiences in agroecological territorialization from Latin America. *Agroecology and Sustainable Food Systems* 43 (7-8):785-809. doi:10.1080/21683565.2019.1585402.
Goulet, F., and D. Vinck. 2012. Innovation through Withdrawal. Contribution to a Sociology of Detachment. *Revue Française de Sociologie (ENGLISH)* 53 (2):117-146.
Goulet, Frédéric. 2021a. Biological inputs and agricultural policies in South America: between disruptive innovation and continuity. *Perspectives* (55). doi:https://doi.org/10.19182/perspective/36383.
Goulet, Frédéric. 2021b. Characterizing alignments in socio-technical transitions. Lessons from agricultural bio-inputs in Brazil. *Technology in Society* 65:101580. doi:https://doi.org/10.1016/j.techsoc.2021.101580.
Goulet, Frédéric. 2022. The role of alternative technologies in the enactment of (dis)continuities. In *Technologies in Decline: Socio-Technical Approaches to*

Discontinuation and Destabilisation, eds. Zahar Koretsky, Peter Stegmaier, Bruno Turnheim, and Haro van Lente, 167-184. London: Routledge.
Goulet, Frédéric, Alexis Aulagnier, and Matthieu Hubert. 2022. Retrait fort ou retrait faible : les pesticides et leurs alternatives. In *Faire sans, faire avec moins. Les nouveaux horizons de l'innovation*, eds. Frédéric Goulet, and Dominique Vinck, 113-126. Paris: Presses des Mines.
Goulet, Frédéric, and Matthieu Hubert. 2020. Making a Place for Alternative Technologies: The Case of Agricultural Bio-Inputs in Argentina. *Review of Policy Research* 37 (4):535-555. doi:https://doi.org/10.1111/ropr.12384.
Goulson, Dave. 2020. Pesticides, Corporate Irresponsibility, and the Fate of Our Planet. *One Earth* 2 (4):302-305. doi:https://doi.org/10.1016/j.oneear.2020.03.004.
Goulson, Dave. 2022. *Silent Earth. Averting the Insect Apocalypse*. HarperCollins Publishers.
Goulson, D., E. Nicholls, C. Botías, and E. L. Rotheray. 2015. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. Science 347:1255957.
Guichard, Laurence, François Dedieu, Marie-Hélène Jeuffroy, Jean-Marc Meynard, Raymond Reau, and Isabelle Savini. 2017. Le plan Ecophyto de réduction d'usage des pesticides en France : décryptage d'un échec et raisons d'espérer. *Cah. Agric.* 26 (1):14002.
Gusfield, J. 1981. *The Culture of Public Problems: Drinking, Driving, and the Symbolic Order*. Chicago: University of Chicago Press.
Guthman, Julie. 2004. *Agrarian dreams : The paradox of organic farming in California*. Berkeley: University of California Press.
Guthman, Julie. *Wilted: Pathogens, chemicals, and the fragile future of the strawberry industry*. University of California Press, 2019.
Heimstädt, Cornelius. 2023. Making plant pathology algorithmically recognizable. *Agriculture and Human Values*. doi:10.1007/s10460-023-10419-5.
Hill, Stuart B. 1998. Redesigning agroecosystems for environmental sustainability: a deep systems approach. *Systems Research and Behavioral Science* 15 (5):391-402. doi:https://doi.org/10.1002/(SICI)1099-1743(1998090)15:5<391::AID-SRES266>3.0.CO;2-0.
Hill, Stuart B., and Rod J. MacRae. 1996. Conceptual Framework for the Transition from Conventional to Sustainable Agriculture. *Journal of Sustainable Agriculture* 7 (1):81-87. doi:10.1300/J064v07n01_07.
Hillocks, R. J. 2012. Farming with fewer pesticides: EU pesticide review and resulting challenges for UK agriculture. *Crop Protection* 31 (1):85-93. doi:https://doi.org/10.1016/j.cropro.2011.08.008.
Hossard, Laure, Laurence Guichard, Céline Pelosi, and David Makowski. 2017. Lack of evidence for a decrease in synthetic pesticide use on the main arable crops in France. *Science of The Total Environment* 575:152-161. doi:https://doi.org/10.1016/j.scitotenv.2016.10.008.
