RISE Foundation 2020

CROP PROTECTION & THE EU FOOD SYSTEM: Where are they going?

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CROP PROTECTION & THE EU FOOD SYSTEM: Where are they going?

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Abbreviations

AS	ACTIVE SUBSTANCE
CAP	COMMON AGRICULTURAL POLICY
CET	(EU'S) COMMON EXTERNAL TARIFF
CP	CROP PROTECTION
EC	EUROPEAN COMMISSION
ECA	EUROPEAN COURT OF AUDITORS
EEA	EUROPEAN ENVIRONMENT AGENCY
EFSA	EUROPEAN FOOD SAFETY AUTHORITY
EU	EUROPEAN UNION
FAO	FOOD AND AGRICULTURE ORGANISATION OF THE UNITED NATIONS
GM	GENETICALLY MODIFIED
GMOs	GENETICALLY MODIFIED ORGANISMS
HRI	HARMONISED RISK INDICATORS
IBMA	INTERNATIONAL BIOCONTROL MANUFACTURERS ASSOCIATION
IPM	INTEGRATED PEST MANAGEMENT
MS	MEMBER STATE
NAPs	NATIONAL ACTION PLANS
NBT	NEW BREEDING TECHNIQUES
NGO	NON-GOVERNMENTAL ORGANISATION
PA	PRECISION AGRICULTURE
PPP	PLANT PROTECTION PRODUCT
RNA	RIBONUCLEIC ACID
SDGs	SUSTAINABLE DEVELOPMENT GOALS
SUD	DIRECTIVE ON THE SUSTAINABLE USE OF PESTICIDES (2009/128/EC)
WTO	WORLD TRADE ORGANISATION

PREFACE

Dr Janez Potocnik
Chairman, The RISE Foundation

The need for an ecological transition is now finally starting to be discussed by governments and international organisations around the world. This and the climate momentum can give us real hope that action may start to be taken to shift our production and consumption systems towards a circular and sustainable model. But talking is one thing, and doing is another.

Without fundamental changes, the costs of dealing with global heating, extreme weather events and consequences of biodiversity loss will soon be difficult to sustain, and in order to address these challenges, all sectors need to embrace this transition, and agriculture is no exception.

In Europe, where agricultural land accounts for almost half of the European territory, it is evident that the way we farm can make fundamental changes in addressing today's challenges. How we protect our crops against pest and disease attack is one issue that must be effectively addressed, and in recent years the use of pesticides has become emblematic of the wider concerns of how we manage our agricultural systems today. Arguments have become entrenched as 'for' and 'against'; between gains in agricultural productivity and growing demand, on one hand, and the resulting environmental and health costs, on the other.

There are opportunities to be gained here, as elsewhere in agriculture. In order to tackle the issue of crop protection, we need to move away from reliance on chemistry alone towards more actively working with nature and biological solutions. To enable this, the system must be helped to become more resilient by restoring natural ecosystem functioning. Farming practices must adapt, land use change is necessary, technology and innovation embraced. By addressing the system of agriculture as a whole we can move to eliminate the harm of these products, whilst simultaneously tackling biodiversity restoration, reversing soil degradation, improving soil sequestration and water quality. In order to be effective in changing one aspect of the way we farm, we need to address the whole food chain, including consumption and production methods.

The key word here is 'systemic'. There must be systemic transformation in the agricultural system if we are to reduce the harm caused by our current predominant form of production. Strong regulations on what we apply on our fields will always be necessary, but perhaps by focusing less on doing 'less bad' and celebrating the opportunities that this transition can bring, we can enable and engage stakeholders to find ways to benefit from the wholesale shift in the way in which we farm today.

EXECUTIVE SUMMARY

1 The focus of this report is **crop protection** in the European Union (EU). However, because the EU has significant influence and trades globally some wider considerations are also treated. This study set out to consider the general unhappiness of all stakeholders with the predominant way in which crops are protected, namely the reliance on Plant Protection Products (henceforth PPP), especially synthetic PPPs. What are the roots and facts of this unhappiness? What new directions could provide relief? These are the questions addressed.

2 The nature and extent of use of PPPs is now one of the totemic issues in the EU food system. Yet, PPP use is only one approach to crop protection, and crop protection is just one, albeit a very important, aspect of the principal production system of conventional EU agriculture. Discussion of crop protection inevitably broadens-out to embrace questions about the whole production system in the food chain. This is entirely consistent with the fact that the climate and biodiversity crises are driving transformations and system change in energy, mobility and other fundamental aspects of 21st Century life. It would be surprising if the food system had no need similarly to adapt.

3 What is the nature of the unhappiness of the major stakeholders with the status quo in crop protection? In short, farmers fear the loss of products from their crop production toolbox, the PPP industry fears the rising cost and time for getting product approval which undermines investment, environmentalists and many scientists believe that health, biodiversity, water and soils are still suffering unacceptable harm from PPPs, public authorities can't handle and enforce the existing legislation effectively, politicians have been proposing cuts in use of PPPs for many years but little change is observed. No one is satisfied.

4 The current EU crop protection strategy as defined in legislation has the goal to protect health and environment, maintain agricultural competitiveness and to encourage farmers to reduce dependency on PPPs giving priority to non-chemical methods of plant protection by implementing Integrated Pest Management (IPM). The intention of the current approval process is to replace more damaging products with less damaging ones.

5 This strategy is not working well in practice. Risks are not being sufficiently reduced for some stakeholders, IPM is not comprehensively implemented, risk assessments for PPPs are not fulfilling expectations, timetables for product approvals are not respected due to under-resourced regulations and lack of clear targets, data on current PPP use is inadequate. The approval process for active substances based on EU Regulation 1107/2009 has hardly changed the overall availability of active substances up to 2016, as measured by numbers of actives. However, numbers of active substances do not tell the whole story, efficacy and risks to health and environment are multi-faceted and complex to assess. Most stakeholders expect that there will be deletions of active substances in coming years including some widely used PPPs.

6 Whilst there are substantial criticisms that the approval process requires significant further elaboration to catch up with science, a recent REFIT evaluation did not recommend big changes. No stakeholder group is asking for new or substantial revisions to the approval process for synthetic chemical PPPs; the principal regulatory amendment being proposed is for a new approval process for biocontrol products. The broad objectives of the current strategy are not contested, and there is agreement that implementation can and should be improved. The principal controversy concerns the way risks are assessed and the agronomic practices for crop protection that are considered acceptable.

7 The key societal choice of crop protection system is initially examined through two perspectives. The first offers continuation of status quo conventional agriculture with high reliance on synthetic-based PPPs. The second suggests that the food system should undergo a substantial transition with the aim of restoring ecosystem functioning in soils, enhancing nature-based crop protection and reducing reliance on synthetic PPP use.

8 The **status quo** is rejected as neither desirable nor possible; it is unsustainable. Why? For four reasons. The continued decline in biodiversity and soil fertility. The resulting loss of ecosystem services. The constant emergence of pathogen resistance to PPPs, and the corresponding problem of antimicrobial resistance in human disease resulting from certain fungicide use in crop production. The expected fall in the availability of active substances as more are either not submitted for re-approval or fail to be approved, and new modes of action dry up. In addition, the challenge for agriculture and land use of reducing GHG emissions and creating more carbon sinks signal that there has to be a change in the food and agricultural system, including crop protection, to restore ecosystem function and bring about substantial reduction in environmental damage and risks to human health.

9 **A transition in the food system** to restore natural protection and resilience, in which the ultimate aim is to phase out routine synthetic PPP use, would reverse the decline into environmental unsustainability. But the risks for example of crop failure or food toxins such as mycotoxins, when such sustainable systems are expanded to the scale necessary to feed the population, are not known. Key questions are the extent to which this system change is technically, economically and socially feasible and acceptable, whether it is geopolitically negotiable as it may require higher food prices and import restrictions if pursued unilaterally in the EU.

10 Without determination and purposive measures such transition could easily be delayed. Lower intensity sustainable farming systems are bound to produce lower total output unless *more* land is allocated to agriculture, and yet climate change almost certainly means *less* land will be available for agriculture as a more important role for some agricultural land will be to sequester carbon. Can food security be maintained with lower intensity on less land? It is clearly only feasible if food waste and over-consumption of livestock and other products are reduced commensurately. Such a system switch will therefore require inducements and assistance to farmers, higher food prices and social transfers to the poorest to make the latter acceptable. These are crucial questions in determining the future strategy for the EU food and land management system. These questions are prompted by considering crop protection but clearly have implications way beyond this component of current production systems. Significant research and monitoring covering environmental, economic and social impacts will be required to provide the answers.

11 The conclusions are that crop protection should move towards this new system. This should follow a new goal for crop protection: ***to re-establish ecosystem functions on agricultural land to provide nature-based solutions for pest, disease and weed threats, and to utilise all means to eliminate the harms caused to health and environment by use of PPPs***. In the time frame, say, to mid-Century it is not clear that it is feasible to redirect *the whole of* food production down a transition path to sustainable farming. In any case more fruit, vegetables, herbs and spices may be produced in controlled, contained and vertical systems; livestock products may be partially substituted by 'farmed' insects, algae and cultured products. There can be no guarantee that the transition can reliably provide sufficient food unless coupled with significant changes in consumption and waste. Therefore, the wisest strategy is to devise a multi-track transitional development path which embraces the best that science can bring to help the wide variety of existing production systems, including agroecology, to converge on achieving the stated goal.

12 The **transition strategy** should therefore seek contributions from each of five developments towards achieving the above goal. Pre-requisites to enable progress are the firm establishment at regional/national level and farm level of environmental baselines against which to demonstrate achievement and further review of the adequacy of the approval criteria for PPPs. The five developments discussed are:

- i Encourage the adoption of sustainable farming principles and practices.
- ii Drive Integrated Pest Management as the coordinating framework.
- iii Encourage biocontrol where possible.
- iv Deploy precision agriculture, robotics, artificial intelligence and big data where appropriate.
- v Internalise pest and disease resistance through breeding.

13 The final chapter on **policy recommendations**, considers the actions necessary to make progress in reducing the controversy surrounding EU crop protection and the unhappiness of the stakeholders. The policies are considered under four headings.

- i *High level food system strategy*. Progress is not likely until and unless there is positive engagement of major stakeholders in the necessity and direction of the transition.
- ii *Agricultural and environmental policy*. The Common Agricultural Policy should be the major instrument for assisting the necessary system change including meaningful adoption of IPM principles. If this proves unacceptable then it should be supplemented with parallel stronger measures in the form of polluter-pays taxes.
- iii *Specific crop protection policy* including further development of data on PPPs use and risk indicators, better resourcing and execution of the approval process, consideration of a new regulation for biocontrol products and the current review of the applications of genomics in crop breeding.
- iv *Enabling policy measures* which include education, training, advisory services and research.

Glossary

The terminology of crop protection is often quite confused in practice. Key concepts used in this report are defined below (in a logical sequence rather than alphabetical). These are based where possible on the definitions enshrined in EU legislation.

Crop protection toolbox: includes agronomic practices and landscape management tools, physical crop protection tools, biocontrol and chemical pest control in addition to monitoring, forecasting and the use of warning systems.

Active substance: the substance responsible for acting against pests, disease, and weeds in a plant protection product. The Regulation classifies some of these substances as low risk and basic active substances.

Low risk active substance: defined in Annex II of Regulation EC 1107/2009 as distinct from non-low risk active substances. Substances are not considered low risk if they are classified in one of the following categories according to Regulation (EC) 1272/2008: carcinogenic, mutagenic, toxic to reproduction, sensitising chemicals, very toxic or toxic, explosive, or corrosive. And also if 'they are persistent (half-life in soil is more than 60 days), their bioconcentration factor is higher than 100, they are deemed to be an endocrine disrupter or they have neurotoxic or immunotoxic effects' (*Annex II of Regulation (EC) 1107/2009*).

Basic active substance: active substance which is not a substance of concern, does not have an inherent capacity to cause endocrine disrupting, neurotoxic or immunotoxic effects, is not predominantly used for plant protection purposes but nevertheless is useful in plant protection either directly or in a product consisting of the substance and a simple diluent, and is not placed on the market as a plant protection product (*Article 23 of Regulation (EC) 1107/2009*).

Plant Protection Products (PPP): Products consisting of or containing active substances, safeners or synergists, and intended for one of the uses described in Regulation (EC) 1107/2009: protecting plants or plant products, influencing the life processes of plants, preserving plant products, destroying undesired plants or parts of plants and checking or preventing undesired growth of plants. In this report the term PPP includes all those products under Regulation (EC) 1107/2009: synthetic PPPs and those commonly classified under 'biocontrol' (also called 'biopesticides'). Both groups can be further classified as low risk PPPs as long as they fulfil a set of criteria.

Low risk plant protection products: Products containing active substances that are low risk active substances, that need no specific risk mitigation measures following a risk assessment, and that comply with a specific set of requirements (*as listed in Article 47 of Regulation (EC) 1107/2009*).

Synthetic plant protection products: products based on active substances that don't originate in nature nor are nature identical, these products are synthesised in the laboratory. This excludes PPPs defined under biocontrol (sometimes called biopesticides or nature based PPPs). The word 'conventional' is sometimes used instead of 'synthetic' to refer to these products.

Biocontrol (or bioprotection): refers to a range of tools used to control pests, diseases and weeds based on naturally occurring compounds or organisms. These include: macrobials (invertebrate control agents), microbials (e.g. bacteria), semiochemicals (e.g. pheromones) and natural substances (e.g. garlic extract). PPPs used in biocontrol must be sourced from nature or can be synthetized as long as they're nature identical and are sometimes called biopesticides.

Pesticide: the term is used to designate both plant protection products and biocides. In everyday use this word is often a synonym for plant protection products, but it´s not the case in this report.

Organic agriculture: according to Regulation (EC) 2018/848: 'Organic production is an overall system of farm management and food production that combines best environmental and climate action practices, a high level of biodiversity, the preservation of natural resources and the application of high animal welfare standards and high production standards in line with the demand of a growing number of consumers for products produced using natural substances and processes. Organic production thus plays a dual societal role, where, on the one hand, it provides for a specific market responding to consumer demand for organic products and, on the other hand, it delivers publicly available goods that contribute to the protection of the environment and animal welfare, as well as to rural development (*initial paragraphs of the regulation*). The use of PPPs should be significantly restricted. Preference should be given to measures to prevent damage by pests and weeds through techniques which do not involve the use of plant protection products, such as crop rotation or natural enemies (*Annex II of the Regulation (EU) 2018/848*). If primary crop protection measures fail, organic farmers are allowed to use products and substances as authorised by Regulation 1107/2009. These include PPPs based on natural substances, semiochemicals and microbials, as well as substances traditionally used in organic farming such as copper and sulphur (*full list in Annex II of Regulation 889/2008*).

Sustainable agriculture: agricultural systems that preserve and restore natural ecosystem functioning; both within agricultural soils and in above-ground crop systems working from the field to the landscape scale and integrating semi-natural elements. Focus is placed on restoring soil fertility and thus soil function. This is achieved by extending and widening crop rotations, mixing plant and animal agriculture where possible, providing nutrients by making more use of legumes, manures, composted material and digestates, cover and companion crops and legumes and introducing greater diversity in fields and around them. The essence is to restore soil and above ground biodiversity to maximise natural and circular processes for plant nutrition, health, resistance to pests and disease thereby increasing the resilience of the production system. In these systems, the use of synthetic plant protection products as well as mineral fertilizers is greatly reduced or not allowed. (*RISE own definition*).

Chapter 1

CROP PROTECTION IS AN ENDURING SOURCE OF CONTROVERSY

The current EU crop protection strategy as defined in legislation has the goal to protect health and environment, maintain agricultural competitiveness and to encourage farmers to reduce dependency on PPPs giving priority to non-chemical methods of plant protection by implementing Integrated Pest Management (IPM). However, it is not working well in practice and the major stakeholders (farmers, consumers, PPP industry, environmentalists, scientists, public authorities, and politicians) are unhappy with the status quo.

This report is concerned with crop protection in the European Union. However, because the EU is a significant international trader in agricultural products and EU regulations have influence on policy in other parts of the world, reference will be made to the global dimension of EU choices.

At first glance the subject of this report might seem to concern just one specific technical aspect of EU agriculture. In fact, the predominant approach to crop protection in the EU involving the use of Plant Protection Products (henceforth PPPs), is an integral part of the whole ethos of the predominant current system of production. Pesticides, as they are called in the public discourse, have become a totemic issue in the debate about the correct farming system for the challenges faced this century. But, important as crop protection is, it makes no sense to focus narrowly and solely on the specific list of chemicals permitted as PPPs. It is necessary to confront much wider changes in farming systems, including food consumption behaviour. Agricultural system change, in turn, is part of a much wider transition in society necessitated by the major challenges of the 21st Century.

Climate change and biodiversity destruction are motivating a reassessment of all the major resource-using human activities for energy, mobility and manufacturing. The food system cannot be apart from this. It is a major user of land and water and has critical impacts on biodiversity, ecosystems and landscape. Systemic change means a great deal more than doing 'less bad' it means transitioning to a new system which as far as possible decouples prosperity from resource use and negative environmental impacts[1]. The immediate challenge is to discover how these ideas might apply to European crop production, and the chosen point of entry is through the way crops are protected.

1.1 The purpose and science behind crop protection

The goal of crop protection is to reduce yield losses and improve product quality of plants, e.g. by reducing contaminants such as mycotoxins, that are grown for direct or indirect human consumption or non-food purposes. This is done by protecting plants against pests (mostly insects and nematodes), diseases (fungal, bacterial and viral) and competition with weeds (for light, water and nutrients).

Traditionally, before the 1940s, this was mostly done using cultural and mechanical practices, including crop rotation, soil inversion and manual weeding. However, the idea of combatting pests by direct treatment using materials at hand, and by what we now term biological control has ancient origins. Technical and structural developments in agriculture, especially since the middle of the last century, have been highly successful in breeding and managing crops with consistently higher yields. This has come about through the combined developments of plant breeders, agronomists, agricultural mechanisation, crop nutrition and plant protection science. It has also occurred through the willingness of farmers to adopt new technologies and practices and to restructure their farms and businesses to utilise these developments.

There is no doubt at all that this technical 'progress', as it was seen and called, led to a complete change in scale and approach to crop production. Indeed, it has been referred to as the green revolution. The focus has been on increasing the quantity of crop output as well as improving the consistency and reliability of crop production

[1] Potocnik J and Okatz J. 2019. *Systemic transition through smart resource management. In: The overlooked side of the ecological transition*, Friends of Europe, pp 34-37 www.friendsofeurope.org/wp/wp-content/uploads/2019/07/2019_FoE_CLEN_The-overlooked-side-of-the-ecological-transition.pdf

and the uniformity of the product. Whilst there continue to be many smallholder farmers around the world with little or no access to modern techniques and technology, in general crop farming has become considerably more intensive as measured by inputs per hectare of seeds, nutrients, crop protection products, mechanisation, management, information, and technical and financial services. This has led to increased output per hectare. In the process, field and farm sizes have increased and farming systems have become more specialised with simpler rotations. This multi-faceted development was driven by the exploitation of fundamental scientific advances during the 20th century in chemistry, biology, molecular genetics, agricultural science, mechanization and crop spraying technology and other sciences which were financed both publicly and privately.

