



## Towards less chemical inputs in agriculture

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Agriculture is undoubtedly one of the human activities with the heaviest impact on the environment, because of a variety of reasons ranging from extensive land use to losses of biodiversity caused by pesticides. I will focus here on the situation regarding the use of chemical pesticides (see review in Jacquet et al. 2022) whose production and use rely on petrochemistry. Despite their serious negative impacts on the environment and health, and despite public actions to reduce their use in many countries worldwide, these chemical inputs have not displayed any significant decrease of use over the last twenty years (e.g. Eurostat data).

Most food systems are currently locked in an unsustainable equilibrium in which the primary production sectors rely upon chemical inputs. The reason behind this situation is that each part of the agricultural sector, from farms to retail, relies on the use of pesticides (Wilson and Tisdell 2001). After World War II, the objective of increasing agricultural production led to intensification of agriculture. This intensification, enabled by high-yielding varieties, chemical pesticides, chemical fertilizers, and mechanization, has been associated with an increase in farm size, to the detriment of biodiversity (Ricciardi et al. 2021), and pest control services provided by ecosystems (van der Sluijs 2020). The dependence of these systems on chemical inputs has thus progressively increased (Meehan et al. 2011). In addition, upstream and downstream sectors have been organized to facilitate and benefit from the intensification of agriculture, leading to a technological lock-in around pesticide use (Wilson and Tisdell 2001). Among all factors involved in this lock-in, the lack of created added value is likely the one that limits implementation of pesticide-free practices the most. Since the products from these practices are not sold at higher prices than conventional ones, farmers have no incentive to implement them. In specific sectors (e.g., fruits and vegetables), implementing pesticide-free practices can also be compromised by market demands for undamaged products (Skevas and Lansink 2014). Undoubtedly, the market does not consider the impact of pesticides on the environment and health (Becker 2017).

Currently, two main consistent strategies for reducing pesticide use exist: integrated pest management (IPM) and organic agriculture. On the one side, IPM is defined by the European Union as the combination of "all available plant protection methods and subsequent integration of appropriate measures that discourage the development of populations of harmful organisms" and "encourage natural pest control mechanisms" (European Commission 2017). The EU has supported the research and implementation of IPM through National Action Plans (European Commission 2020), based on the idea that pesticide use can be substantially reduced by

developing IPM on a large scale (Lamichhane et al. 2015). However, this strategy has not been effective since pesticide use has not decreased (FAOSTAT 2020). Several factors can explain this low impact. First, there is a lack of added value for the sectors that implement IPM, which does not increase the value of products for farmers. Second, there is a wide range of IPM-based practices and farmers often adopt only parts of the spectrum of IPM principles (Lefebvre et al. 2015). On the other side, organic agriculture clearly reduces pesticide use, since it prohibits the use of synthetic fertilizers or pesticides, while maintaining soil fertility and closing nutrient cycles (Reganold and Wachter 2016). Organic agriculture represents a growing sector (increase of 74% from 2008 to 2018 in the EU), but it covers only a small percentage of all farmlands (8% in 2018 in the EU) (Eurostat 2020b). However, organic systems tend to have lower yields than conventional systems (Seufert et al. 2012), even though they are offset at the farm scale by the higher prices of certified organic products, lower input use and agro-environmental premiums in some countries. In addition, some technical issues, (e.g., weed management) are not yet fully solved. Depending on the type of crop production, organic systems can also have more variable yields, which increases risks (Smith et al. 2019).

Agricultural research has a major role to play to go beyond this state of the art and foster new agrifood systems using little or no chemical inputs. However, research concerns itself with pesticide dependence: most research programmes are looking for progressive reduction of pesticides and focus mainly on substitution solutions (Vanloqueren and Baret 2009). This trend gives little priority to research that could lead to disruptive agroecological innovations, not only for pesticide-free agriculture but also for reducing pesticide use greatly. It can be likened to a “fixation” effect, which is characterized by the development of common and conservative solutions to address a complex problem that should require breakthrough innovations (Vourc’h et al. 2018). One solution for overcoming this fixation effect is to clearly state that research and innovation need to work within a pesticide-free paradigm right now. This paradigm removes or relaxes a set of implicit constraints that limit creativity and innovation and are inherited from the agrochemical systems set after World War II, in which curative chemical inputs are the cornerstone. Indeed, currently R&D of agroecological methods must adapt to systems designed for pesticides (monoculture, large fields, little use of resistant cultivars, machinery designed to spray pesticides, advice and distribution channels configured for pesticides, etc.). This not only limits innovation possibilities but also decreases the perceived efficiency of other methods that are used in unfavourable conditions, which restricts their adoption and ultimately public and private investment in their development. Moreover, investment in pesticides still competes with investment on agroecological methods, which remains at a level that is insufficient when considering the current challenge of an agroecological transition in agriculture.

To achieve the pesticide-free goal, several strategies must be designed and implemented simultaneously, which require an investment in fundamental and applied research, and research activities mixing disciplines from biological to social sciences. First, regarding agricultural sciences, cropping systems should be redesigned based on agroecological principles to implement radical change from a curative approach (using curative inputs) to a preventive approach (optimizing prophylaxis and pest control services provided by agrosystems and their surroundings). Second,

regarding biological control, strategies should be diversified (with a shift to more services related to conservation biocontrol and inoculative strategies aiming at enhancing permanent or transient pest control) and tailored to a variety of environments and practices. Third, regarding genetics, breeding programs should involve concepts of functional biodiversity and evolutionary ecology. Fourth, regarding machinery, agricultural equipment should be modified to facilitate the transition to pesticide-free agricultural practices, while digital technologies should help optimize pest control and improve epidemiological surveillance. Fifth, regarding economic and social sciences, public policies and private initiatives for the transition toward pesticide-free systems should be implemented.

To achieve this goal, the organisation of research and innovation activities should also be adapted. Previous technical innovations emerged and spread mainly through top-down dynamics: researchers produced knowledge that was transferred to development organizations, which adapted it into applicable techniques and then disseminated it to farms as widely as possible. In contrast, the pesticide-free objective cannot be limited to top-down approaches, but should also value the expert knowledge and know-how of stakeholders in their own geographic area and value chain. This bottom-up approach therefore aligns with the conceptual framework of AKIS (i.e., Agricultural Knowledge and Innovation Systems), which calls for stakeholders along the entire agricultural value chain to interact in order to manage knowledge and develop innovations among them (Knierim et al. 2015). These knowledge flows and innovation-design processes can be managed and supported through participatory research and cooperation organizations, such as living labs, which represent promising tools to enhance open innovations (Kok et al. 2019). This approach is particularly important because many of the solutions that will be developed will not be generalizable everywhere and will require situation-specific innovation. Thus, they must be designed as closely as possible to target situations by considering the resources available and the objectives of the stakeholders concerned, and by closely relating agricultural production and consumption, to engage entire value chains in the design of these transformations (Meynard et al. 2017).

This change of paradigm is supported by several groups of academic players, such as the European alliance "Towards a chemical pesticide free agriculture" (<https://www.era-pesticidefree.eu/>) and a recently born international initiative on Agroecological Crop Protection. Such initiatives should contribute to produce scientifically sound evidence that pesticide-free systems are possible and sustainable (economically, environmentally, and socially) and that agroecology-oriented value chains benefit from research and innovation activities following this paradigm, and vice versa.

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