Hough, Peter. 2003. Poisons in the System: The Global Regulation of Hazardous Pesticides. *Global Environmental Politics* 3 (2):11-24. doi:10.1162/152638003322068182.
Inserm. Effects of pesticides on health: New data. Summary. Collection Expertise collective. Montrouge: EDP Sciences, 2022.
Jansen, Kees. 2017. Business Conflict and Risk Regulation: Understanding the Influence of the Pesticide Industry. *Global Environmental Politics* 17 (4):48-66. doi:10.1162/GLEP_a_00427.
Jansen, Kees, and Milou Dubois. 2014. Global Pesticide Governance by Disclosure: Prior Informed Consent and the Rotterdam Convention. In *Transparency in Global Environmental Governance: Critical Perspectives*, eds. Aarti Gupta, and Michael Mason, 0. The MIT Press.

Jas, Nathalie. 2007. Public Health and Pesticide Regulation in France Before and After Silent Spring. *History and Technology* 23 (4):369-388. doi:10.1080/07341510701527435.
Jas, Nathalie. 2021. Corporate Systemic Ascendency: Perspectives from the Pesticide Industry in Postwar France. In *Pervasive Powers. The Politics of Corporate Authority*, eds. S.A. Aguiton, M.-O. Déplaude, N. Jas, E. Henry, and V. Thomas. Routledge.
Joly, Pierre-Benoît, Marc Barbier, and Bruno Turnheim. 2022. Gouverner l'arrêt des grands systèmes sociotechniques. In *Faire sans, faire avec moins. Les nouveaux horizons de l'innovation*, eds. Frédéric Goulet, and Dominique Vinc, 35-49. Paris: Presses des Mines.
Jouzel, Jean-Noël. 2019. *Comment ignorer ce que l'on sait.* Paris: Presses de Sciences Po.
Jouzel, Jean-Noël, and Giovanni Prete. 2015. Becoming a Victim of Pesticides: Legal Action and Its Effects on the Mobilisation of Affected Farmworkers. *Sociologie du travail* 57:e63-e80. doi:https://doi.org/10.1016/j.soctra.2015.09.010.
Karabelas, A. J., K. V. Plakas, E. S. Solomou, V. Drossou, and D. A. Sarigiannis. 2009. Impact of European legislation on marketed pesticides — A view from the standpoint of health impact assessment studies. *Environment International* 35 (7):1096-1107. doi:https://doi.org/10.1016/j.envint.2009.06.011.
Koch, Marcus A., Jale Tosun, Laura Kellermann, Charlene Marek, Markus Kiefer, and Mike Thiv. 2023. Reducing pesticides without organic certification? Potentials and limits of an intermediate form of agricultural production. *Cogent Food & Agriculture* 9 (1):2202892. doi:10.1080/23311932.2023.2202892.
Kogan, Marcos. 1998. Integrated Pest Management: Historical Perspectives and Contemporary Developments. *Annual Review of Entomology* 43 (1):243-270. doi:10.1146/annurev.ento.43.1.243.
Koretsky, Zahar, Peter Stegmaier, Bruno Turnheim, and Haro van Lente. 2022. Technologies in Decline: Socio-Technical Approaches to Discontinuation and Destabilisation. London: Routledge.
Kroma, Margaret M., and Cornelia Butler Flora. 2003. Greening pesticides: A historical analysis of the social construction of farm chemical advertisements. *Agriculture and Human Values* 20 (1):21-35. doi:10.1023/A:1022408506244.
Kvakkestad, Valborg, Anette Sundbye, Roma Gwynn, and Ingeborg Klingen. 2020. Authorization of microbial plant protection products in the Scandinavian countries: A comparative analysis. *Environmental Science & Policy* 106:115-124. doi:https://doi.org/10.1016/j.envsci.2020.01.017.
Lamine, Claire. 2011. Transition pathways towards a robust ecologization of agriculture and the need for system redesign. Cases from organic farming and IPM. *Journal of Rural Studies* 27 (2):209-219. doi:https://doi.org/10.1016/j.jrurstud.2011.02.001.