Crop production is now a knowledge-intensive activity and the development of precision agriculture utilising digital technologies, robotics, drones, artificial intelligence and big data is expected by many to lift this to a still higher plane. In these sophisticated crop production systems it is hard to determine the relative shares of each of the many contributors to higher yields. Breeding, nutrition, plant and soil health, crop protection, mechanisation and management are all important. There is strong interaction between these elements. New plant varieties are developed to respond to optimal nutrients and to benefit from better crop protection through improved tolerance of pests and diseases. Yet, the very scale, intensity and specialisation of crop production may itself have increased the likelihood and severity of pest damage and this, in turn, may have increased dependency on crop protection products. Also, in the development of high yielding varieties there can be a fall in their resilience against pests and disease necessitating use of PPPs, sometimes produced by the same company which developed the new varieties. Furthermore, without careful management, these systems have become susceptible to the development of resistance to the substances used to control disease-causing organisms. This motivates development of further crop protection modes of action, new products and new approaches including biological control, biostimulants and, for example, through new breeding techniques to build protective mechanisms into plant genotypes.

For most producers of commercial crops, knowledge of the weeds, pests and diseases which compete with, feed or reproduce in or on, crops and how to deal with them is an important part of their training. Information about the causes, nature and processes of plant disease and of the many tools developed to help avoid infection or infestation, and to minimise the effects if they occur, is now freely available. The same therapeutic approach as used in human medicine and animal disease became natural for treating plant disease. It is unsurprising therefore that crop protection has become almost synonymous with 'reaching for Plant Protection Products' when challenges to crops arise. By and large, from the farmers' perspective these products have a fairly quick and clearly visible effect. The private economic calculus of their use is also compelling, the pay-back to the very real costs of buying and applying these products is quite quickly and visibly seen in most cases. The assurance of a sellable crop these products are perceived to give the farmer is also a significant factor in their use. Unfortunately the negative external impacts are not noticed nor priced in.

The scientific drive to assist plant and soil health also has a strong and curiosity-driven self-propelled momentum. As the techniques of analysing, measuring, depicting and manipulating molecules have developed there has been a convergence of chemistry, biochemistry and biology. This has been given further encouragement by understanding the very basis of life, genetics and cell reproduction. All these disciplines have enabled scientists to identify and indeed create molecules with potentially interesting 'activity' to deal with plant and soil pathogens through understanding better the host – pathogen interactions and how they might be manipulated.

These advances in knowledge have been exploited in the fields of medicine and pharmacology to protect and prolong human life. Not surprisingly, the same scientific drive and scientific breakthroughs which provide understanding of human health and disease, the modes of action of treatments to deal with disease, and of the disease-causing organisms, can also be applied to the understanding of animal and plant health. So indeed, veterinary and plant scientists perform the same roles for animal and plant pests and diseases. The plant scientist seeking to understand the responsible organism, the route of entry, mode of action and best treatment for a rapidly spreading disease, for example causing death of olive trees[2], is motivated by the same curiosity and desire to prevent or cure disease in a valued living organism as is found amongst medical or veterinary scientists. The scientific world behind crop protection, which is found in universities and public research institutes as well as the research laboratories of commercial companies, is a global, large and long-established community which spans a wide range of scientific disciplines and practical functions. Its work ranges from fundamental scientific research to highly focussed and commercially aware farm crop protection practice. There is no doubt (because it is repeated in most big-picture presentations) that a prime scientific motivation behind such research efforts is what is seen as the necessity to produce more and better food to feed the still-growing global population. The complexities of this argument, and its application and implications for Europe are evaluated in Chapter 3.

1.2 The profound unease amongst the principal stakeholders in crop protection

The intensification and specialisation of agricultural systems has been accompanied by significant unwanted side-effects: biodiversity loss including non-target organisms, soil degradation and water pollution, and concerns about impacts on human health. As the EU single market emerged, national regulations to limit such degradation and risks were harmonised and developed. One aspect of this regulation of agriculture has focussed on PPPs and their impacts including hazard-based criteria and updated risk assessments, as well as setting a strategy towards reduced risks and use of PPPs. This has led to the removal of a number of PPPs from the market and this is expected to continue.

However, none of the principal stakeholders concerned with crop production are happy with the current state of affairs and the stance their organisations take on crop protection has become a totemic issue in debates about the European food system and the way our principal foods are produced. The **public and thus many politicians** are nervous about PPPs, both concerning the pressures they put on health and on the environment and they are somewhat distrustful of the authorisation process. Most **environmentalists and many scientists** are concerned that Europe is not acting sufficiently strongly or fast enough to reduce biodiversity loss by what they see as a necessary system change in farming methods. A considerable body of opinion advocates a substantial transition in food production and consumption systems. For production many suggest moves towards systems of sustainable agriculture which utilise a more restricted set of PPPs. The principal mainstream **Farmers' organisations** are concerned that crop protection products they consider indispensable to producing profitable crops are being removed from their 'toolbox' with no suitable substitutes. They feel increasingly pressured to move towards non-chemical crop protection methods but without the necessary information, knowledge and products available. They list three consequences of a reduced synthetic PPP toolbox: (i) fewer available PPPs will create dependence on a smaller range of products and consequently faster development of resistance in crop pathogens, (ii) reduced capacity to protect crops leading to lower,

[2] The organism responsible for the death of olive trees sweeping through Italy is the bacterium Xylella fastidiosa, it is believed it is spread by an insect vector whose behaviour may have been influenced by climate factors.

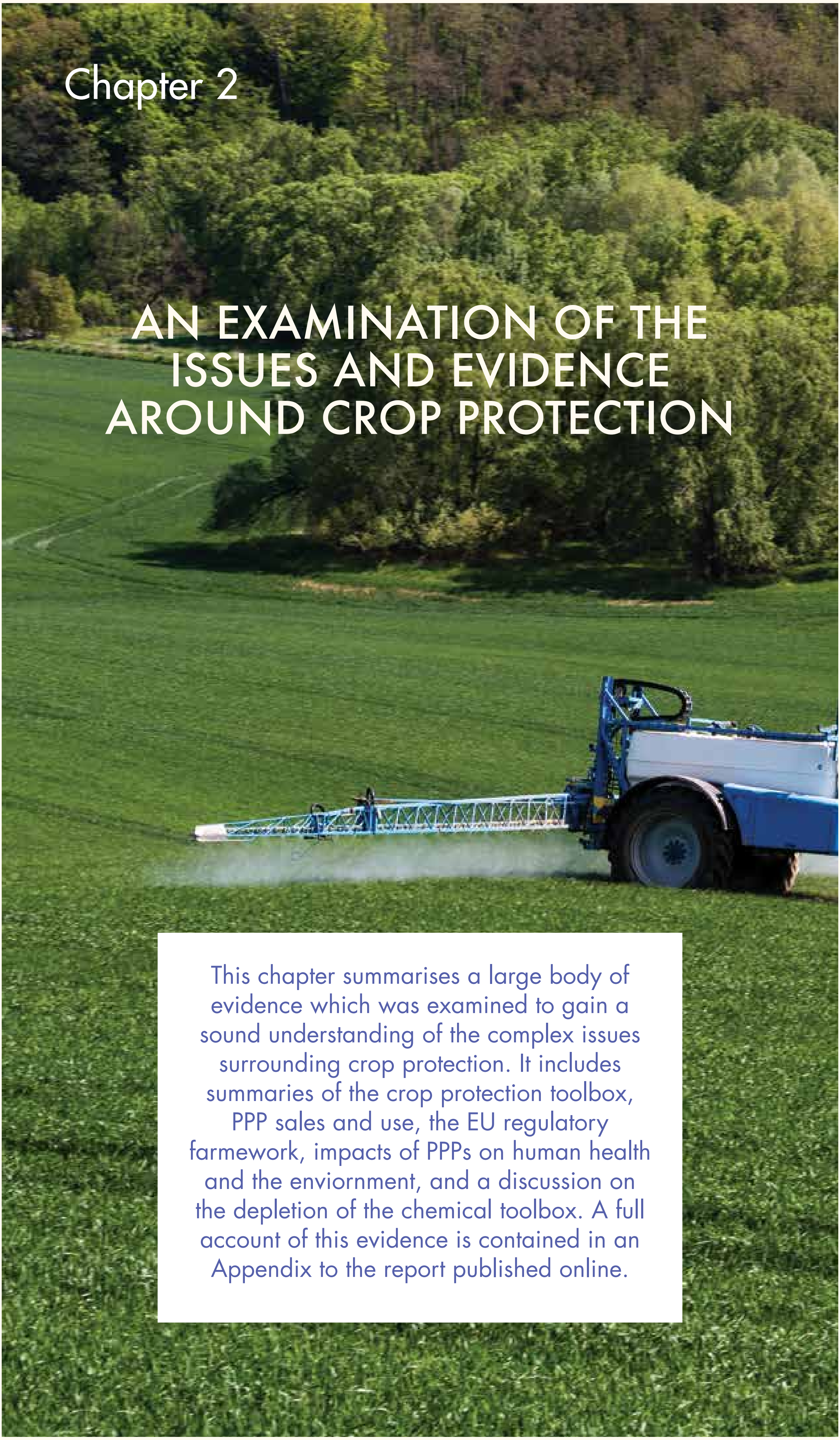
more volatile yields and reduced EU agricultural outputs and higher risks of microbial contamination of foods impacting human health, (iii) reduced competitiveness of EU agriculture with less viable farm businesses. The Crop **Protection industry** is concerned that the core of their activity, which is to develop effective and commercially viable solutions for farmers to protect their crops is ignored or denied. In the process, the value of innovation such as constantly searching to develop more sustainable alternatives is inhibited. They are also specifically concerned about the time taken, cost and unpredictability of the EU regulatory system which threatens their ability to develop new products for the European market. The **EU regulators** in this sphere have three concerns. First, the regulatory system and timetable is not well enough resourced and structured to work as defined in the legislation. There are more active substances to be approved for use than resources to appraise them within the timetables set in legislation. Second the Sustainable Use of Pesticides Directive (SUD) whose objective is to reduce the risk from pesticide use by encouraging a wholesale shift to integrated pest management is perceived not to have produced the results sought. Third, the Green Deal announced in December 2019, and the associated Farm to Fork and biodiversity strategy for the food system to be published in spring 2020 are posing challenges to adjust policies to improve the environmental performance of the food system specifically mentioning reductions in pesticides and fertilisers.

1.3 Drawing these threads together, the research questions and report structure

In short, the EU public, when prompted, exhibits nervousness about the use of PPPs. Consequently, EU legislators have enacted precautionary measures to remove many substances from the market and through the Sustainable Use of Pesticides Directive have tried to encourage farmers to turn to PPPs only as a last resort. Evidently this is not working. Environmentalists advocate stronger ambitions to reduce PPP use and even to abandon their use altogether particularly to halt and reverse biodiversity degradation. Their conclusion is that the current food production system with its high degree of dependence on synthetic PPPs is unsustainable. Senior politicians respond by proclaiming goals to reduce substantially the use of PPPs in agriculture. Understandably, the manufacturers and users of PPPs are alarmed. First, the language in the debate is ambiguous, does "pesticides" mean *all* PPPs or just certain categories of them? Second, these stakeholders claim that health and the environment are now sufficiently protected from impacts of PPPs by a system that is acknowledged to be the most stringent in the world – therefore they wonder why further, more radical, efforts are required. They see the regulatory system is already reducing the availability of existing active substances, threatens to remove more, and has raised the cost and reduced the research efforts to find new ones. This, it is claimed, will lead to greater use of a smaller set of products hastening the time when weed, insects and pathogens will develop resistance to existing products reducing their effectiveness. Producers' big concern is that reduced use and effectiveness of PPPs will inevitably lead to lower crop yields and lower product quality. In addition to the impact of this on farm financial viability, yield reduction if not compensated with more land devoted to cropping, will lead to a fall in EU production eroding global and, they claim, maybe even EU food security. Yet land use change from forestry or grassland to crop production is known to be damaging to climate and biodiversity, and in any case climate change is bringing new threats to agricultural production demanding more, not less, crop protection.

This study set out first to investigate the current EU strategy for crop protection. How well understood is it? For which aspects of the strategy are stakeholders seeking change? In doing so it became clear that the crop protection strategy comprises two elements: first the regulatory framework and then the agronomic practices in place on the ground. In the light of these controversies the report initially considered whether the EU crop protection strategy is clear and satisfactory, and to examine if the key concerns are the regulatory framework or the farming practices which are taking place within the framework.

Chapter 2 assembles the evidence base about the way crops are protected, some patterns and trends in the use of PPPs, the regulatory framework, the impacts of PPPs on health and environment and whether the crop protection toolbox is being depleted. It then draws some conclusions on the EU crop protection strategy. It emerges that the problem is not primarily defects in the regulatory system for PPPs and their use, although implementation could certainly be improved. Rather, it is more to do with a claimed fundamental sustainability of current crop production systems. **Chapter 3** analyses this by considering why the status quo in conventional crop production is suggested to be no longer feasible. Agricultural systems have to change and the most commonly indicated transition path is to move towards systems which revert to nature-based protection of crops from pests, disease and weeds. How far this could be progressed and the challenges it poses are examined for the main groups of crops. The chapter concludes by suggesting a clearer long-term goal for EU crop protection. **Chapter 4** then examines the mix of agronomic practices which can provide a transition path embracing the new goal. The final **Chapter 5**, draws the threads of the argument together and discusses the policy changes which will be necessary to induce farming systems onto the new transition path.



Chapter 2

AN EXAMINATION OF THE ISSUES AND EVIDENCE AROUND CROP PROTECTION

This chapter summarises a large body of evidence which was examined to gain a sound understanding of the complex issues surrounding crop protection. It includes summaries of the crop protection toolbox, PPP sales and use, the EU regulatory farmework, impacts of PPPs on human health and the enviornment, and a discussion on the depletion of the chemical toolbox. A full account of this evidence is contained in an Appendix to the report published online.

2.1 The Crop Protection Toolbox

Agriculture is the selective control and manipulation of plant and animal reproduction and growth for the benefit of human use. It usually represents a significant disturbance of natural ecosystems, displacing many of their elements to use natural resources of soil, water and light in order to grow a relatively small number of agronomic species, selected for their high value for humans and creates artificial concentrations of these species. Unintentionally this also both provokes reactions from, and provides favourable nutrition and breeding conditions for, a wide range of unwanted plants, animals, fungi, insects, nematodes and microbes. These variously termed pests, diseases, pathogens and weeds, are seen as competition and threats to the productivity and profitability of agriculture.

Reducing crop losses has been a priority for farmers and land managers since agriculture began. There are several mechanisms through which crops can be protected from pests including agronomic and landscape practices and direct elimination of pests through manual (physical), biological or chemical control techniques. It is estimated that, globally, in the absence of crop protection tools (mainly PPPs), crop losses to pests, weeds and disease could amount to an average 50%, but with wide regional variation[3]. However, others suggest that the role of natural enemies and resistant traits in combating pests and diseases is much more important than usually perceived[4].

A comprehensive list of the approaches to crop protection which make up the toolbox available to EU farmers[5] includes:

i A range of **agronomic practices and landscape management tools** with various aims including: increasing the pest control function of the soil (soil preparation, longer crop rotations, use of mulches), increasing the population of natural pest enemies (under-sowing, intercropping, field margin management), reducing pest pressure (longer crop rotations, intercropping, crop diversification, hedgerows), and increasing the resistance of crops to pests (breeding, choice of seeds and seed diversification).

ii **Physical crop protection tools**, which deal primarily with weeds. There are two main groups of measures, those preventing weed development and those eliminating weeds. The first group includes mulching and plastic covers, often used in organic agriculture, and the second includes practices such as direct weed removal and mechanical tillage. Physical methods, such as nets can also be used against birds, insects and hail damage.

iii **Biological pest control tools**. Biological pest control is first and foremost an ecosystem function in which naturally occurring beneficial organisms (natural predators) can reduce pests without human intervention. Farmers can increase the effectiveness of natural predators by stimulating the performance of natural enemies or cultivating them externally and releasing them until a temporary balance is reached. The organisms are called biological control agents and can be classified according to their size into macrobials (also called invertebrate control agents) and microbials (microorganisms).

iv **Chemical pest control** makes use of Plant Protection Products (PPPs) to attack the weed, disease organism or pest. These are based on the presence of at least one

[3] Oerke, E.-C. 2006. *Crop losses to pests*. Journal of Agricultural Science, 144: 31-43.

[4] Pimentel, D. and M. Burgess 2014. *Environmental and Economic Costs of the Application of Pesticides Primarily in the United States. In: Integrated Pest Management*, Pesticide Problems Vol. 3 (eds Pimentel, D. et al.). Springer, The Netherlands: 47–71.

[5] This is based on elements that constitute Integrated Pest Management (IPM) as promoted in the Sustainable Use of Pesticides Directive (2009/128/EC)

active substance, defined as "*any chemical, plant extract, pheromone or micro-organism (including viruses), that has action against 'pests' or on plants, parts of plants or plant products*[6]". PPPs can be classified in various ways, according to their functionality, mode of entry or chemical class. The most frequently used PPPs are fungicides, herbicides and insecticides. A difference is often made between synthetic PPPs and those PPPs that are part of biocontrol.

- **Precision agriculture and breeding** of varieties that are more resistant to pests and environmental conditions (both traditional and the use of new techniques) are two currently rapidly evolving fields of crop protection. These techniques are expected to increase the performance of the elements listed above and reduce the damage associated to some of these pest control tools. This is further examined in Chapter 4.

These set of tools are not mutually exclusive and indeed many, if not most, farmers use combinations of all of these measures. Data is currently lacking on the extent to which each of these measures is taken up among EU farmers. The concept of Integrated Pest Management (IPM) (which is explored in sections 2.3 and 4.2 below, and in much more detail in the Appendix to this chapter) has been developed to indicate how to combine these approaches for the best balance of effective crop protection and care of the environment.

2.2 Plant Protection Product (PPP) sales and use

Given the controversy which surrounds the use of PPPs it was surprising to discover the difficulty in establishing a clear and detailed picture of the patterns and trends in their use by EU Member States and for the EU as a whole.

The data are complex, there are many types of PPPs, designed to deal with weeds, fungi, insects and other disease-causing agents, and they are used on many crops. Some PPPs are applied as seed dressings, others sprayed once or multiple times per season. Some PPPs are wide spectrum, others highly specific to individual pest species, there is a wide range of modes of action, and great differences in their risks for non-target organisms. Dosage rates differ widely between products and have generally diminished over time.

It has also to be mentioned that, as in any field of human activity, illegal practice does occur. PPPs which contain active substances which have been withdrawn from the EU list of approved substances but for which stocks still exist or use of which is still permitted in other countries, are being transacted and used in the EU. The European Commission (EC) estimates that illegal and counterfeit PPPs represent 10% of the EU PPP market and the number of sanctions is considered to be too low to incentivise compliance[7]. Wildlife organisations are alive to this issue and produce evidence of wildlife, e.g. raptors, poisoned by illegal substances from banned PPPs.