Lee, Rhiannon, Roos den Uyl, and Hens Runhaar. 2019. Assessment of policy instruments for pesticide use reduction in Europe; Learning from a systematic literature review. *Crop Protection* 126:104929. doi:https://doi.org/10.1016/j.cropro.2019.104929.
Lefebvre, Marianne, Stephen R. H. Langrell, and Sergio Gomez-y-Paloma. 2015. Incentives and policies for integrated pest management in Europe: a review. *Agronomy for Sustainable Development* 35 (1):27-45. doi:10.1007/s13593-014-0237-2.
Levain, Alix, Pierre-Benoît Joly, Marc Barbier, Vincent Cardon, François Dedieu, and Fanny Pellissier. 2015. Continuous discontinuation – The DDT Ban revisited. Paper presented at the International Sustainability Transitions Conference "Sustainability transitions and wider transformative change, historical roots and future pathways, University of Sussex, Brighton, UK,
Liévanos, R. S., London, J. K., & Sze, J. (2011). Uneven transformations and environmental justice: Regulatory science, street science, and pesticide regulation in California. In:

Ottingen G. and Cohen B. *Technoscience and environmental justice: Expert cultures in a grassroots movement*, 201-228.
Loconto, Allison, and Eve Fouilleux. 2019. Defining agroecology: Exploring the circulation of knowledge in FAO's Global Dialogue. *The International Journal of Sociology of Agriculture and Food.* 25 (2):116-137. doi:https://doi.org/10.48416/ijsaf.v25i2.27.
Luna, Jessie K. 2020. 'Pesticides are our children now': cultural change and the technological treadmill in the Burkina Faso cotton sector. *Agriculture and Human Values* 37 (2):449-462. doi:10.1007/s10460-019-09999-y.
Maguire, S., and C. Hardy. 2009. Discourse and Deinstitutionalization : The Decline of DDT. *Academy of Management Journal* 52 (1):148-178.
Maxim, Laura. 2023. *Economics and Power in EU Chemicals Policy and Regulation: Socio-economic Analysis for Managing Risks*. Edward Elgar Publishing.
McCulloch, Jock, and Geoffrey Tweedale. 2008. *Defending the Indefensible: The Global Asbestos Industry and Its Fight for Survival*. New York: Oxford University Press.
McHenry, L. B. 2018. The Monsanto Papers: Poisoning the scientific well. *Int J Risk Saf Med* 29 (3-4):193-205. doi:10.3233/jrs-180028.
Mie A, Rudén C, Grandjean P. 2018. Safety of Safety Evaluation of Pesticides: developmental neurotoxicity of chlorpyrifos and chlorpyrifos-methyl. *Environ Health.* Nov 16;17(1):77.
Milhorance, Carolina. 2022. Policy dismantling and democratic regression in Brazil under Bolsonaro: Coalition politics, ideas, and underlying discourses. *Review of Policy Research* 39 (6):752-770. doi:https://doi.org/10.1111/ropr.12502.
Möhring, Niklas, Karin Ingold, Per Kudsk, Fabrice Martin-Laurent, Urs Niggli, Michael Siegrist, Bruno Studer, Achim Walter, and Robert Finger. 2020. Pathways for advancing pesticide policies. *Nature Food* 1 (9):535-540. doi:10.1038/s43016-020-00141-4.
Florencia Arancibia & Renata Motta (2019) Undone Science and Counter-Expertise: Fighting for Justice in an Argentine Community Contaminated by Pesticides, *Science as Culture*, 28:3, 277-302.
Müller, Birgit. 2021. Glyphosate—A love story. Ordinary thoughtlessness and response-ability in industrial farming. *Journal of Agrarian Change* 21 (1):160-179. doi:https://doi.org/10.1111/joac.12374.
Navas, Grettel. 2022. 'If there's no evidence, there's no victim': undone science and political organisation in marginalising women as victims of DBCP in Nicaragua. *The Journal of Peasant Studies*:1-24. doi:10.1080/03066150.2021.2024517.
Oreskes, N., and E.M. Conway. 2010. *Merchants of Doubt*. New York: Bloomsbury Press.
Pelaez, Victor, Letícia Rodrigues da Silva, and Eduardo Borges Araújo. 2013. Regulation of pesticides: A comparative analysis*. *Science and public policy* 40 (5):644-656. doi:10.1093/scipol/sct020.
Pelosi, C., C. Bertrand, G. Daniele, M. Coeurdassier, P. Benoit, S. Nélieu, F. Lafay et al. 2021. Residues of currently used pesticides in soils and earthworms: A silent threat? *Agriculture, Ecosystems & Environment* 305:107167. doi:https://doi.org/10.1016/j.agee.2020.107167.
Pellow, David Naguib. *Resisting global toxics: Transnational movements for environmental justice*. mit Press, 2007.
Phung, D. T., D. Connell, G. Miller, S. Rutherford, and C. Chu. 2012. Pesticide regulations and farm worker safety: the need to improve pesticide regulations in Viet Nam. *Bull World Health Organ* 90 (6):468-473. doi:10.2471/blt.11.096578.
Rigal, Stanislas, et al. "Farmland practices are driving bird population decline across Europe." *Proceedings of the National Academy of Sciences* 120.21 (2023): e2216573120

Rosset,Peter M., and Miguel A. Altieri. 1997. Agroecology versus input substitution: A fundamental contradiction of sustainable agriculture. *Society & Natural Resources* 10 (3):283-295. doi:10.1080/08941929709381027.
Sawyer, Richard C. 1996. *To Make a Spotless Orange. Biological Control in California*, Iowa State University Press
Saxton, D. I. 2021. *The Devil's Fruit: Farmworkers, Health, and Environmental Justice*. Rutgers University Press.
Shattuck, A. 2021. Generic, growing, green?: The changing political economy of the global pesticide complex. *The Journal of Peasant Studies, 48*(2), 231-253.
Shattuck, A., Werner, M., Mempel, F., Dunivin, Z., & Galt, R. 2023. Global pesticide use and trade database (GloPUT): New estimates show pesticide use trends in low-income countries substantially underestimated. *Global Environmental Change*, *81*, 102693.
Schwindenhammer, Sandra. 2020. The Rise, Regulation and Risks of Genetically Modified Insect Technology in Global Agriculture. *Science, Technology and Society* 25 (1):124-141. doi:10.1177/0971721819890042.
Seibold, Sebastian, Martin M. Gossner, Nadja K. Simons, Nico Blüthgen, Jörg Müller, Didem Ambarlı, Christian Ammer et al. 2019. Arthropod decline in grasslands and forests is associated with landscape-level drivers. *Nature* 574 (7780):671-674. doi:10.1038/s41586-019-1684-3.
Shattuck, Annie. 2021. Generic, growing, green?: The changing political economy of the global pesticide complex. *The Journal of Peasant Studies* 48 (2):231-253. doi:10.1080/03066150.2020.1839053.
Sherwood, Stephen G., and Myriam Paredes. 2014. Dynamics of Perpetuation: The Politics of Keeping Highly Toxic Pesticides on the Market in Ecuador. *Nature and Culture* 9 (1):21-44. doi:10.3167/nc.2014.090102.
Star, S.L., and J. Griesemer. 1989. Institutionnal ecology, "translations" and boundary objects : amateurs and professionals on Berkeley's museum of vertebrates zoology. *Social Studies of Science* 19 (3):387-420.
Stegmaier, P., S. Kuhlmann, and V.R. Visser. 2014. The discontinuation of socio-technical systems as a governance problem. In *The governance of socio-technical systems*, eds. S. Borras, and J. Edler, 111-131. Cheltenham: Edward Elgar.
Suryanarayanan, Sainath, and Daniel Lee Kleinman. 2013. Be(e)coming experts: The controversy over insecticides in the honey bee colony collapse disorder. *Social Studies of Science* 43 (2):215-240. doi:10.1177/0306312712466186.
Syed Ab Rahman, Sharifah Farhana, Eugenie Singh, Corné M. J. Pieterse, and Peer M. Schenk. 2018. Emerging microbial biocontrol strategies for plant pathogens. *Plant Science* 267:102-111. doi:https://doi.org/10.1016/j.plantsci.2017.11.012.