6 From https://ec.europa.eu/food/plant/pesticides_en

7 European Commission 2015. Ad-hoc study on the trade of illegal and counterfeit pesticides in the EU — DG Health and Food Safety.

There is a problem of understanding whether legal use of PPPs is increasing or decreasing and if risks are being reduced because several changes are taking place at once. First note that data sometimes refers to sales and other times to use. Stock changes and trade can make these different. It is generally the case that over time the physical quantities of products per hectare per application of many products has fallen, sometimes substantially. But simultaneously the potency of the products has changed, the product mix and formulation changes, and the number of applications may increase. Statisticians have long been aware of these issues but disentangling the data for the wide range of products in all the EU Member States has proved a heavy task.

The raw data on use and sales of PPPs, FAOSTAT figures on total pesticide use[8], shows an erratic downward trend from the mid-1990s until 2010, and an increase since. Eurostat data on pesticide sales for the EU28, but over the rather short period of 2011 to 2018, shows small variations with no strong trend (Figure 1). There are differences between Member States over this latter period, for example an increase in total PPP sales occurred in France and a more pronounced decrease occurred in Denmark, which has introduced a pesticide tax. For Great Britain (GB), detailed and reliable statistics of PPP usage by product and crop come to our attention including application rates and numbers of applications per season. The total quantity of PPP used in GB fell by 51% since 1990 and the rate of application of PPP per treated hectare fell over the same period by 70% from 700 g/ha to 230 g/ha[9]. It is not possible to say if these patterns are repeated across other Member States of the EU. The PPP industry claims that active substance application rates (grams per hectare) have fallen

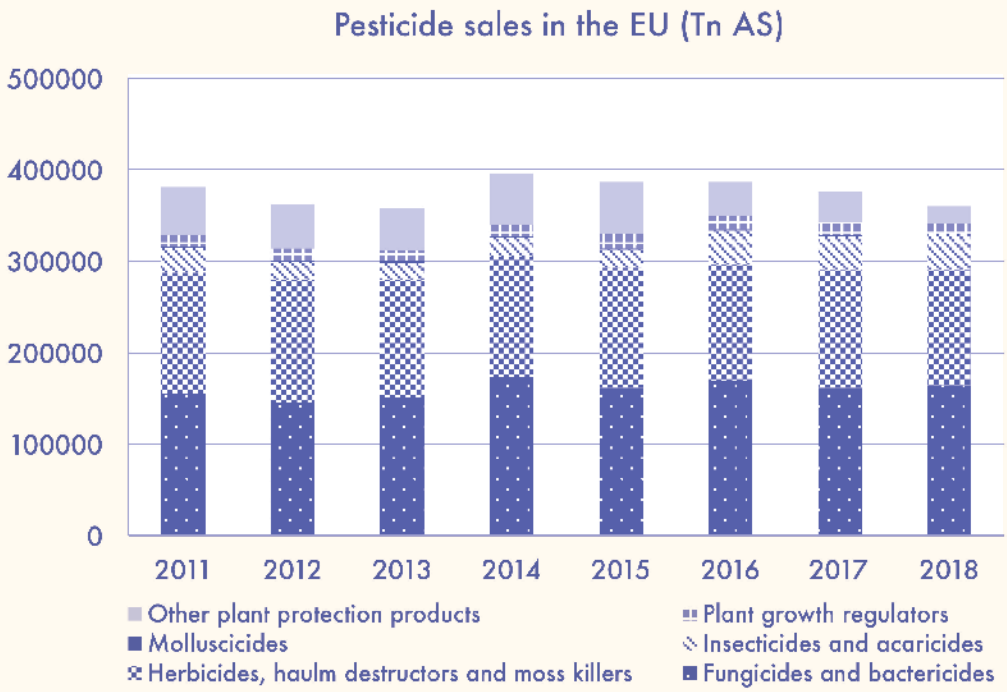


Figure 1 Pesticide sales in the EU 2011-2018 (data source: Eurostat)

8 FAOStat data reports the quantities used (in tonnes of active substances) of pesticides used or sold to the agricultural sector for crops and seeds. Annual use of pesticides can differ from sales given inter-year storage and trade. Country reporting practices can be different and may include the report of data by: use or imports of formulated product, sales, distribution or imports for use in the agricultural sector in active substances (Source: www.fao.org/faostat/en/#data/RP/metadata)

9 See FERA, Pesticide Use Statistics in Great Britain, https://secure.fera.defra.gov.uk/pusstats/index.cfm

dramatically by more than 90% since the 1950s[10]. However, the source of this data and the countries and products to which it applies are not stated.

The need for a measure of PPP use which tries to embody the risk to health and environment was anticipated in the Sustainable Use of Pesticides Directive (see section 2.3). This Directive established the concept of **Harmonised Risk Indicators** (HRIs). Initial results for two such indicators were finally published in 2019. The first indicator HRI1 was an index of the quantity of the product of each active substance multiplied by one of four weighting factors to reflect the risks to human health and environment of each substance. The index was based on the average of 2011 to 2013 and showed a 20% decline over the six-year period to 2017 (Figure 1). This provides some evidence that years of effort to encourage lower use of PPPs, especially higher risk products, is yielding results. However, this is a very short time period and, in any case, the second HRI produced what seems a contrary result. The second indicator HRI2 calculated an index of the number of emergency authorisations of active substances also weighted by the same weighting factors, and with the same base. It showed a 50% increase over the period 2011-17. The data is also available for individual Member States showing their different trends over the same short period. Whilst this development of HRIs is a welcome start to providing more meaningful indicators of the risks of PPP use, more such work is required especially to extend the period of analysis if this is possible. Although the public might be reassured by the indicated decline in this risk-weighted use of PPPs, the measurement of risk is crude, and this reassurance may be neutralised by the rapid rise in emergency authorisations. It may leave concerns whether the regulatory system is providing the expected degree of protection.

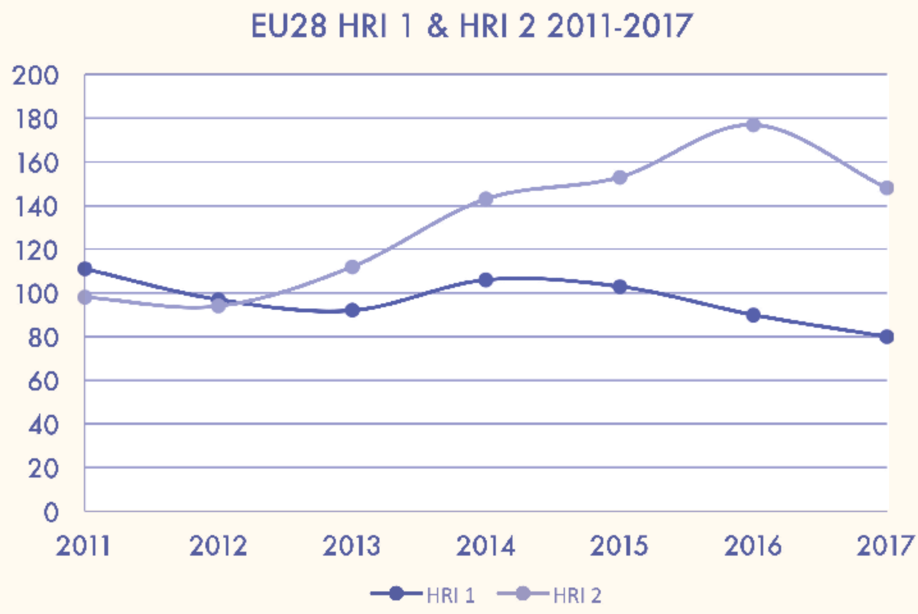


Figure 2 Harmonised risk indicators (data source: European Commission)

The absence of good information on PPP use, by all farming sectors including the organic sector, is a serious failure. Neither total quantities of PPP used nor crude application rates per hectare tell the whole story. The characteristics of PPPs, their toxicity, persistence and tendency to bio-accumulate, varies between products and changes over time. There is a trend towards more concentrated products, i.e., with more active

[10] McDougal, 2018. *Evolution of the Crop Protection Industry since 1960*, Phillips McDougal, Agribusiness intelligence / Informa. This document claims that fungicide, insecticide and herbicide use has fallen from 1200, 1700 and 2400 g/ha respectively in the 1950s to 100, 45 and 75 g/ha today. However, the origin of, and countries to which, these statistics apply is not clear.

substance per gram of product, and towards smaller volumes of product applied as spray technology and more precision farming is adopted. The development of the HRIs is a step in the right direction. It is essential that such work is taken further and appropriately resourced so that the public debate can be informed by systematic, meaningful and comparable data collected for all Member States. There is still some way to go to formulate metrics of PPP use with which to judge current strategies which aim to reduce their use.

2.3 The EU regulatory Framework for crop protection

There are nine EU regulations which most directly influence crop protection[11]. The goals of the three major regulations are as follows.

An overall framework for crop protection in the EU is provided by Directive 2009/128/EC, the **Sustainable Use of Pesticides Directive** (commonly abbreviated to SUD)[12]. The objectives of the SUD are to reduce the risks and impacts of pesticide use on human health and the environment and to encourage the development and introduction of integrated pest management and of alternative approaches or techniques in order to reduce dependency on the use of pesticides.

Regulation (EC) No 1107/2009 concerns the **placing of plant protection products on the market**[13]. Its purpose is "to ensure a high level of protection of both human and animal health and the environment and at the same time to safeguard the competitiveness of Community agriculture". The regulation says that "*particular attention should be paid to the protection of vulnerable groups of the population, including pregnant women, infants and children. The precautionary principle should apply, and this Regulation should ensure that industry demonstrates that substances or products produced or placed on the market do not have any harmful effect on human or animal health or any unacceptable effects on the environment.*" There are two subsets of active substances and PPPs defined in Regulation (EC) 1107/2009 which deserve particular attention. These are low risk active substances and products and basic substances. Among the 476 approved active substances in the EU, only 18 are considered low risk, and 20 are basic substances[14]. The majority of approved low risk active substances are currently fungicides. In 2018 the EC identified 57 approved active substances that could potentially be classified as low risk, 30 of which are microorganisms[15].

Regulation (EC) No 396/2005 concerns **maximum residue levels** (MRL)[16]. The regulation does not define specific goals. The recitals make it clear that (as with Regulation 1107/2009) the purpose of the regulation was partly to harmonise controls across the Member States to ensure the working of the single market. It is quite clear

11 This discussion of the regulatory framework focuses entirely on EU regulations. In some member states there is important additional national regulation, in the Danish case pesticide taxes.

12 Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 Establishing a Framework for Community Action to Achieve the Sustainable Use of Pesticides, OJ L 309, 24.11.2009, p. 71–86.

13 Regulation (EC) No 1107/2009 of the European Parliament and of the Council of 21 October 2009 Concerning the Placing of Plant Protection Products on the Market and Repealing Council Directives 79/117/EEC and 91/414/EEC OJ L 309, 24.11.2009, p. 1–50

14 EU pesticide database consulted on 10/02/2020

15 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018XC0727(01)&rid=7

16 Regulation (EC) No 396/2005 of the European Parliament and of the Council of 23 February 2005 on Maximum Residue Levels of Pesticides in or on Food and Feed of Plant and Animal Origin and Amending Council Directive 91/414/EEC, OJ L 70, 16.3.2005, p. 1–16.

from Article 3.2(d) that this is a public health measure to be achieved through good agricultural practice. The article states that "maximum residue level' (MRL) means the upper legal level of a concentration for a PPP residue in or on food or feed set in accordance with this Regulation, based on good agricultural practice and the lowest consumer exposure necessary to protect vulnerable consumers". The Regulation is not primarily intended to protect the environment.

Six other relevant regulations which impact on the permissible use of PPPs are: the drinking water[17] and water framework[18] Directives, the Regulation concerning the packaging and labelling of dangerous chemicals[19], the requirements, inspection and maintenance of equipment used for pesticide application[20], the collection of data on pesticide use[21], and pesticide use in organic farming[22,23]. Beyond the SUD, the principal policy aimed at influencing the behaviour of farmers and which might be used to influence the way crops are protected is the Common Agricultural Policy.

As part of a REFIT review of PPP regulation, two of these regulations concerning the placing PPPs on the market and determining maximum residue levels have been formally evaluated by the consultancy company Ecorys[24].

The conclusions of the Ecorys evaluation were that, overall, the two regulations (1107/2009 and 396/2005) are effective and relevant. They noted that there has been criticism about the approval process and especially its timeliness, delays and lack of predictability. They observed that the system of rapporteur countries was not working well. As far as the main purpose of the regulation is concerned, which is to protect health and environment, Ecorys concluded that these goals are being achieved. But they drew this conclusion indirectly and not from evidence about the health or environmental effects of PPPs. The conclusion is contested by some scientists who argue that the approval process overlooks many potential routes of harm to biodiversity and because updating the detailed criteria and protocols is extremely slow and is lagging behind current science[25]. The response of the European Commission to the Ecorys report is awaited.

17 Council Directive 98/83/EC of 3 November 1998 on the Quality of Water Intended for Human Consumption OJ L 330, 5.12.1998, p. 32–54.

18 Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy, OJ L 327, 22.12.2000, p. 1–73.

19 Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on Classification, Labelling and Packaging of Substances and Mixtures, Amending and Repealing Directives 67/548/EEC and 1999/45/EC, and Amending Regulation (EC) No 1907/2006, OJ L 353, 31.12.2008, p. 1–1355

20 Directive 2009/127/EC of the European Parliament and of the Council of 21 October 2009 Amending Directive 2006/42/EC with Regard to Machinery for Pesticide Application, OJ L 310, 25.11.2009, p. 29–33

21 Regulation (EC) No 1185/2009 of the European Parliament and of the Council of 25 November 2009 Concerning Statistics on Pesticides (Text with EEA Relevance) OJ L 324, 10.12.2009, p. 1–22" OJ L 324 (October 12, 2009): 1–22.

22 Commission Implementing Regulation (EU) 2016/673 of 29 April 2016 Amending Regulation (EC) No 889/2008 Laying down Detailed Rules for the Implementation of Council Regulation (EC) No 834/2007 on Organic Production and Labelling of Organic Products with Regard to Organic Production, Labelling and Control, OJ L 116, 30.4.2016, p. 8–22.

23 It may come as a surprise to many that PPPs are indeed widely used in organic farming; the current 2016 regulation lists 132 active substances presented in 26 groups of substances, including many basic substances micro-organisms and pheromones.

24 Ecorys, 2018. *Study supporting the REFIT Evaluation of the EU legislation on plant protection products and pesticides residues (Regulation (EC) No 1107/2009 and Regulation (EC) No 396/2005)* (Final report)

25 Van der Sluijs, at the public hearing on "Environmental impacts of pesticides, including mitigation measures at Member State level" and "Stakeholders' recommendations on the current EU regulation on the approval of plant protection products" pest committee meeting of 6 September 2018, suggested the current risk assessment methods for pesticides in the EU are inadequate because they do not sufficiently consider [i] the cumulation of effects from the same substance used on other crops in the same area, [ii] the cumulation of effects from other pesticides that have the same mode of action and bind for instance to the same receptor, (iii) the cumulation of effects from exposure to other pesticides and (iv) the cumulation of effects of other stress factors. He further argues that a flaw is that the risk assessment of PPP is that each risk assessment

The SUD was not part of the REFIT exercise, but its implementation by MSs was reviewed in 2017, and again more recently by the European Court of Auditors[26]. Both agreed that the Member States have been slow to formulate their National Actions Plans that indicate how they are implementing the directive and setting targets. The targets have been vague and mostly not achieved. However, one area in which progress has been made is in the area of operator safety, through better training and certification of operators, and equipment, design and operation for sprayer loading and washing down.

2.4 The impacts of PPPs on health

European citizens show concerns about the presence of PPP residues in the food they eat, this is the issue of dietary exposure. However, the more severe impact of PPPs on health are for those who are directly exposed to them, this is the occupational exposure issue. This is dealt with first. There are four common ways through which PPPs can enter the human body in cases of direct exposure: dermal entry is the main one, the others are orally, through the eye and via respiratory pathways[27,28]. PPPs are distributed throughout the human body through the bloodstream and they can be metabolised or excreted through urine, skin, and exhaled air[29,30]. In particular, in economic terms, the impact of PPPs on human health in the EU could cost 78 million EUR per year, 90% of this cost derived from the impact of 13 substances, 9 of which are no longer approved in the EU[31]. The high-risk groups exposed to PPPs include production workers, formulators, sprayers, mixers, loaders and agricultural farm workers[32], as well as potentially, casual users and people living in rural areas. In addition to the above-stated health conditions, the high-risk group may accidentally or intentionally be exposed to doses leading to hospitalisation or death[33]. Member States are required to report on these acute poisoning incidents, but there are currently no standard rules for the collection of data nor its reporting[34].

for each individual application incorrectly assumes that that application occurs in a world where no other applications of the same active substance exist, while in reality there are often many other applications of the same pesticide AND of other pesticides with the same mode of action AND of other pesticides that may act synergistically AND of other stress factors. As a result, Sluijs suggests the risks of pesticides are systematically underestimated and ecosystems and human health are not sufficiently protected.

26 European Court of Auditors (ECA) 2020. Special report on Sustainable use of plant protection products: limited progress in measuring and reducing risks. Publications Office of the European Union, Luxembourg.

27 Kim, K.-H., Kabir, E., Jahan, S.A., 2017. *Exposure to pesticides and the associated human health effects.* Sci Total Environ 575, 525–535.

28 Alavanja, M.C.R., Bonner, M.R., 2012. *Occupational Pesticide Exposures and Cancer Risk: A Review.* J Toxicol Env Health, Part B 15, 238–263.

29 World Health Organization. 1990. Public Health Impact of Pesticides Used in Agriculture. England: World Health Organization.

30 Alewu, B., Nosiri, C., 2011. *Pesticides and Human Health*, in: Stoytcheva, M. (Ed.), Pesticides in the Modern World - Effects of Pesticides Exposure. InTech. DOI: 10.5772/18734.

31 Fantke, P., Friedrich, R., Jolliet, O., 2012. *Health impact and damage cost assessment of pesticides in Europe.* Environ Int 49, 9–17.

32 Aktar, W., Sengupta, D., Chowdhury, A., 2009. *Impact of pesticides use in agriculture: their benefits and hazards.* Interdiscip Toxicol 2, 1–12.

33 Gunnell, D., Eddleston, M., Phillips, M.R., Konradsen, F., 2007. *The global distribution of fatal pesticide self-poisoning: Systematic review.* BMC Public Health 7, 357.

34 Settimi, L., et al. 2016. *Development of a new categorization system for pesticides exposure to support harmonized reporting between EU Member States.* Environ Int 91, 332–340.