Tosun, Jale, Herman Lelieveldt, and Trevelyan S. Wing. 2019. A Case of ‘Muddling Through’? The Politics of Renewing Glyphosate Authorization in the European Union. *Sustainability* 11 (2):440.
Tosun, Jale, and Frédéric Varone. 2021. Politicizing the Use of Glyphosate in Europe: Comparing Policy Issue Linkage across Advocacy Organizations and Countries. *Journal of Comparative Policy Analysis: Research and Practice* 23 (5-6):607-624. doi:10.1080/13876988.2020.1762076.
Turnheim, Bruno, and Frank W. Geels. 2013. The destabilisation of existing regimes: Confronting a multi-dimensional framework with a case study of the British coal industry (1913–1967). *Research Policy* 42 (10):1749-1767. doi:https://doi.org/10.1016/j.respol.2013.04.009.

Vanloqueren, G., and P. Baret. 2009. How agricultural research system shape a technological regim that develops genetic engineering but locks out agroecological innovations. *Research Policy* 38:971-983.
Vanloqueren, Gaëtan, and Philippe V. Baret. 2008. Why are ecological, low-input, multi-resistant wheat cultivars slow to develop commercially? A Belgian agricultural 'lock-in' case study. *Ecological Economics* 66 (2):436-446. doi:https://doi.org/10.1016/j.ecolecon.2007.10.007.
Vialatte, Aude, Anaïs Tibi, Audrey Alignier, Valérie Angeon, Laurent Bedoussac, David A. Bohan, Douadia Bougherara et al. 2022. Chapter Four - Promoting crop pest control by plant diversification in agricultural landscapes: A conceptual framework for analysing feedback loops between agro-ecological and socio-economic effects. In *Advances in Ecological Research*, eds. David A. Bohan, Alex J. Dumbrell, and Adam J. Vanbergen, 133-165. Academic Press.
Villemaine, Robin, Claude Compagnone, and Camille Falconnet. 2021. The social construction of alternatives to pesticide use: A study of biocontrol in Burgundian viticulture. *Sociologia Ruralis* 61 (1):74-95. doi:https://doi.org/10.1111/soru.12320.
Wachenheim, Cheryl, Linfeng Fan, and Shi Zheng. 2021. Adoption of unmanned aerial vehicles for pesticide application: Role of social network, resource endowment, and perceptions. *Technology in Society* 64:101470. doi:https://doi.org/10.1016/j.techsoc.2020.101470.
Weir, David, and Mark Shapiro. 1981. *Circle of poison : pesticides and people in a hungry world*. San francisco, CA: Institute for Food and Development Policy.
Wezel, A., S. Bellon, T. Doré, C. Francis, D. Vallod, and C. David. 2009. Agroecology as a science, a movement and a practice. A review. *Agronomy for Sustainable Development* 29 (4):503-515. doi:10.1051/agro/2009004.
Wezel, Alexander, Marion Casagrande, Florian Celette, Jean-François Vian, Aurélie Ferrer, and Joséphine Peigné. 2014. Agroecological practices for sustainable agriculture. A review. *Agronomy for Sustainable Development* 34 (1):1-20. doi:10.1007/s13593-013-0180-7.
Wilson, Clevo, and Clem Tisdell. 2001. Why farmers continue to use pesticides despite environmental, health and sustainability costs. *Ecological Economics* 39 (3):449-462. doi:https://doi.org/10.1016/S0921-8009(01)00238-5.
Wuepper, David, Fiona H. M. Tang, and Robert Finger. 2023. National leverage points to reduce global pesticide pollution. *Global Environmental Change* 78:102631. doi:https://doi.org/10.1016/j.gloenvcha.2022.102631.
Young, J. C., S. Calla, L. Lécuyer, and E. Skrimizea. 2022. Understanding the social enablers and disablers of pesticide reduction and agricultural transformation. *Journal of Rural Studies* 95:67-76. doi:https://doi.org/10.1016/j.jrurstud.2022.07.023.