The accumulation of evidence, in particular relating PPPs and various types of cancer and other health conditions, has been growing over the last two decades[35,36]. Exposure to PPPs has been linked to a number of health conditions including: cancer[37,38,39], endocrine disruption[40,41], respiratory conditions[42], reproductive problems[43,44] and neurological and cognitive effects[45,46]. Assessing health risks from dietary exposure through consumption of food which may have PPP residues is complex. Studies linking PPP exposure and health outcomes are for the most part epidemiological studies. It is not possible to establish causal relationships between a specific substance and particular human health risk through such studies, and yet, these links would be helpful to guide action to protect public health. Meanwhile reliance is placed on scrutinising test animals for health impacts in the course of toxicity studies required for the authorisation process. This uncertainty explains why the appropriate regulatory stance for PPPs is exceedingly difficult to draw. The EFSA publishes annual reports on 'pesticide residues in food'. In 2017[47], in 96% of the analysed samples[48] PPP residues fell within legal limits, and more than half of the tested samples reported no quantifiable PPP residues. This indicates that PPPs are mostly being used as prescribed.

The REFIT evaluation of the current regulations of placing PPPs on the market (1107/2009) and of maximum residue levels, MRLs (396/2005), concluded that, based on current knowledge, EU food consumers are correctly and adequately protected from harm from individual PPP residues on their food. Additionally, the European Food Standards Agency (EFSA) concludes that, based on 2017 MRL data, "*according to current scientific knowledge, acute and chronic dietary exposure to pesticide residues is unlikely to pose concerns for consumer health*[49]". However, the Ecorys report highlights that there is still no assessment of cumulative risks in place to judge acceptable maximum residue levels for combinations of PPPs in food. Their evaluation came to the general conclusion that the current criteria and cut offs used to determine this safety are adequate. The EU is following international standards and it was concluded that the EU has amongst the most stringent regulation in the world. As all active substances are subjected to the renewal regulatory process any remaining substances not satisfying the hazard cut-off criteria and risk assessment will ultimately be removed. An additional consideration not embraced in the REFIT

35 Ntzani EE, et al. 2013. *Literature review on epidemiological studies linking exposure to pesticides and health effects*. EFSA supporting publication 2013:EN-497, 159 pp.

36 Bassil et a. 2007. *Cancer health effects of pesticides*. Can Fam Physician 53, 1704–1711.

37 Alavanja and Bonner, 2012. Full reference in p.25..

38 Ntzani E.E., et al. 2013. Full reference above.

39 Bassil, K.L., et al. 2007. Full reference above.

40 Shelton, J.F., et al. 2014. *Neurodevelopmental Disorders and Prenatal Residential Proximity to Agricultural Pesticides: The CHARGE Study*. Environ Health Persp 122, 1103–1109.

41 Street, M., et al. 2018. *Current Knowledge on Endocrine Disrupting Chemicals (EDCs)* from Animal Biology to Humans, from Pregnancy to Adulthood: Highlights from a National Italian Meeting. IJMS 19, 1647.

42 Hoppin, J.A., et al. 2008. *Pesticides and Atopic and Nonatopic Asthma among Farm Women in the Agricultural Health Study*. Am J Respir Crit Care Med 177, 11–18.

43 García, A.M., 2003. Pesticide exposure and women's health: Pesticide Exposure and Women's Health. Am. J. Ind. Med. 44, 584–594.

44 Roeleveld, N., Bretveld, R., 2008. *The impact of pesticides on male fertility*. Curr Opin Obstet Gyn 20, 229–233.

45 Pimentel, D. and Burgess M., 2014. Full reference in p.19.

46 Shelton, J.F., et al. 2014. Full reference above.

47 EFSA. 2019. The 2017 European Union report on pesticide residues in food. European food safety authority. EFSA J. 17(6):5743.

48 88,247 food samples from the 28 MSs.

49 www.efsa.europa.eu/en/topics/topic/pesticides

evaluation, is whether there is sufficient attention devoted to the threat from PPP use for farm (and other) operators who apply these products as their job and perhaps rural dwellers exposed by their proximity to sprayed fields, even when the products are correctly used. A number of epidemiological studies carried out on farmers show an association between repeated exposure to certain plant protection products and specific chronic illnesses[50], although it is not easy to make a direct link between the illnesses and the exposure[51].

Another matter whose importance is being noticed concerns risks to human health because organisms which infect humans are becoming resistant to the drugs customarily used because the same class of chemicals are being routinely used as PPPs in agriculture, horticulture and as biocides for non-crop use. While the issue of antimicrobial resistance is a well-publicised issue in relation to antibiotic use in livestock production, some chemical classes used in human medicines are also applied in crop production and the corresponding problem can arise[52]. An example concerns the lung condition aspergillosis. This is caused by the fungus Aspergillus fumigatus which has become resistant to the previously effective azole drugs. The result is a rise in death rates from this condition[53]. These are complex issues, and just as with antibiotics the over-prescription and misuse of human medicines is part of the problem of resistance development. Nonetheless, pathogen resistance to chemical treatments is a growing concern.

In summary, from a scientific and regulatory perspective European food consumers are deemed satisfactorily protected from potential adverse impacts of plant protection products, given current knowledge. However, it is not clear if this perception is shared by consumers themselves. Remaining concerns about the safety of PPP use for human health are the health impacts of those who are most exposed to these products, farmers and farm workers. Other issues raised are the potential impacts of the "*cocktail effect*" of PPPs on human health and the problem of resistance.

2.5 The impacts of PPPs on the environment

Some PPPs can persist in the environment for decades, threatening soil and water quality and contributing to the loss of biodiversity. The degradation of many aspects of the environment is now well established and documented by EU and Member State public and private environmental agencies. Terrestrial biodiversity loss has occurred below-ground and above-ground, and aquatic biodiversity has declined too. These losses mean that the vital ecosystem services that these organisms provide, such as natural pest control, are impaired or lost. The analysis of the causes of biodiversity decline, and attempts to assess the responsibility of PPPs, are difficult because of the large number of other factors involved both outside agriculture habitat loss, industrial chemicals, household chemicals, cosmetics and medicines, and within agriculture through habitat loss, fertilizer use and mechanisation. In addition are the impacts of alien invasive species, and climate change. Attributing cause and effect are difficult because of the large number of PPPs which have been used over the decades, and the complex interactions among species. The effects of PPPs on non-target organisms can be direct and lethal, or sub-lethal but having impacts on the longer run health and numbers of such species. The impacts can also be indirect, such as the subtle and multi-stage interactions between organisms that may be disrupted when a local

50 Although they use the personal protective equipment in agreement with the current regulation.

51 www.anses.fr/en/content/occupational-exposure-pesticides

52 FAO 2018. Antimicrobial Resistance and Foods of Plant Origin. Summary report of an FAO meeting of experts. www.fao.org/3/BU657en/bu657en.pdf

53 Fisher, M.C., et al. 2018. Worldwide emergence of resistance to antifungal drugs challenges human health and food security. Science 360, 739–742.

target or non-target organism population is removed or substantially reduced by PPP application or through other crop protection methods. Reductions in one species can interfere with the food supply, nesting place, nesting materials, or other conditions impacting on other species further down the food chain. In addition, there is growing evidence showing that low, but long-lasting, concentrations of PPPs can have serious impacts on biodiversity[54,55].

The impact of PPPs on soil organisms has been studied mostly over the past two decades. However, given the early stage at which the scientific community finds itself in the identification of soil organisms, in particular microorganisms especially bacteria, it is very difficult to establish baseline levels from which to assess PPP impacts. The soil biome is exceptionally complex and is influenced by rainfall, temperature, sunlight, and plant coverage. It is very difficult to pin down the characteristics of healthy well-functioning soil. Research to date suggests that the presence of PPPs can alter a variety of functions performed by soil organisms, including natural pest control[56], but the magnitude of such a disturbance remains unquantified and the evidence is not consistent[57]. The lack of monitoring for the presence of PPP residues on the environment at the EU level makes these assessments more complicated. The PPP approval process attempts to allow for these uncertainties by considering worst case scenarios and building in large safety factors. However, **in the absence of baselines and monitoring data questions about the environmental safety of PPPs are difficult to answer**.

The impacts and potential risks of PPPs on terrestrial above-ground and water organisms are better documented. In the case of terrestrial biodiversity, insects (particularly pollinators) and birds are the two most studied groups. The European Commission assesses changes in agricultural biodiversity using two main indicators: the farmland bird index and the grassland butterflies index. These indexes show similar decreases between 1990 and 2015: 32% reduction in common farmland bird numbers and a 34% reduction in grassland butterfly population[58]. Indeed, insects are under threat and declining in the EU and other parts of the world[59,60,61,62,63] and several studies have linked the use of PPPs and insect decline[64]. There is also little doubt that agricultural intensification has contributed to farmland bird declines in the EU

54 Simon-Delso, N., et al., 2015. *Systemic insecticides (neonicotinoids and fipronil): trends, uses, mode of action and metabolites*. Environ Sci Pollut R 22, 5–34.

55 Topping, C.J., Aldrich, A., Berny, P., 2020. *Overhaul environmental risk assessment for pesticides*. Science 367, 360–363.

56 Dainese, M., et al. 2019. *A global synthesis reveals biodiversity-mediated benefits for crop production*. Sci. Adv. 5, eaax0121.

57 FAO and ITPS, 2017. *Global assessment of the impact of plant protection products on soil functions and soil ecosystems*, Rome, FAO. 40 pp.

58 www.eea.europa.eu/data-and-maps/indicators/abundance-and-distribution-of-selected-species-7/assessment

59 Hallmann, C.A., et al., 2017. *More than 75 percent decline over 27 years in total flying insect biomass in protected areas*. PLOS ONE 12, e0185809.

60 Sánchez-Bayo, F. and Wyckhuys, K.A.G., 2019. *Worldwide decline of the entomofauna: A review of its drivers*. Biol Conserv 232, 8–27.

61 Wepprich, T., et al. 2019. *Butterfly abundance declines over 20 years of systematic monitoring in Ohio, USA*. PLoS ONE 14, e0216270.

62 Powney, G.D., et al., 2019. *Widespread losses of pollinating insects in Britain*. Nat Commun 10, 1018.

63 van Strien, A.J., et al., 2019. *Over a century of data reveal more than 80% decline in butterflies in the Netherlands*. Biol Conserv 234, 116–122.

64 Geiger, F., et al., 2010. *Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland*. Basic Appl Ecol 11, 97–105 (and references therein).

[65,66,67,68]. Despite the difficulty in attributing the causes of documented bird declines, it has been suggested that habitat loss, the most often mentioned factor, cannot alone explain the scale of bird decline[69]. Several studies have found links between PPPs and sub-lethal effects on birds, resulting mainly from the change in food availability, as a result of PPP use, leading to declining bird numbers and species diversity[70,71]. Correspondingly, other studies have shown that bird abundance is higher in organic managed land compared to conventionally farmed land[72,73,74,75] the main reason being a reduced PPP input and the greater presence of semi-natural habitat in organic farms[76]. However, such an increase in bird numbers has not always been observed, suggesting that the impact of PPPs on biodiversity may persist longer than expected[77].

Evidence has also been mounting over the last decade on the impact that PPP residues in EU waters is having locally on aquatic organisms and freshwater ecosystems[78,79,80,81,82,83,84]. There is some evidence that plankton, invertebrates, fish and amphibians are affected by certain PPPs, in some cases at levels which are considered safe

65 Butler, S.J., et al. 2010. *Quantifying the impact of land-use change to European farmland bird populations.* Agr Ecosyst Environ 137, 348–357.

66 Donald, P.F., Green, R.E., Heath, M.F., 2001. *Agricultural intensification and the collapse of Europe's farmland bird populations.* Proc. R. Soc. Lond. B 268, 25–29.

67 Donald, P.F., et al., 2006. *Further evidence of continent-wide impacts of agricultural intensification on European farmland birds, 1990–2000.* Agr Ecosyst Environ 116, 189–196.

68 Reif, J. and Vermouzek, Z., 2019. *Collapse of farmland bird populations in an Eastern European country following its EU accession.* Conserv Lett 12, e12585.

69 Mineau, P. and Whiteside, M., 2013. *Pesticide Acute Toxicity Is a Better Correlate of U.S. Grassland Bird Declines than Agricultural Intensification.* PLoS ONE 8, e57457.

70 Kohler, H.-R., Triebskorn, R., 2013. *Wildlife Ecotoxicology of Pesticides: Can We Track Effects to the Population Level and Beyond?* Science 341, 759–765.

71 McKenzie, A.J. and Whittingham, M.J. 2009. *Why are birds more abundant on organic farms?* J Food Agric Environ 7: 807–814.

72 Batary, P., Matthiesen, T., Tscharntke, T. 2010. Landscape-moderated importance of hedges in conserving farmland bird diversity of organic vs. conventional croplands and grasslands. Biol Conserv 143: 2020–2027.

73 Mckenzie and Whittingham, 2009. Full reference above.

74 Tuck, S.L., et al. 2014. *Land-use intensity and the effects of organic farming on biodiversity: a hierarchical meta-analysis.* J Appl Ecol 51, 746–755.

75 Winqvist, C., et al. 2011. *Mixed effects of organic farming and landscape complexity on farmland biodiversity and biological control potential across Europe: Organic farming and landscape affect bio control.* J Appl Ecol 48, 570–579.

76 Mckenzie and Whittingham, 2009. Full reference above.

77 Geiger, F., et al., 2010. Full reference in p.28.

78 Beketov, et al. 2013. Pesticides reduce regional biodiversity of stream invertebrates. Proc Natl Acad Sci USA 110, 11039–11043.

79 Liess, M. and von der Ohe, P.C., 2005. *Analyzing effects of pesticides on invertebrate communities in streams.* Environ Toxicol Chem 24, 954–965.

80 Brühl, C.A. et al., 2013. *Terrestrial pesticide exposure of amphibians: An underestimated cause of global decline?* Sci Rep-UK 3, 1135.

81 McMahon et al., 2012. *Fungicide-induced declines of freshwater biodiversity modify ecosystem functions and services.* Ecol Lett 15, 714–722.

82 Malaj et al., 2014. *Organic chemicals jeopardize the health of freshwater ecosystems on the continental scale.* Proc Natl Acad Sci USA 111, 9549–9554.

83 Stuart et al. 2004. *Status and Trends of Amphibian Declines and Extinctions Worldwide.* Science 306, 1783–1786.

84 Stehle, S. and Schulz, R., 2015. *Agricultural insecticides threaten surface waters at the global scale.* Proc Natl Acad Sci USA 112, 5750–5755.

in current regulation[85,86,87,88]. In freshwaters, some active substances are monitored to determine the risk they pose to the aquatic environment based on requirements from the Water Framework Directive. The list currently includes a few insecticides[89].

The status of EU waters is improving gradually year-by-year. Yet, according to the European Environment - State and Outlook (SOER) report for 2020 produced by the European Environment Agency (EEA)[90] the majority of Europe's water bodies still do not meet EU's minimum target to be classified as having a 'good ecological status'. They advise that the 2020 objective will not be met even though it is a legally binding commitment in the Water Framework Directive (2000/60/EC). Although there is undoubtedly a mixture of pollutants from non-agricultural and agricultural sources, the EEA report highlights agricultural production as one of the activities responsible for diffuse pollution (nutrients and PPPs). The EEA has also recently acknowledged[91] that the danger posed by the *cocktail effect* of multiple PPPs of low concentrations of chemicals in water bodies deserves more attention. This includes not only PPPs but also chemicals present in industrial and sewage discharges.

In summary, **there is increasing evidence that PPPs could be contributing to the observed biodiversity decline and the reduced quality of EU waters and soils.** However, the multiplicity or organisms potentially affected by PPPs and the complexity of their interactions with each other and with all aspects of human activity including food production make it hard to determine the magnitude of the specific contribution of PPPs to the loss of soil and water quality and biodiversity decline. These gaps in current knowledge on the actual impact of PPPs on the environment also have potential implications for comprehensive risk assessments, as noted in a 2016 IPBES report[92].

2.6 Has the Crop Protection chemical toolbox been depleted? Do we know the effects?

These questions define the greatest concern of farmers. This section looks at the evidence. The first question is deceptively simple, the answer turns out to be rather more complicated. It is important to distinguish active substances regulated at EU level and PPPs which are regulated by Member State and which may contain more than one active substance, to look at both existing and new active substances, and to distinguish what has happened to date and what is anticipated in coming years.

Focusing on the number of active substances, in February 2020[93] there were 476 available in the EU and this has changed little compared to ten years previously when the current regulation (1107/2009) came into force. There are, however, considerably fewer compared to the nearly one thousand substances available during the period

85 Schäfer et al., 2013. *Pesticides reduce regional biodiversity of stream invertebrates.* Proc Natl Acad Sci USA 110, 11039.

86 Liess and von der Ohe. 2005. Full reference in p.29.

87 Köck-Schulmeyer, M. et al. 2012. *Analysis of the occurrence and risk assessment of polar pesticides in the Llobregat River Basin (NE Spain)*. Chemosphere 86: 8–16.

88 Brühl et al., 2013. Full reference p.29.

89 https://ec.europa.eu/jrc/en/science-update/updated-surface-water-watch-list-adopted-commission

90 EEA. 2019. The European environment State and Outlook 2020.

91 www.eea.europa.eu/highlights/more-action-needed-to-tackle

92 Potts et al. 2016. *IPBES: Summary for Policymakers of the Assessment Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on Pollinators, Pollination and Food Production.* Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany. 36 Pages.

93 This was the number on 10/02/2020 on the EU Pesticides Database.

1950 to the 1990s[94]. This reduction in available substances came about as unacceptably risky substances have been eliminated. Numerically most of the reduction occurred because companies did not submit them for renewal or withdrew them. This was presumably partly for commercial reasons and to avoid the expense and risk of having them actively assessed and rejected as not meeting the safety criteria for renewal. Since the procedures under Regulation 1107/2009 finally came into operation in 2011 the number of active substances has not declined. The REFIT evaluation[95] identified that, between 2011 and 2016, 23 active substances were not-approved, not-renewed, or withdrawn based on health-based criteria and 15 substances were not-approved or not-renewed due to environmental concerns. In addition, restrictions were laid down for three neonicotinoids due to concerns over their impact on bees. Over this same period new products have appeared, and it is not clear that the rate of appearance of new actives has strongly diminished despite large increases in regulatory costs and time taken for approval. Based on this information the 'toolbox depletion' fear of the farming industry has not materialised to this point, as measured by numbers of substances available.

The number of active substances does not tell the whole story. The efficacy of products and their applicability differs greatly. Also, having a range of products with different modes of action is an important part of farmers' resistance management strategy. Losing one particular product may lead to more rapid appearance of resistance for the others previously used in combination. However, given the above numbers, the focus of the 'toolbox depletion' concern of farmers therefore shifts to prospective changes, both in overall numbers and to the specifics of two cases: the broad-spectrum herbicide glyphosate and the neonicotinoid insecticides. It was decided at the outset of this project that it will not seek to engage in the on-going disputes of these two cases. This lies beyond the scope concerning the broad future for crop protection.

Looking at prospective numbers, the principal fears of (conventional) farming organisations is that the EU is now on the brink of disappearance of many active substances including some which have no clear candidate for substitution[96]. This is evidenced by the 100 pending active substances which should have been assessed before the end of 2018, and the 215 active substances due for renewal by the end of 2021. Of this latter group, applications for consideration for renewal have been received for only 158, so the other 60 will certainly disappear from the market. Given that the approval system has capacity to process no more than 60 substances per year it will take more than four years to work through the backlog. It is impossible to estimate the outcome of this process, the evaluation of each individual active substance is a detailed scientific inquiry. However, there is a presumption that the number of active substances available to EU agriculture is likely to fall, and this is likely to include some key products hard to replace in current farming systems. By how much, and which substances, and with what effects is difficult to gauge without a case-by-case analysis for over two hundred substances which is beyond the scope of this study. It is important to state that the reason the number of active substances will fall is because society has mandated the removal from the market of substances which pose what are deemed unacceptable risks. What is seen as a loss by farmers is viewed as a gain in terms of citizen and consumer confidence.

The increasing number of instances for which emergency authorisations or postponements of expiry dates are issued to allow continued use of the substance is partly a

[94] This refers to the 979 PPPs reviewed since the adoption of Directive 91/141/EEC in 1991. Note, this number was not available in any single member state, it is the total of the available substances summed over the numbers available in each Member State.

[95] Ecorys 2018. Full reference in p.24.

[96] Loss of PPPs is not solely the concern of conventional farmers, organic producers are worried about the loss of copper compounds which are currently also defined as candidates for substitution because of their toxic effects.

consequence of the inability of the approval system to process active substances before the expiry of their approval date. Such authorisations are also sometimes given to allow more time for substitute products to be developed or to cover the protection of crops not widely grown in the EU (minor uses) or with small markets which is considered insufficient[97]. The extent to which this is happening is indicated by the 50% increase in (risk-adjusted) emergency authorisations in five years shown by Harmonised Risk Indicator 2 discussed in section 2.2 above. This is a deeply unsatisfactory state of affairs which undermines confidence in the system for all parties, farmers and consumers alike.

Turning to the impacts on agriculture of the loss of PPPs, although the banning of well-used PPPs arouses strong feelings amongst farmers, there are few published case studies of the economic and other effects of loss of active substances. One such report is on neonicotinoids[98]. This looked at 13 studies of the economic impacts of inability to use neonicotinoids on oilseed rape production in 6 EU countries. It found an average yield loss of 4% (ranging from 0.5% to 22%), an average of 0.73 consequential extra foliar spray applications (ranging from 0.33 to 2.0), and a total economic impact (made up of reduced output, reduced quality and thus lower selling price, and some additional costs) of €512m per annum. There is no reason to doubt that these are indeed the measurable impacts comparing the situations immediately before and after neonicotinoids were proscribed. They do not measure the subsequent years' impacts as farmers take other longer-term actions to find ways to protect their crops without a PPP on which they had previously relied. Such actions include turning to substitute PPPs which are likely to be less effective and shorten the time until resistance develops, introducing new crops and changing crop rotations. Such future rounds of adjustments will generally show lower losses. These are the adjustment costs facing farmers as established PPPs are deleted from the lists of approved products. Society has implicitly valued the societal gain from the reduction of actual, or risk of, negative impacts on health or environment as larger than these costs to farmers[99]. This is the primary purpose of the approval process which is not in dispute. Studies extending beyond the farm-level to assess the impact of non-approvals at the crop sector level have not been found. The economic impacts at the sector level would be expected show up as potential loss of competitiveness of the affected EU sector, and with possible impacts of raising domestic prices and inducing changes in international trade flows. The Ecorys evaluation did consider the impacts of Regulation 1107/2009 on competitiveness, although not through any modelling studies. They concluded there was little noticeable impact.

2.7 Conclusions to this point. Does the EU have a satisfactory Crop Protection strategy?

The EU regulatory framework for crop protection is diffuse. It is embraced principally in a collection of nine regulations which evolved over many years of EU enlargement and integration. They are summarised in section 2.3 above. The aim of the current EP crop protection strategy can be summarised as: *to reduce harm to health and environment by Plant Protection Products whilst not impeding competitiveness of EU agriculture*. In regulatory terms, this is to be achieved first, by removing from/only approving for the market, products which are not hazardous to humans, animal health and the

97 Ecorys 2018. Full reference in p.24.

98 Noleppa, S. 2017. *Banning neonicotinoids in the European Union, An ex-post assessment of economic and environmental costs*, HFFA research GmbH, 91 pages.

99 Studies to evaluate the benefits to public health and environment from PPP regulation do not exist. Such analysis is not easy as the measurement demands difficult to determine base lines, appropriate system boundaries and counterfactual policies and conditions.

environment[100]. Second, by insisting on extremely low residues of PPPs on foods, and in drinking water, and by taking steps to ensure all water bodies are in good ecological and chemical health. Third, by encouraging the sustainable use of pesticides by, *inter alia*, requiring Member States to set up and implement National Action Plans to encourage all farmers to reduce dependency on PPP use and to reduce risks of PPP impacts by implementing Integrated Pest Management. There is general agreement of these objectives of the regulatory framework, although there is ambiguity about the precise long run goal particularly the future for synthetic PPPs. Most dissatisfactions are found in the implementation of the regulations for approving active substances and PPPs, the SUD and the environmental Directives. This is not as good as it should be.

Criticisms of the current regulatory framework[101]

Some of the main criticisms of the regulatory framework are listed as follows, noting that different stakeholders have different criticisms.

i There is ambiguity between reducing *harm attributable* to PPPs and reducing their *use*.

ii The ultimate aim is not clearly stated. It would help if it was. It is unclear if the aim ultimately is to avoid the use of PPPs altogether. The fact that such products are accepted as a final resort under the SUD, and that there is a list of PPPs available to organic farming suggests *elimination* of PPP use is not the long run goal.

iii There are no clear indicators or mechanisms for measuring and balancing unwanted impacts on EU agricultural competitiveness.

iv The approval process is complex, it is not well administered nor sufficiently resourced to work within the time periods and criteria set in legislation. This creates uncertainty and costs for applicants.

v The consequential frequent resort to emergency and temporary authorisations introduces uncertainty for all stakeholders and most directly for farmers and the PPP industry and undermines public confidence in the regulations.

vi There are concerns amongst conventional farming organisations and the PPP industry that the last stage of the approval process is too open to what they regard as non-scientific, political, considerations.

vii There are concerns amongst NGOs that health and environment are inadequately protected because: impacts are not assessed for all groups of species, tests on individual species do not reveal the impacts on ecosystems, and the potential interactive 'cocktail' effects of multiple PPP use are not taken into account.

[100] This is, of course, a highly simplified statement. It is difficult to convey the full subtlety of the regulation is a short phrase. Active substances can be approved which are hazardous, as long as their exposure levels don't impose a risk to humans.

[101] It is interesting to note that a European Court of Auditors (ECA) paper entitled: *Sustainable use of plant protection products: limited progress in measuring and reducing risks*, was published as this report was in its final stage. The broad conclusion is plain in the title. The ECA set out to discover if EU policy has reduced the risks relating to PPP use. They found that the question could not be answered because the definitions and data are not adequate to judge. They suggest: improvements in the statistics on PPPs to make them more accessible useful and comparable; that there should be more work on developing better harmonised risk indicators; and there should be more effort to help the Member States convert the principles of IPM into practical criteria and verify them at farm level linked to payments under the CAP. www.eca.europa.eu/en/Pages/DocItem.aspx?did=53001

viii There is some distrust that much of the data used in the approval process originates in the applicant companies and is sometimes subject to non-release for commercial reasons.

ix There is concern that innovative and potentially lower risk PPPs such as biopesticides are deterred from the market by the complex, expensive and long approval procedure not suited to their characteristics. A separate regulation may be justified for such products.

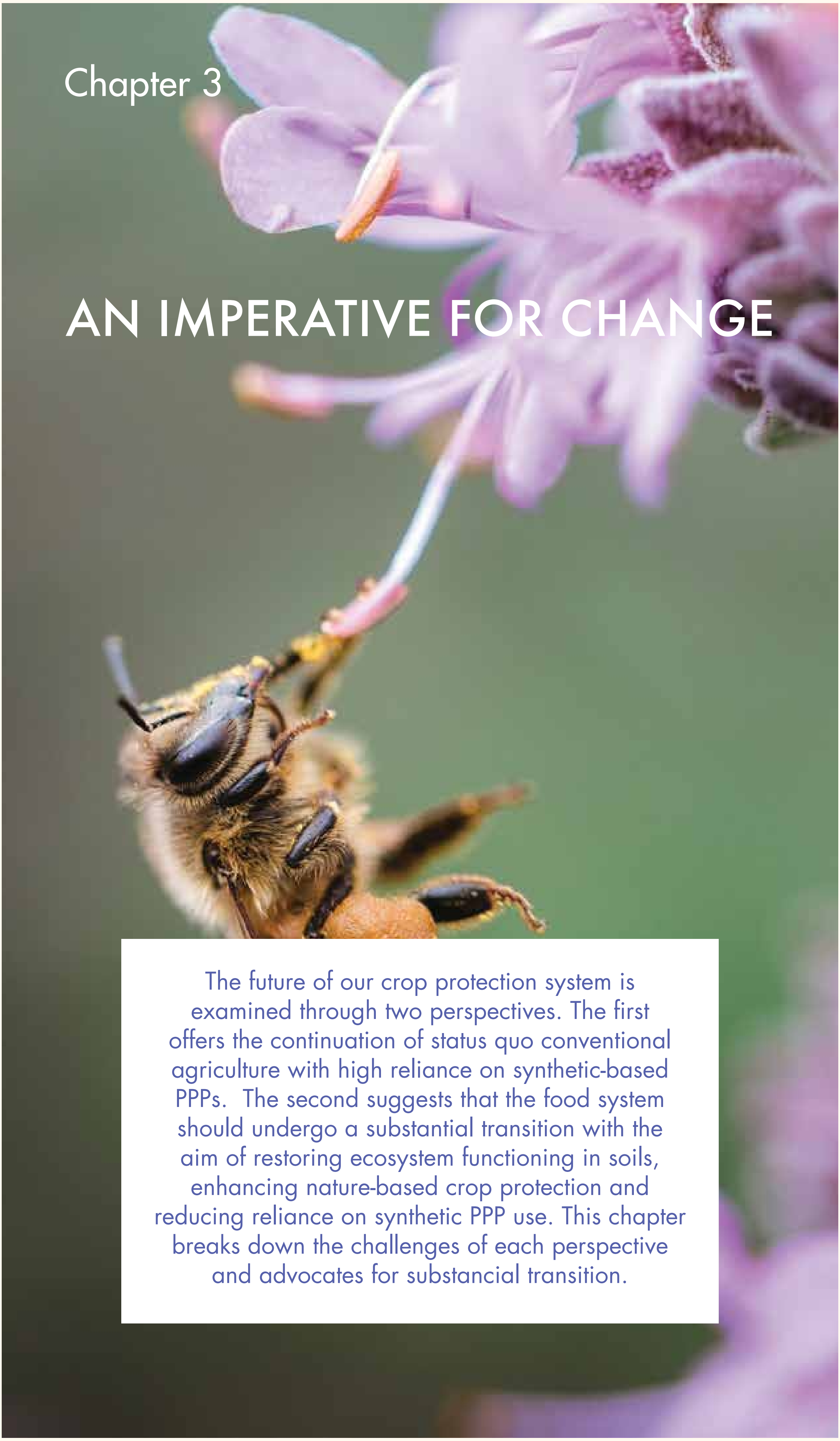
x The SUD does not provide precise enough guidance or quantitative goals to Member States on what constitutes adequate National Action Plans, nor are there milestones and indicators defined for implementing many of the IPM actions and measuring their impacts. There is also inadequate monitoring of PPP use and contamination at EU level.

xi Other EU policies such as the Common Agricultural Policy have not, to this point, given strong steer or sufficient practical incentives to help the implementation of IPM.

Meanwhile it is noted that while there are organisations proposing targets for reductions in PPP use[102], there is only one clearly articulated demand for a new regulation, and this is for the approval of biocontrol products (also called bioprotectants). Stakeholders are not suggesting fundamentally different objectives for EU strategy from those summarised above. Despite their criticisms of the shift from risk-based to hazard-based assessment of substances for approval neither farming organisations nor the crop protection industry have proposed reopening the regulation to return to the pre-1107/2009 approach. The conclusion is therefore that the EU does have in place a broadly satisfactory regulatory framework for its crop protection strategy. Whilst no fundamental change is sought in this framework, there could certainly be **better implementation with clearer targets, better statistics and better monitoring of progress.** There is a continual need for the detailed technical provisions of the regulations to adapt as scientific advances and knowledge changes the possibilities for crop protection. Regarding the clarity of the strategy, the principal ambiguity concerns the ultimate goal. Is this to reduce, or to eliminate, the use of PPPs? Does this refer to all PPPs or just to synthetic PPPs? Or is the goal to reduce the risks and negative impacts of PPP use? These ambiguities are linked to deep disagreements about the acceptable set of agronomic practices operating in place within the regulatory framework. This ambiguity and the disagreements are an expression of the fundamental issue dividing stakeholders which is the economic and environmental sustainability of current and alternative agricultural systems.

The next section tries to tease out these disagreements in the hope of finding some common ground and reducing the tensions over these issues. It starts by examining two quite different perspectives on what is considered to be the correct way forward for crop protection. The hope is that out of this dialectic might emerge some agreement on what constitutes a less ambiguous long run goal for crop protection and a feasible and desirable set of practices to lead to this goal.

102 For example, Save Bees and Farmers in a European Citizens Initiative are asking for synthetic pesticide use to be reduced by 80% by 2030 and phased out by 2035. www.savebeesandfarmers.eu/eng



Chapter 3

AN IMPERATIVE FOR CHANGE

The future of our crop protection system is examined through two perspectives. The first offers the continuation of status quo conventional agriculture with high reliance on synthetic-based PPPs. The second suggests that the food system should undergo a substantial transition with the aim of restoring ecosystem functioning in soils, enhancing nature-based crop protection and reducing reliance on synthetic PPP use. This chapter breaks down the challenges of each perspective and advocates for substancial transition.

Current debates on future farming often polarise around two perspectives, or paradigms, of food production. One centres around the status quo conventional agricultural production system. This is not static; it developed during the 20th Century through the application of the natural sciences to crop and animal production. It is energy intensive and has steadily substituted capital for labour embodied in genetics, nutrition, protection and management of plants and animals. It makes heavy use of synthetic and manufactured inputs especially nutrients and PPPs, mechanisation and more recently electronic technologies. The other perspective strives for nature-based approaches to growing crops. The principal expression of these latter systems found in practice is organic or bio agriculture. There are numerous variants of this approach one of whose principal common features is that they seek to avoid the use of manufactured fertilisers and chemical based synthetic PPPs substituting nature-based solutions for crop nutrition and plant protection. Although these two broad systems tend to be characterised as opposing paradigms they may not be totally incompatible and could even be combined on the same farm, or one could perhaps evolve into the other. Such possibilities deserve consideration. They are considered here with respect principally to their environmental and economic sustainability. They are discussed as general approaches towards EU agricultural production and not intended to apply to each and every farmer; individual farmers may well follow either of these routes all the while they are both available. Although this report is focussed on crop protection, the two perspectives are described as broad approaches to agricultural production implicitly embracing the whole production system including breeding and crop nutrition as well as crop protection. It makes little sense to isolate crop protection from the broad production system in which it is practiced.

3.1 Can and should the status quo system of crop protection survive?

The status quo refers to business-as-usual, conventional, intensive agricultural production systems with their strong reliance on the use of synthetic chemical-based PPPs for crop protection. These systems are highly dynamic evolving with changes in technology, markets and in the policy and regulatory environment. With respect to crop protection, proponents of this perspective defend the status quo in both the production systems and the regulatory framework. They emphasise the principal tasks are to improve performance of both practices and the operation of current regulations and to communicate better to the public why they can put their trust in a transparent, independent, science-based regulatory approach to ensure health and environmental safety. Under this perspective, it is proposed that there should be no contradiction with the aim to constantly seek to reduce and even eliminate **harm** to health and environment from PPP use, but there would be no necessary presumption about the trend of **use** of PPPs. The option could, in principle, even include the situation where agricultural production in the EU, and PPP use, had to increase if other parts of the world found their agricultural production is more badly affected by climate change than Europe.

The key proposition in defence of status quo, conventional, agriculture is that crop yields must be maintained to provide sufficient food output for the growing and enriching global population. In turn, this means, *inter alia*, maintaining the current system of crop protection to maintain yields. This is questioned in three ways.

First, it is suggested in two recent studies by IDDRI[103] and IPES[104] that the current[105] conventional food production system (not only in the EU but in the developed world generally) is unsustainable[106]. It constitutes a disruption of ecosystem functioning in agricultural soils and around agricultural crops. It has depleted soil fertility, aquifers and biodiversity, it has polluted waters and damaged climate to such an extent that current production levels are not capable of indefinite continuation[107]. As far as crop protection is concerned, the very names of fungicides, herbicides and insecticides indicates they are designed to reduce certain biodiversity. In any case the ability to depend on PPPs is diminishing because the current regulatory system is expected systematically to reduce the synthetic PPPs available in coming years. Meanwhile the development of resistance by pathogens means new products and modes of action have constantly to be sought, yet they too, over time, are likely to encounter resistance. The problem of resistance does not only apply to crop diseases/pathogens, weeds, and pests becoming resistant to the PPPs designed to treat them, it is also arising in related pathogens which cause disease in humans. The rise of antimicrobial resistance to drugs used in human medicine is a growing concern. That environmental quality has been degraded in these ways is not in doubt[108]; the evidence that environmental tipping points or thresholds have been, or will soon be, reached is less clear, except for the critical case of climate damage. It is deduced from the literature measuring the exceedances of planetary boundaries for climate, nutrients and biodiversity loss that major regions with intensive agriculture such as the EU must be unsustainable and therefore must undergo some kind of system change to bring their food system back within a safe operating space[109]. These are the arguments which lead to the conclusion that continuing "business as usual" will, sooner or later, become a failed strategy as it depletes the very elements underpinning agriculture. The status quo therefore cannot continue indefinitely.

Second, and explicitly narrowing down to the European context, the arguments about the drive for more production to feed the EU itself have to be reconsidered. The EU can be characterised as having: (i) slowing population growth and slowed economic

103 Poux, X., Aubert, P.-M., 2018. *An agroecological Europe in 2050: multifunctional agriculture for healthy eating. Findings from the Ten Years For Agroecology (TYFA) modelling exercise.* Iddri-AScA, Study N°09/18, Paris, France, 74 p.

104 IPES-Food Panel 2019. *Towards a common food policy for the European Union.* http://ipes-food.org/pages/commonfoodpolicy

105 Invariably the adjectives intensive or industrial are added here. These are general arguments and not specifically focussed on crop protection and PPPs. However, in all such analyses the two key factors indicating unsustainability are the use of mineral fertilisers and, the word normally used, pesticides. No studies have been found which eliminate PPP use alone.

106 This is chiefly argued from an environmental perspective and sometimes from a social perspective too.

107 They also argue that the average European diet is excessively rich. It is too high in calories, but especially in protein and sugar. It is also unbalanced, with the excessive calorie and protein intake compounded by a low consumption of fibre, which reflects in particular a lack of fruit and vegetables. The average consumption of red meat is also almost double that of WHO recommendations (from the IDDRI report (Poux and Aubert 2018).

108 See for instance the latest EEA's report, The European Environment State and Outlook SOER 2020, for indicators on soil, water and biodiversity.

109 This is the kind of general argument which underpins most claims that EU agriculture is unsustainable. It has to be noted that apart from climate, planetary boundaries for other factors are not robustly established quantitatively, and closer inspection suggests that some, like nutrients are more usefully conceived as regional boundaries. See RISE Foundation, 2017, *Where is the Safe Operating Space for EU livestock?* for a discussion of the interpretation of planetary boundaries for a continent such as Europe.

growth,[110] (ii) waste and loss levels in the food system of at least 20%[111], and (iii) widespread over-consumption of carbohydrates, fats, and protein leading to high incidence of metabolic disorders (diabetes and coronary heart disease) and associated health costs for citizens. In such a context, the need to maintain and further increase yields and total output is not clear. Correspondingly the yield and total production loss which might follow a de-intensification of agricultural systems, which are in any case also damaging the natural environment, take on a quite different complexion. The last decade has seen a succession of reports from natural science[112], medicine[113], NGOs[114] including the RISE Foundation[115], suggesting that consumption of livestock products should diminish by a substantial amount (these studies include a range of reductions from 20% to 90%). Given that livestock utilise almost all the grassland areas and over half of the crop area for their feed, a contraction of livestock consumption, together with a significant reduction in food waste, would substantially reduce the pressure on land. Of course, the food security argument never disappears, but its power with respect to the developed world diminishes greatly if EU citizens' dietary and food behaviour follow the current discourse on food, health, well-being and waste.

The third level concerns the wider international dimensions of EU domestic policy. This involves addressing questions such as: EU responsibilities towards global food security; the impacts of EU policies on acceptable technologies (e.g. for crop protection and crop breeding) in other regions, and the displacement of environmental impacts of agricultural production from the EU to other parts of the world. The EU is a protected market with significant tariff and non-tariff barriers which maintain it as a relatively high-food price zone. Nonetheless the EU is a significant exporter of agri-food products, a high proportion of which are high quality processed foods and drinks. EU agri-food imports have a high proportion of fruit, beverages and vegetables less easily grown in temperate climate and animal feed especially protein. If it could be credibly claimed that EU policy on PPPs in Europe could have damaging side effects on the alleviation of poverty, hunger and malnutrition in other parts of the world or if EU policies had the effect of stimulating greater deforestation or use of fragile lands in such regions, then these would be material considerations in the EU policy process. Such developments are not just fanciful possibilities, they could come about if a switch in EU domestic policy resulted in significantly more imports from, or lower exports to, the rest of the world. This point is taken up again below.

Bringing these arguments together, continuing indefinitely with the status quo is rejected as not feasible mostly because it is thought to create unacceptable harm to the environment. Furthermore, highly intensive production may not be necessary if food consumption changes as suggested in most official dietary advice and if food waste were to be reduced substantially as is policy to do across the EU.

[110] Eurostat, 2017. The EU-28's population is projected to peak around 2045, reaching 529 million, an increase of 18.8 million (or 3.7 %) compared with the situation as of 1 January 2016. The size of the EU-28's population is then projected to progressively fall with a population of 519 million persons by the start of 2080. https://ec.europa.eu/eurostat/statistics-explained/index.php/People_in_the_EU_-_population_projections#Population_projections

[111] FAO, 2011. *Global food losses and food waste – Extent, causes and prevention*. FAO, Rome, 37 p.

[112] Westhoek, H., et al. 2015. *Nitrogen on the Table: The influence of food choices on nitrogen emissions and the European environment.* (European Nitrogen Assessment Special Report on Nitrogen and Food). Centre for Ecology & Hydrology, Edinburgh, UK.

[113] Willett, W., et al. 2019. *Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems.* The Lancet 393, 447–492.

[114] Such as Greenpeace: Tirado, R., et al. 2018. *Less is more: Reducing meat and dairy for a healthier life and planet - Scientific background on the Greenpeace vision of the meat and dairy system towards 2050.* Greenpeace Research Laboratories Technical Report (Review) 03-2018 or the WWF: Audsley, E., et al., 2009. *How low can we go? An assessment of greenhouse gas emissions from the UK food system and the scope to reduce them by 2050.* FCRN-WWF-UK

[115] Buckwell, A., Nadeu, E., 2018. What is the Safe Operating Space for EU Livestock? RISE Foundation, Brussels.

Understandably, this conclusion is resisted by producer interests in the EU. The nature and scale of the contribution of PPPs to biodiversity decline is contested by the PPP industry, farmers and some scientists. However, the societal view has hardened and is clearly expressed in repeated commitments by politicians in many Member States to "reduce pesticide use". This has been the explicit goal in many of the National Action Plans of Member States following the Sustainable Use of Pesticides Directive. More recently it has been taken up at the highest political level in Europe. French President Emmanuel Macron included the quite specific issue of pesticide use in his March 2019 high-level appeal for European renewal which flagged three themes: freedom, protection and progress[116]. On progress he said, *inter alia* that "*The European Union needs to set its target – zero carbon by 2050 and pesticides halved by 2025 – and adapt its policies accordingly with such measures as a European Climate Bank to finance the ecological transition, a European food safety force to improve our food controls and, to counter the lobby threat, independent scientific assessment of substances hazardous to the environment and health.*" It is telling that this issue was singled out for mention amongst the myriad issues of political concern in Europe. It seems at once to set quite a precise target for pesticide use and also to cast doubt on the independence of Europe's current pesticide regulation system.

These aims on PPP use have been part of French domestic policy on agriculture since 2008. The French National Action Plan for PPPs under the Sustainable Use of Pesticides Directive has sought to reduce PPP use by 50% by 2025 through successive plans, Ecophyto, Ecophyto II and Ecophyto II+. To date these plans have failed to bring about a reduction in overall PPP use[117]. The PPP targets are part of the broader approach of the 2014 French Law for the Future for Agriculture, Food and Forestry which promotes the idea of agroecological practices[118]. These ideas have been followed up as part of a much broader environmental initiative in the European Commission's proposals for a European Green Deal[119]. The biodiversity chapter of this document promises a new Farm to Fork Strategy which 'will work to reduce the use of pesticides and fertilisers in agriculture'. Both the Green Deal and the Farm to Fork Strategy are broad statements of strategic direction. All the details of implementation are work in progress but one aspect of the Farm to Fork strategy is quite explicit: "to increase the level of ambition to reduce significantly the use and risk of chemical pesticides as well as the use of fertilisers and antibiotics". The seriousness and urgency of these ideas is given greater force by the use of the words 'crisis' and 'emergency' in relation to climate change and biodiversity loss. The challenge for agriculture and land use of reducing GHG emissions and creating more carbon sinks, signals that there has to be a change in the food and agricultural system, including crop protection, to restore ecosystem functions and bring about substantial reduction in environmental damage and risks to human health.

116 www.elysee.fr/emmanuel-macron/2019/03/04/for-european-renewal.en

117 Two reports on progress with the Ecophyto plans are: www.sciencemag.org/news/2018/10/france-s-decade-old-effort-slash-pesticide-use-failed-will-new-attempt-succeed, and https://agriculture.gouv.fr/le-plan-ecophyto-quest-ce-que-cest

118 As explained by Gonzales *et al* The French government worked on a new law made public on 13 October 2014, under the name of "LOI No. 2014–1170 d'avenir pour l'agriculture, l'alimentation et la forêt" (Law 2014–1170 of 13 October 2014 of the future for agriculture, food, and forestry). This law provides a rationale for the combination of economic, environmental, and social performance through sustainable and highly productive agroecological practices. (Ajates Gonzalez, R., Thomas, J., Chang, M., 2018. *Translating Agroecology into Policy: The Case of France and the United Kingdom.* Sustainability 10, 1–19). The progress on both the pesticide action plan and the new move towards agroecological practices has been rather limited in practice.

119 This is a high-level strategic statement from the new European Commission as it took office in late 2019, https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

3.2 The challenges for alternative, sustainable production systems

The conclusion that the current dominant production system is unsustainable naturally invites the question what is an alternative and sustainable production system? There are many candidate farming systems which claim to be sustainable. They share the characteristic of defining farming systems which are more closely aligned to natural ecosystem functioning. The definition and development of such systems has been underway for almost a century since the 1920s coinciding with, and indeed reacting to, the fast-developing mechanisation of agriculture and expansion of the use of mineral fertiliser and early crop protection chemicals in Europe at that time. Recent brainstorming has identified a number of systems which have claims to be sustainable agriculture[120]. Steiner's Biodynamic agricultural practices in 1924 is identified as the earliest example, followed by Agroecology which was defined in 1928 by Bensin, and the term Organic Farming coined in 1939 by Northbourne. Since those days there has been a proliferation of many other systems claiming to be sustainable[121]. Of these numerous systems only organic/bio agriculture has established itself as a well-recognised brand in European markets and through formal certification systems which are now consolidated in EU regulations. The extent of organic farming is reasonably well documented, but the numbers of farms, areas farmed and outputs from the other sustainable approaches is not documented at all. The definitions of these systems vary greatly although there are strong features in common[122], also some of these systems propose wide and deep social and economic change including to land tenure systems and capitalism itself.

In the rest of this report the descriptor adopted for the system alternative to the status quo will be called '**sustainable agriculture**'[123]. Inevitably, because organic farming is the only well-documented practical expression of such systems, some of the discussion below will rely on organic farming examples, data and experiences to discuss the issues. This is not intended to suggest that organic farming is the only, or best, form of sustainable agriculture. The key features of sustainable agriculture are summarised in italics in the next paragraph.

The crop protection methods, particularly the extent and mix of use of PPPs in these systems of sustainable agriculture, differs across these systems. Some may permit biological agents and some (such as organic farming) permit a set of plant protection products including 'manufactured' materials such as the copper compounds[124]. Leaving aside the socio-economic considerations in these sustainable food systems, and confining discussion to the primary agricultural production system, *the defining*

[120] One such list including a limited number of approaches to sustainable agriculture is being compiled in a project underway in the International Union for Conservation of Nature (IUCN).

[121] Sustainable farming systems which are often referred to for example: organic agriculture, permaculture, regenerative agriculture, agro-ecology, agro-forestry and nature-based farming.

[122] For agroecology the FAO has organized a database of definitions, see www.fao.org/agroecology/knowledge/definitions/en/. This includes definitions of agroecology from published documents, authored by scientists, civil society, academia, governments, legal documents and policies, among other sources.

[123] Readers should note that this nomenclature was finally adopted after many alternatives (e.g. variations of agroecology) had been considered and rejected as creating confusion. It is acknowledged that it is a short-hand phrase which leaves many questions unanswered as to its precise formulation. Its environmental sustainability is presumed. Its economic sustainability is scrutinised in what follows. This usage reflects that although most users of the word sustainability insist that it should cover, and give equal importance to, all three aspects: environmental, economic and social, the predominant use of the word sustainability refers to the first aspect.

[124] IPES 2019 (full reference in p. 37) suggests in its Objective 2 adoption of agroecology as the model for agriculture which includes "ultimately phasing out the routine use of chemical inputs", Executive summary, p 10.

attribute of environmentally sustainable farming systems is an attempt to restore natural ecosystem functioning. This is done both within agricultural soils and in above-ground crop systems working from the field to the landscape scale and integrating semi-natural elements. The intention is to restore soil fertility and thus soil function, and this should be achieved by extending and widening crop rotations, mixing plant and animal agriculture where possible, providing nutrients by making more use of legumes, manures, composted material and digestates, including cover and companion crops and introducing greater diversity in fields, and around them. **The essence is to restore soil and above ground biodiversity to maximise natural and circular processes for plant nutrition and in-built health, pest and disease resistance thereby creating a resilient production system.**

Could such systems be the basis of the whole or majority of the EU food production?

The principal criticism of conventional agriculture which lead to the conclusion it is unsustainable is its environmental performance. There is a presumption that the lower intensity of the alternative systems described above will lead to better environmental credentials. The prime questions to be considered for the alternative self-styled sustainable systems therefore concerns the technical feasibility of producing the majority, let alone the entire, EU domestic food supply, and the economic sustainability of such systems.

As noted, empirical evidence from which to answer these questions is lacking because there is little systematic data collected on these various systems with the exception of organic farming. Organic agriculture certainly claims to be sustainable agriculture, it operates a system without mineral fertilisers and in which PPP use is quite restricted and it doesn´t necessarily follow all agroecological principles. Substituting mechanical weed control, i.e. cultivations, for herbicides can increase the soil disturbance and use more energy, both contributing to further GHG emissions, but this can be minimised through adequate nutrient management, reduced tillage intensity, and the use of cover crops and crop rotations. Also, complete elimination of fungicides for disease control may be associated with higher levels of fungal diseases and natural toxins compared to conventional agriculture. Such considerations complicate the assessment of the overall environmental impacts of different farming systems.

Based on organic farming statistics such lower intensity systems with, *inter alia*, their lower levels of applied nutrients and PPPs invariably have lower yields. All sustainable systems **by design and intent** are less intensive and eschew most if not all use of artificial, synthetic inputs, they will therefore aim to extract lower output than a conventional system from a given area in a given season so as to not over stretch ecosystem functioning, hence the principal doubts will relate to the economic sustainability of such systems. Meta studies of organic farming show yield penalties compared to conventional farming of between 5% and 45%, depending on the crop[125,126]. Therefore, unless the farmed area is expanded proportionately the output of food would fall if most or all EU land were converted to sustainable systems[127]. However, an expansion of the agricultural area could be highly damaging to habitat and biodiversity.

125 Ponisio, L.C. et al. 2015. *Diversification practices reduce organic to conventional yield gap*. P Roy Soc B: Biol Sci 282, 20141396.

126 Seufert, V., Ramankutty, N., Foley, J.A., 2012. *Comparing the yields of organic and conventional agriculture*. Nature 485, 229–232.

127 It is curious that advocates of alternative systems often argue that if the volume of research and development devoted to intensive agricultural systems had been devoted to agroecology then the yield penalty would be much smaller or could disappear. This seems improbable. The R&D efforts of the last 60 years were indeed devoted to raising yields. The principal findings were that the main constraints (given sufficient water) on crop yields were nutrient availability, and pests and disease. But the success in stretching ecology to enable high agricultural yields brought with it the environmental degradation discussed above. Lower intensity, more environmentally friendly farming is bound to involve lower nutrient and crop protection inputs per hectare and therefore lower outputs per hectare.

Indeed, as is examined in section 3.3 below, action to mitigate climate change in the EU might necessitate *reducing* the agricultural area to reallocate land to nature restoration to provide carbon sinks and biodiversity. Reducing both the *intensity* of agricultural land use *and* the *area* of agricultural land could be a risky strategy.

Advocates of a system shift to sustainable agriculture (e.g. the IDDRI and IPES studies cited above) make it very clear that their concept refers to the whole food system including food industry and consumers and not just farm production systems. They argue that current food consumption is unsustainable, not just production. They propose consumption behaviour change and food waste reduction are integral parts of the preferred system. This is a crucial element of the argument. Without it the case for less intensive systems to produce the entirety of European food output is much more difficult to make. With this understanding, the food security threat of de-intensifying agriculture may not of itself rule out this approach as a feasible possibility.

Is this switch possible? Continuing with the evidence of organic farming as a proxy indicator for sustainable agriculture, the EU Member States which have gone furthest in this direction as measured by the share of agricultural land farmed organically are Austria at 24%, and Estonia 20% and Sweden 19%[128]. Only 7 of the EU28 Member States have more than 10% of their agricultural area classified as organic. The current proportion of EU consumer food and drink expenditure on organic products is thought to be less than 5%[129]. This is after decades of favourable media attention and support from NGOs, food and countryside writers, plus significant economic incentives. The incentives take the form of (i) the market price premia which offset the lower productivity per hectare of organic production, (ii) generous policy funding support under the Common Agricultural Policy for the conversion period when yields fall and the organic premium is not available, and sometimes for maintenance, (iii) direct access to CAP greening payments for ongoing production for all organic producers[130] and (iv) access to funding under agri-environment schemes. The slow rate of adoption of a production system which has been praised so widely and for such a long time must be explained by some substantial barriers for farmers. They deserve examination, and indeed further focussed research.

First is the element of belief. This works strongly in both directions. Those brought up, or indeed trained, in mainstream agricultural schools with their reductive natural science approach to agriculture strongly believe that intensification is the way to address what they see as technological challenges of producing more output from scarce agricultural land. Agricultural science set off with a production-focussed objective. This was a natural starting position given historic chronic food insecurity. The evidence-based outputs of twentieth-century agricultural science were highly successful in developing the breeding and nutrition of crop plants and protecting them against insect and fungal attack and weed competition. This success reinforced the belief in this approach. Such believers find it hard to understand and accept the rejection of the plant nutrition and crop protection approaches of conventional agriculture. Organic agriculture to them seems the antithesis of what they believe. Equally, those who have chosen to switch to organic farming generally strongly believe that the more nature-based approaches are the only sustainable way to produce food. The point is that such beliefs are harder to change than attitudes.

128 https://ec.europa.eu/eurostat/statistics-explained/index.php/Organic_farming_statistics. Note that these figures may include a lot of permanent grass and rough grazing on which there is little production at all.

129 The 5% is an educated guess. In Germany, EU's largest market for organic groceries, 10 billion euros worth of organic products were sold in 2017, an estimated market share of over 5%. Denmark had the highest market share for organics in the world, with over 10%. The average share also masks a very uneven degree of penetration of organic production by product class some with very low organic shares. [Source]

130 For example organic producers receive the 30% greening element of the Pillar 1 direct payments in the post 2014 CAP by virtue of farming organically without any further action.

Second, even when disbelief is overcome, only a slow pace of conversion to organic production by farmers may be expected because it is perceived as not easy. Reducing the use of PPPs increases the complexity of farming management and requires additional decision-making[131]. It demands strong motivation, understanding and sympathy for the underlying ecological principles. It then requires detailed husbandry knowledge and experience to devise practicable rotations and crop and animal management. It usually takes time, patience, experimentation and some nerve to see through the conversion process and the early years of farming without the tools of conventional farming[132]. These lessons can be learned if the motivation exists and, of course, if agricultural colleges and advisory services majored on these production systems this could no doubt assist the process.

It is an open question just what proportion of EU's food could feasibly be produced by systems which deny themselves use of manufactured mineral fertilisers and most synthetic plant protection products. This question is better considered by broad product sectors.

Take fruit, vegetables and nuts first. Under the food system change to sustainable agriculture it is expected that consumption of animal-based protein is reduced and the consumption and production of plant-based protein and fibre especially fruit, vegetables and nuts should grow. Could this be achieved if all or most production switches to sustainable agriculture? It is suggested that the technical challenge of producing the required volume of these products from businesses with sufficient scale and consistency of throughput and quality to meet the demands of processors, retailers and food service will be a challenge for sustainable producers. This assertion is based on the observation that such crops are grown in closely coordinated operations where large volumes of highly consistent, uniform disease- and blemish-free produce can be harvested, sorted, washed, packed and sent to the equally sophisticated processors and distributors. Such systems have low tolerance for untimely, uneven or unreliable delivery or quality. There are few organic farming businesses which can meet these exacting standards at volume. It will be a significant challenge for sustainable systems to match this. Of course, there are some businesses doing this already. Sustainably grown fruit and vegetables (this refers to organic production) already occupy designated sections in most stores, and there are many specific local markets and outlets prepared to pay for such produce precisely because it is produced in this way. The question under debate is whether and how this can move beyond the current niche status to become the majority if not the totality of production.

Meanwhile, the production of some of these crops, such as some fruit, vegetables, salad crops, herbs and mushrooms has moved in the opposite direction away from soil-based sustainable systems towards even more capital-intensive systems. These take place in protected production, this can be in glass house, poly tunnels, or in the case of so-called vertical farming in warehouses or underground with LED lighting. Crops are grown in soil-less hydroponic systems, with micro-climate control, high biosecurity, biological pest control and sealed non-polluting water systems. Such systems have extremely limited biodiversity and thus little or no ecosystem functioning. They are entirely artificial, yet they may be highly resource efficient and non-polluting. There is great interest and indeed investment in pushing these systems much further and potentially embracing a wider range of crops.

It is suggested that for fruit and vegetables sustainable systems could expand but are probably not capable of producing the bulk of the production in this sector in the time

131 Lechenet, M., Dessaint, F., Py, G., Makowski, D., Munier-Jolain, N., 2017. Reducing pesticide use while preserving crop productivity and profitability on arable farms. Nature Plants 3, 17008.

132 There are many accounts of this process. A very readable personal story of a large (670 Ha) arable farm in southern England which converted to organic over a 15-year period from 1970 is: B Wookey (1987) *Rushall, The Story of an Organic Farm*, Blackwell, Oxford.

frame of, say, the next three decades. Similar arguments may also apply to the larger area crops such as potatoes and sugar beet.

Turning to the broad acre, grandes cultures, cereal and oilseeds crops, these together occupy the major share (58%[133]) of the EU cropland area, and they account for a high proportion (73% in the UK[134]) of the overall national total PPP use per annum. This is because they occupy a large share of the PPP treated agricultural area and not because they have high application rates[135]. Precisely because these crops occupy such a significant share of the arable area, and they are the crops most criticised as tending towards monoculture and degrading soils, they could be prime candidates for incorporation into sustainable systems. Under the assumption that the economic incentives are put in place and given the expected contraction in animal feed demand which is a key part of the food strategy in the sustainable farming perspective, it might be feasible for sustainable production to provide the necessary EU domestic output of these crops even with lower yields.

The remaining major sectors of agriculture are livestock production with its relatively intensive and mostly cereals/oilseeds-based pigs and poultry sectors and the more grassland based ruminant beef, dairy, sheep and goat sectors. At risk of over-simplifying, the key challenges for sustainable livestock production[136], is a sufficient supply of appropriately sustainable feed[137] (fodder and concentrates), and provision of enough manure for crop production. This reverts to the arguments of the previous paragraph.

Summarising this highly generalised analysis, sustainable production of a major share of EU livestock, cereals and oilseeds could technically be feasible without drawing in more agricultural land or imports. However, this would be highly conditional on receiving the right economic incentives and technical help and assumes the scenario where there is substantial contraction of the total EU consumption and production of livestock and associated feed. The feasibility is less clear for fruit, vegetables, nuts and pulses whose consumption would be expected to increase, and for wine. But, the economics of such a transition and ultimately the politics of such a transition, require closer examination. Once again, the analysis of sustainable systems is hampered by absence of data for such systems except for organic farming. One of the key common features of all sustainable systems is that by design they substitute natural processes for the dependence on what are seen as artificial, synthetic, chemical based farming inputs[138]. These processes invariably involve longer and wider rotations including legumes and grass and various of the other practices (listed on p.41). Such systems are *intended* to be less intensive in both inputs and therefore outputs and therefore less exploitative and destructive of ecosystem functioning. Therefore, at the level of generality of this analysis it is suggested that the broad conclusions in what follows about sustainable systems are not invalidated simply because the main evidence is based on experiences with organic farming.

133 OECD-FAO Agricultural Outlook 2018 2027.

134 Based on Pesticide Use Surveys in Great Britain in the absence of data for other countries. It is not clear how typical this is for the rest of the EU.

135 Again, based on GB data the average PPP application rates on cereals and oilseeds (.21 kg/ha) are 60% of the rate of use on vegetables (.35 Kg/ha) and 30% of the rate of use on fruit, salads and ornamentals (.69 Kg/ha).

136 There are significant other challenges for maintaining the health, welfare and productivity of farmed livestock, in particular the need to reduce or eliminate reliance on antibiotics to tackle the problem of antimicrobial resistance. But these go beyond this study on crop protection.

137 This assumes that, just as with organic farming, all other sustainable farming systems have equivalent 'rules' that livestock feed should be produced to the same sustainable standards as the human food crops.

138 There is a frustrating degree of ambiguity in the use of all of these words in this field. The inconsistencies in the way sustainable is used has already been exposed. But the words inputs, artificial, synthetic and conventional are also used in an imprecise way. Inputs invariably refers only to mineral fertilisers and PPPs ignoring the long list of other man-made, i.e. synthesised, and delivered inputs to farming (energy, animal medicines, mechanisation, electronics, breeding, financial and technical services).

Considering the economics. There are several issues, costs and farmer's incomes, prices and trade. Costs per unit of sustainable production may be higher[139] because of the reduced yields. This poses a challenge at farm level to make this a viable proposition for farmers. Continuing with the evidence from organic agriculture, it is an empirical question whether conventional or organic agriculture is more profitable. The comparison is not straight forward. Organic and conventional farms even of the same broad type (arable, dairy, fruit) and in the same region will often have different product mixes. In the EU they may also have different access to the supports, and different levels of support under the two pillars of the Common Agricultural Policy. Organic farmers sell into a different segment of the market. In essence, organic farms will have lower variable costs (zero mineral fertiliser and very low PPP costs[140]) which are partly offset by higher cultivation and energy costs. They will produce lower yields but enjoy higher product prices, the so-called organic premium[141]. The variability of inputs and outputs may also differ between organic and conventional farms, however as organic farms tend to be more diversified income variation may be lower. There are many studies showing higher financial returns from organic farming[142] but the empirical basis for the comparisons is not strong. In the long run with restored soil fertility, more harmonious diversified field biodiversity, and a more diversified farm business, sustainable systems should be more technically resilient and better at tolerating the variability in weather, pest and disease which pervade farming and they may be potentially more financially resilient too[143]. The comparative economics of the two systems will change if the balance of the market changes so that sustainable products become the mainstream market. Whether and how much such premia are eroded is an empirical question. It notably depends on the relative shifts in demand and supply.

Second, consider food price effects. It is generally expected that sustainable production will mean higher food prices for consumers and/or substantial help from the public purse. Most advocates of the system switch towards sustainable agriculture acknowledge this. They suggest that food prices are below their socially optimal level given the large external costs imposed on the environment. Raising prices is also a way to reduce over-consumption and to discourage waste. However, such a policy would be regressive because it would impinge most on households with the highest share of their expenditure on food. These are the households with younger people, larger families and lowest incomes. Again, this is acknowledged by those advocating this perspective who emphasise the need for a 'just transition' with essential adjustments to the social welfare system to compensate losers.

[139] This is the issue contested by van der Ploeg, J.D., et al. 2019. *The economic potential of agroecology: Empirical evidence from Europe*. J Rural Stud 71, 46–61. Simplifying their arguments they seem to suggest the reduction in the variable costs of fertilisers and PPPs more than offsets the lower yields. Why the bulk of conventional farmers do not seem to have noticed this is hard to explain. Clearly the issues are more complex.

[140] Using UK data, fertilisers plus sprays account generally for over 80% of the variable costs of cereals and oilseeds production, and lower proportions for other (higher value) crops, 39% for vining peas, 35% for sugar beet, 25% for maincrop potatoes and in the range of 2 to 7% for soft and top fruit. Source, John Nix Farm Management Pocketbook 49e, 2019.

[141] The premium of organic over conventional prices tends to be higher for crop products than animal products, and not all of the products from organic livestock can be sold in the premium market. The organic premia are variable. There are examples, such as organic milk in the UK after 2010 when organic production growth outran consumption growth and the price premium collapsed, leaving many producers in difficulty causing some to revert to conventional production.

[142] There is a large literature on the comparative economics of organic and conventional farming. Two examples are: Nemes, N. 2009 *Comparative analysis of organic and non-organic farming systems: critical assessment of farm profitability*, FAO Natural Resources Management and Environment Department, www.fao.org/3/a-ak355e.pdf and Bevan, T. 2016. *Review of organic farm business incomes in England and Wales from 2006-2015*, Soil Association. www.soilassociation.org/media/6860/review-of-farm-business-incomes-2006-2015.pdf

[143] Van der Ploeg *et al* (Full reference above) argue from a theoretical and empirical basis that agroecology can be both more profitable and increase rural employment. The empirical basis for this conclusion is slender.

Third, is the trade issue. If the EU were, unilaterally, to take measures to drive through the system change towards sustainable agriculture, including pushing up EU domestic food process, this would attract imports. Maybe clear labelling of food origin could deter some consumers from switching to cheaper imports, such labelling would get quite complex for processed convenience foods and the food service and hospitality sectors with multiple ingredients. In any case producer interests would be reluctant to trust labelling to deter import substitution. Farmers' organisations are highly sensitive to the level playing field argument that they should not be expected to compete on price with goods produced to lower and less costly environmental standards, for example using PPPs which are not allowed in the EU. They would demand border measures to restrain or prohibit produce not produced to EU standards. Herein lies significant trade policy negotiation and potentially disputes through the World Trade Organisation (WTO) system with potentially economy-wide impacts.

The political challenge is one of getting societal acceptance for a new food strategy based more heavily on sustainable agriculture and all it implies. Expressed bluntly, it requires getting public support for the proposition that the best/only way to safeguard EU citizens from the risks to health and environment from PPPs is to use public policy and funds to assist the development and maintenance of sustainable production and consumption of food, and further public funds to safeguard low income households from the consequentially more expensive foods, and to negotiate the appropriate trade regime to prevent this system being undermined by cheaper imports.

Before concluding this section on sustainable agriculture three further points are worth emphasising. First, the section has had to draw heavily on organic farming to illustrate the potential and challenges of sustainable farming systems. And whilst organic farming does embrace many of the agronomic practices mentioned under our definition of environmentally sustainable agriculture not all organic farming practices are ecological; copper compounds are permitted yet are known to have harmful environmental effects, and organic prescriptions offer little on water management. Equally, few specific agroecological practices are mandatory for organic farmers. For example, EU rules do not *require* organic farms to have a certain proportion of land devoted to biodiversity and non-crop habitat, or to practice contour cultivations, cover crops, and extensive grazing rates. This inevitably results in a wide variation of the sustainability of different organic farms. Second, the arguments of this chapter have been presented in a way which reflects the rather polarised public debate about food systems and specifically PPPs. Reality is rather more nuanced than: one system unsustainable, the other sustainable; one uses PPPs and mineral fertilisers the other doesn't use any[144]. Third, inevitably a study on crop protection focusses at farm level, yet the ecological health of the rural environment depends on actions at several scales. Of course, this starts with soil management and crop management, but it must also take account of field and water course boundaries, wider green infrastructure on farms (hedges, ditches, banks, ponds, copses, woodlands) and even wider landscape management to ensure both space and connectivity of nature.

Summarising, it would be a significant challenge for sustainable production systems to provide the bulk of EU food needs in the foreseeable future, say the next three decades[145]. It will take strong encouragement to make these systems economically viable, even if food consumption particularly of livestock products is considerably reduced. First, the scale of change required is large compared to where we are now, and the experience of organic adoption has been slow (even with quite generous

144 A study on almost a thousand non-organic farms in France with a varying degree of PPP use showed that a reduction in PPPs did not affect the productivity and profitability of the majority of the studied farms, indicating a large scope for reduction (Lechenet et al. 2017).

145 The period of three decades is offered as this is the period selected for climate policy targets and it indicates the judgement that the system changes envisaged are likely to require more than the five or seven years of most Member State and EU political cycles.

policy incentives). Second, there are concerns about the technical ability of sustainable agriculture to provide fruit & vegetable production at the desired output level, consistency and quality (including mycotoxin free) demanded by retailers and consumers. Third, any suggestion of eliminating ***all*** PPPs is judged currently infeasible, especially for some crops like vines and fruit. Organic production makes considerable use of PPPs, although these are mostly not synthetic PPPs. Fourth, strong change in the direction of sustainable agriculture will require high-level political commitment in the EU and Member States to make necessary accompanying social welfare and international trade provisions. The proposed European Green Deal is a very important step towards this commitment and exactly such political determination is also needed to meet SDGs and Climate commitments and to encourage EU trading partners to do the same.

3.3 Conclusions on the two perspectives

It has been concluded that the status quo is environmentally unsustainable. This implies that the current system must evolve in a new direction, and the only substantive indication of the direction of system change is towards one with stronger ecological functioning. However, the technical feasibility and economic sustainability of sustainable agricultural systems are far from established at present. This implies that an achievable operational strategy specifically for PPPs requires some transitional option which acknowledges that some forms of these products will be a continuing but declining component of food production for the foreseeable future, and this will include an expansion in use of low risk biological PPPs.

The suggestion is that even if sustainable agriculture does not provide the entire solution for all production in the next three decades, nonetheless it should define the ***ultimate aim*** of EU crop protection strategy. There is certainly a strong drive to want to find an agreed long-term goal, but first three key challenges have to be addressed. First, that sustainable agriculture is unlikely to find it any more possible to operate without ***any*** PPPs than organic farming which has its own permitted list of these products. This list is not static and will develop over time and may well embrace new biological control products, and perhaps also embrace new ways of breeding disease and pest resistance into plant varieties. Second, the challenges for the economic and thus political and societal choices regarding consumption, food prices, and trade discussed in section 3.2 have to be met. Third, a relatively recent question has arisen about the capability of less-intensive agricultural systems to provide sufficient food when the full adjustments in agriculture and land use to contribute to achieving new climate change goals are considered.

Climate change has risen rapidly in policy priorities. Recent analyses published internationally and in some MSs explore the adjustments required in agriculture and land use change to contribute to Europe's determination to achieve Net Zero Greenhouse Gas (GHG) emissions by 2050[146]. Although the issue of climate change and agriculture has been in play for many years it is only recently that analysis of the nature and scale of the adjustments in all the land-based sectors together have been quantified and put into the public domain. Two key points are that agriculture itself is inherently a net emitter of GHGs (Methane CH_4, Nitrous Oxide N_2O and Carbon Dioxide CO_2) for which zero emissions is probably unachievable[147], yet land use change offers the possibility of offsetting remaining agricultural emissions because

146 Two examples are the IPCC *2019 Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems*. Summary for Policymakers; and the UK Committee on Climate Change, (May 2019); Net Zero Technical report.

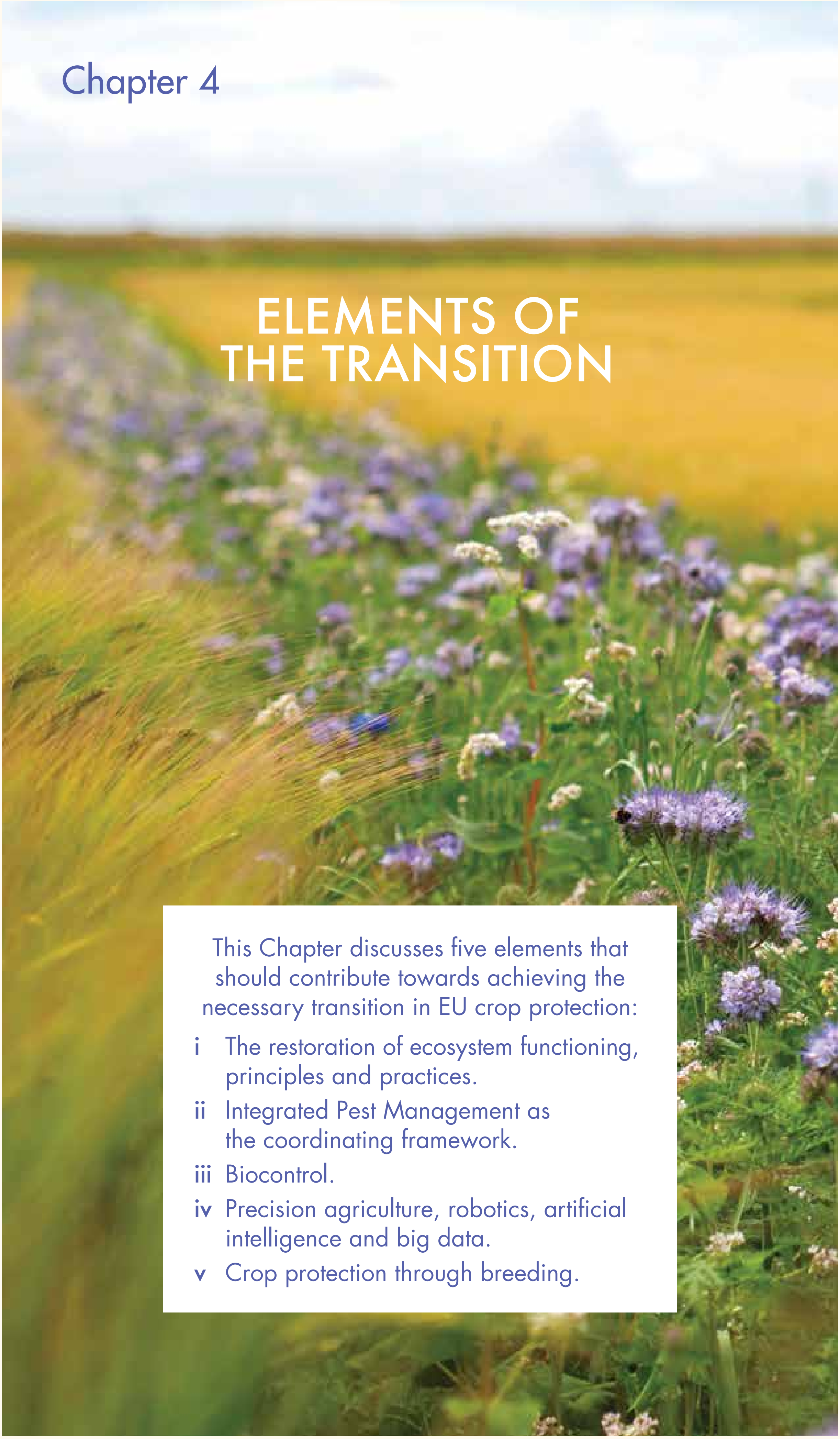
147 Certainly by 2050, even if not in the longer term.

certain land management actions can provide long range, if not permanent, carbon sinks. This means taking an over-view of the competing uses of land: for agriculture, forestry, bioenergy, peat restoration and settlements. Full analysis of what this means for EU agriculture and land use in each Member State is not available. Suffice to say that the required combination of changes will include a mix of the following four elements. (i) Systematic reduction of GHG emission per unit of agricultural output. (ii) Significant reallocation of agricultural land for carbon capture and storage and peat restoration. Any consequential fall in agricultural output must then be balanced by (iii) a reduction in food waste and consumption of livestock (and perhaps other) products, and (iv) an increase in productivity of crop and animal production on the remaining agricultural land. The precise balance of such changes will be different in the different MSs and regions of the EU. The scale of these adjustments may be quite large, and they will have important impacts on EU crop production. How these considerations impact on systems of EU crop production and crop protection has still to be thought through in detail and much greater work needs to be devoted to understanding the future competing demands on land before Europe fully commits the whole of EU food production to one particular path.

Having concluded that change is imperative, the status quo cannot survive in the long run, and a desirable direction of change is a transition towards sustainable agriculture then this suggests a new clearer goal for crop protection is needed. The proposed goal for EU follows.

"To re-establish ecosystem functions on agricultural land to provide nature-based solutions for pest, disease and weed threats, increase system resilience and to utilise all means to eliminate harms caused to health and environment by use of PPPs."

This should be achieved by encouraging a multi-track transitional development path which embraces the best that agricultural and ecological science can bring to help the wide variety of existing production systems to converge on achieving the stated goal. Several strands of this transitional strategy can be identified. Most are not new, some are already in use; they are not mutually exclusive, elements of each could be combined. The key point is that suitably deployed, they all offer ways to protect crops whilst substantially diminishing, and eventually eliminating, harmful side effects. They are brought together in the next chapter.



Chapter 4

ELEMENTS OF THE TRANSITION

This Chapter discusses five elements that should contribute towards achieving the necessary transition in EU crop protection:

i The restoration of ecosystem functioning, principles and practices.

ii Integrated Pest Management as the coordinating framework.

iii Biocontrol.

iv Precision agriculture, robotics, artificial intelligence and big data.

v Crop protection through breeding.

This chapter examines the contributions each of five developments could make towards achieving the new strategic goal suggested for crop protection stated above. The suggested development path lies between the status quo and 100% sustainable agriculture. The language of transition is used to signal the necessity of change from one state to another flagging to farmers and their suppliers that they have to change practices and move in the indicated direction. At the current state of knowledge no one can precisely define the end point of the transition. The most important criterion is that it restores ecosystem functions in agricultural soils, fields and landscapes to benefit from the greatest degree of natural crop protection and in the process minimises harm to the environment and human health.

For this to be a credible significant departure from the status quo certain pre-requisites will have to be satisfied. The first is to find a way of formally signalling the new objective. The second is to establish indicators of ecosystem functioning including baselines against which to demonstrate progress. These will be necessary at both regional/ national level and at farm level. Such indicators must be capable of being practically measured and acted upon at farm level. Third it is necessary to further review the adequacy of the approval criteria for PPPs with respect to biodiversity and soil health to ensure that the products which pose most risk to ecosystem functioning are identified. These policy issues will be discussed in the final chapter.

The five developments to restore ecosystem functions and to help reduce and eliminate harms from PPP use are:

i The restoration of ecosystem functioning, principles and practices.

ii IPM as the coordinating framework.

iii Biocontrol.

iv Precision agriculture, robotics, artificial intelligence and big data.

v Crop protection through breeding.

Firm principles of sustainable agriculture are not yet formally recognised in EU regulations or certification nor in statistics, so the first steps are to establish and agree these principles and the key practices which set farming systems down this road. Meanwhile, integrated pest management still provides a constructive overall framework for crop protection. It already exists. It already embraces the full range of crop protection methods from the major practices of sustainable agriculture to the use of natural biological and synthetic PPPs. The challenge is to make it work meaningfully. Developments (iii), (iv) and (v) offer ways of protecting crops which could help bring about the convergence of conventional and sustainable systems in agriculture and substantially diminish the unwanted side effects of PPPs. They could be targeted to help conventional farmers replace, reduce, and deploy remaining PPPs more accurately, or to remove the need for existing synthetic PPPs. Equally, some aspects of these three developments can assist sustainable systems deal with weed, pest and disease attack.

4.1 The restoration of ecosystem functioning, principles and practices

The restoration of the ecosystem functions in agricultural soils and amongst agricultural crops is thought to require *both* negative and positive actions, i.e. to make less use of some practices and more use of others. The negative actions are to significantly reduce or cease the use of certain inputs and practices which are thought to drown-out or eliminate critical aspects of agro-ecosystem function. This refers principally to the use of mineral fertilisers and synthetic PPPs. The positive actions are the steps required to encourage and maintain high biodiversity in the soil and the above-ground crop environment to enable and encourage maximum fertility, natural protection and thereby, resilience. These positive actions are listed in sections 2.1 and 3.2 above and will not be repeated here. It should also be said that sustainable, resilient, agricultural systems will require actions beyond the crop protection actions which are the focus of this study. Integrated crop management is the term which would include IPM and also pay attention to a range of wider considerations including: soil structures and improvers, irrigation, biostimulants, and reduced till. By following sustainable practices, it is possible to produce crops year-in year-out with a highly restricted range of PPPs - albeit with lower yields than found in conventional agriculture. Indeed, this is what one group of sustainable producers, organic farmers, have been doing, some for many decades.

One important question is to understand the extent to which farmers can move in *the direction* of sustainable agriculture without completely adopting all of the practices listed. Is it an all-or-nothing concept? The absolutes of zero PPPs and zero mineral soil improvers is not a necessity for at least two reasons. First, the certification rules for organic farming allow a range of PPPs termed basic and natural substances, as well as other products traditionally used in organic farming such as copper or sulphur. Second, the increasing development and use of biological control methods (explored in more detail below) may well be consistent with sustainable principles. The extent to which combinations of conventional and sustainable practices are possible and permitted is an unanswered question. This should partly be a scientific empirical matter. It first requires that workable definitions and practical metrics can be found to better understand soil and crop biodiversity, what is meant by ecosystem function and to find indicators of its performance.

This is not a trivial task. The composition of the soil biome, with its vast array of bacteria, fungi, mycorrhizae and microorganisms is scarcely understood. The functions and interactions between these organisms and with crop plants and how these relationships are impacted by crop management is even less understood. There is a better understanding of above ground ecology although much remains to be done to identify useful practicable metrics of well-functioning ecosystems. Progress must be made both at the scientific level and simultaneously at the practical level by farmers. This will require experimentation and experience. The task is to discover the mixes of longer rotations, changed cropping patterns and the other sustainable practices, combined with reduced, rather than eliminated PPP and mineral fertiliser use, and substitution of less risky biological products for more risky chemical-based PPPs which will restore important aspects of ecosystem function and eliminate harm.

During this process answers should be sought to such questions as: is it necessary and useful to define and certify grades or levels of sustainable farming, or will this impede progress? Will farmers wishing to define themselves as sustainable be permitted to use the tools of precision agriculture, robotics and big data? Will they have full access to the range of biocontrol products and systems? Will sustainable agriculture find it useful to discover pest-resistant crop varieties produced using the new breeding techniques? The logic of the suggested new goal for the EU crop protection strategy is that what matters is the restoration of ecosystem function and reduction of harm and therefore *any* farming system which contributes towards this should be acceptable. This suggests that whilst reliable measurement of ecosystem function and harm are being developed, it would be better to avoid trying to define rigidly certified classes of sustainable agriculture which take black or white positions on these questions. **Let a thousand systems bloom and make sure they are monitored and tested for their ecosystem function and potential for harm.**

A key element in this discussion is the resilience of ecosystems and species, i.e. their capacity to recover once synthetic PPPs and other damaging practices are reduced or eliminated. This will differ among species. In some cases, species recovery may happen by keeping areas free of synthetic PPPs. This was observed to be the case for invertebrate communities in streams and other water courses where recolonization processes were observed when upper stream reaches were left undisturbed, compensating for the negative effects of PPPs downstream[148]. But in other cases, more restrictive limitations may have to apply depending on the extent to which food resources and habitat have been disturbed and the recolonization potential of the species themselves[149].

4.2 IPM as the coordinating framework

The **Sustainable Use of Pesticides Directive (2009/128/EC)** already contains Integrated Pest Management (IPM) as its corner stone. Article 14(4) of the SUD states that MSs shall describe in their National Action Plans (NAPs) how they ensure that the eight general principles of IPM, are implemented by all professional users. Along with the promotion of organic farming, IPM was been seen as one of the tools for more sustainable crop protection[150]. The disappointing results to date indicate that it is time for a formal review as a precursor to strengthening this Directive. This should consider if the Directive should be recast as a regulation in order to formally express the new strategic goal and bring about a more effective setting of baselines and targets for its achievement.

The concept of IPM was initially proposed by entomologists in the late 1950s[151]. The SUD[152] defines IPM as the careful consideration of all available plant protection methods and subsequent integration of appropriate measures that discourage the development of populations of harmful organisms and keep the use of plant protection products and other forms of intervention to levels that are economically and ecologically justified and reduce or minimise risks to human health and the environment. IPM emphasises the growth of a healthy crop with the least possible disruption to agroecosystems and encourages natural pest control mechanisms. These are concepts that are not disputed by any of the involved stakeholders.

The problem is that at farm level IPM has many definitions and is open to wide interpretation, its practical expression will also differ between crop types and regions. Most farmers claim they are already applying IPM, they have some rotation of crops, and they perform some monitoring and forecasting of pests and disease. They claim PPPs are expensive to buy and apply so they seek to minimise their use. No doubt many farmers do this. However, there is strong suspicion that many others who have invested heavily in equipment, or contracted with others to provide the crop protection service, may have fallen into a routine of short termism in which more-or-less automatic spraying follows the emergence of certain 'risky' conditions seen at key crop growth stages. Contractors may be keen to ensure their contracted area is treated and under pressure to 'get the job done' without too fine an analysis of whether the spray is the best approach or needed at all. There are also grounds to suspect a bias towards adoption of a safety-first approach by farm advisers. They may find it easier to get their clients to spend up-front to avoid an infestation than to have to provide an *ex-post* explanation after crop failure why it was felt the spray was not absolutely necessary.

148 Liess, M. and von der Ohe, P.C., 2005. Full reference in p.29

149 Kattwinkel, M. et al., 2015. *Recovery of aquatic and terrestrial populations in the context of European pesticide risk assessment.* Environ Rev 23, 382–394.

150 https://ec.europa.eu/food/plant/pesticides/sustainable_use_pesticides/ipm_en

151 Deguine, J.-P. et al. (Eds) 2017. *Agroecological Crop Protection.* Springer Netherlands, Dordrecht.

152 Article 3. Definitions.

A European Commission report on the NAPs in October 2017, indicated that all the plans include some measures on the promotion of IPM, in particular to encourage availability of IPM guidelines, and the provision of training or demonstration farms. It is generally felt that safety standards for the testing, for operator safety and environmental protection have greatly improved, and these are implemented in many Member States. The certification for sprayer operators and regular training to maintain operators' spraying licenses have been tightened. Drift reduction measures, and buffer zones have been mandated. Notwithstanding these improvements, the action plans do not specify how the application of IPM by farmers can be measured, do not set targets or indicate how implementation will be ensured. To date there have been no sanctions for Member States or farmers for the non-implementation of the Directive. These conclusions were strongly endorsed by the report of the European Court of Auditors in February 2020[153].

The challenge is to find practical ways to measure biodiversity and ecosystem functioning at farm level, to establish baselines for farms and accompany this with help to farmers to identify the actions under IPM which have the potential to improve these indicators. Such farm-level measuring, monitoring and action will inevitably require resources. The EU's Common Agricultural Policy is the obvious policy framework to provide such resources. This is taken up in Chapter 5.

4.3 Biocontrol

Biocontrol, biological control or bioprotection refers to the control of pests, diseases and weeds based on naturally occurring compounds or organisms. Although some elements of biocontrol have a very long history in agriculture, it is a field which has grown rapidly in the last two decades. The SUD, through its focus on IPM, encourages non-chemical crop protection methods[154] including biological crop protection, to be preferred to chemical treatment.

The terminology of biocontrol is still developing, products offering such control are often termed biopesticides, biological control agents, bioprotectants, or in common usage 'biologicals'. While the SUD regulation mentions biological control, the term is neither defined for biological control, nor biological control products, in EU regulation[155]. Some authorities subdivide biocontrol agents into the following four categories[156]: 1) Natural enemies, also called biological control agents (BCAs), Invertebrate biocontrol agents (IBCAs) or sometimes macrobials. 2) Microbials, which are based on micro-organisms, such as bacteria, fungi, viruses, protozoans. 3) Semiochemicals, such as pheromones. 4) Natural substances such as plant extracts, algae, animals, minerals. In the EU, the approval for use of microbials, semiochemicals and natural substances falls under the same process and regulation as for synthetic substances and products, that is Regulation (EC) 1107/2009. Registration for invertebrate biocontrol agents is currently done at Member State level, following national law.

There is much promising activity in this sphere. Introductions of new biologicals took off from the late 1970s. In 15 of the last 20 years the rate of introduction of new biological products has exceeded that of conventional products worldwide[157]. The appeal of biocontrol is that it is a nature-based approach which tries to work with the ecology of plants, pests, pathogens, natural enemies and antagonists. There is a

153 ECA 2020 (Full reference in p.33).

154 As defined in Article 3 of Regulation 1107/2009

155 See Articles 3 and 77 of Regulation 1107/2009

156 www.ibma-global.org/en/news/ibma-definition–bioprotection-as-the-global-term-for-all-biocontrol-technologies-

157 Phillips McDougall, "Evolution of the Crop Protection Industry since 1960," November 2018.

presumption that biocontrol methods will be inherently less risky for both human health and the environment as these products have originated and evolved in nature. There should be less concern with these products about persistence, bioaccumulation and residues as they are generally quickly broken down and recycled. They should pose less harm to operators. However, these properties do not automatically apply, so such claims must be subject to the same scrutiny as synthetics. Important questions are their relative cost and effectiveness as seen by farmers and the extent to which they can substitute for synthetic PPPs, or in some cases work together with conventional crop protections. It has to be acknowledged that from the farmers' perspective these products are often less certain in their efficacy, they require knowledge and experience to learn how to make most effective use of them. Some courage may also be required to persist with these products, an expensive batch of released macrobials could fly away! Also, once biocontrol insects are deployed the farmer cannot quickly revert to synthetic chemicals or he destroys his expensively acquired agents. How far these approaches can be developed for field crops has still to be discovered. The answers to these questions will only be discovered by experience.

A survey by the International Biocontrol Manufacturers Association (IBMA)[158] for the years 2013-2015 shows that the macrobial[159] sector is the largest of the biocontrol market, representing 40% of the European market, followed by microbial (24%), the natural and biochemical product (20%) and the semiochemical (16%) sectors. Further, the average growth rate of sales into the European biocontrol market for 2013-2015 was found to be 20% per annum, compared to 16.7% per annum for the global biological control market. The main use of biologicals is to control fungi and insects. Most of this is in horticulture particularly for crops in glass houses and polytunnels, although it is now also successfully being used to protect some outdoor crops. Biological weed control, however, is a discipline in which research has been in a decline since the 1980s and where only very recently there has been little more investment[160]. Most biological weed control products are on the market in countries outside the EU, although there is no widely commercial biological herbicide[161]. The EU pesticide database contains a small number of biological weed control products based on acids (acetic acid, lauric acid, oleic acid).

Despite the recent high growth rate of the biocontrol market currently less than 5% of plant protection products sold are biocontrol agents worldwide[162]. With the Sustainable Use of Pesticides Directive in place and IPM mandatory for Member States, what is impeding a major uptake of biocontrol? One aspect is that biopesticides generally have a narrower spectrum of application of crop/pest combinations. An International Organisation for Biological Control (IOBC) initiative identified[163] the main limitations to biocontrol uptake worldwide as[164]: risk averse and unwieldy regulatory processes; increasingly bureaucratic barriers to access biocontrol agents; insufficient engagement and communication with the public, stakeholders, growers and politicians of the considerable economic benefits of biocontrol; and fragmentation of biocontrol sub-disciplines.

Given this unsatisfactory situation, the biocontrol industry strongly argues that Regulation (EU) 1107/2009, which was designed for synthetic active substances and

158 International Biocontrol Manufacturers Association (IBMA)

159 Also called Invertebrate Control Agents (ICAs)

160 Harding, D.P., Raizada, M.N., 2015. *Controlling weeds with fungi, bacteria and viruses: a review*. Front. Plant Sci. 6.

161 Baylis, A., 2019. *Biopesticides 2019: Biofungicides; Bioinsecticides; Bionematicides & Bioherbicides*. Agribusiness Intelligence.

162 Personal communication from Koppert.

163 Which brought together practitioners and research from widely diverse fields.

164 Barratt, B.I.P., Moran, V.C., Bigler, F., van Lenteren, J.C., 2018. *The status of biological control and recommendations for improving uptake for the future*. BioControl 63, 155–167.

products, is not appropriate for the approval and authorisation of biological plant protection products. This view is supported by Frederiks and Wesseler[165] (2018) and by the Ecorys REFIT study which state that the current data requirements and procedures of Regulation (EC) 1107/2009 are not considered to be appropriate and proportionate to biological solutions[166]. The data required to assess a microorganism will be very different from that required for a chemical substance. Also, the knowledge of the experts evaluating the data will be quite different. The European Commission is currently working to update the data requirements and assessment methodologies for microorganisms, as well as to find a '*common understanding of risk assessment approaches amongst applicants, competent authorities and EFSA*' through the work of an expert group on biopesticides[167]. A separate track for the approval of biological active substances and PPPs is also requested by industry spokespeople. Authorisation for biocontrol products in the EU takes twice as long as in the USA slowing the rate of development of these products[168]. It is argued that criteria for biological substances are often too stringent for products of natural origin.

Biological PPPs are often described as low risk PPPs, because many low risk substances are of biological origin, mainly microorganisms, however some synthetic chemicals may also be classified as low risk. At the same time, not all biological active substances are considered to be low risk, either because they were introduced before the low risk concept was developed or because they don't meet the criteria to be classified as such[169].

4.4 Precision agriculture, robotics, artificial intelligence and big data

Precision Agriculture (PA) has been defined as "*the application of modern information technologies to provide, process and analyse multisource data of high spatial and temporal resolution for decision making and operations in the management of crop production*" (National Research Council, 1997). Increasing the precision of agricultural practices *per se* is not a new thing. Early innovations made agricultural practices such as fertiliser and PPP application more precise and less wasteful by avoiding overlaps and gaps through the combination initially of tramlines, and later with soil mapping and GPS information and tracking. Current developments in precision agriculture aim to combine the potential of these existing tools with big data processing, sensors, robotics and Artificial Intelligence AI. The developers of these technologies expect them constitute a major step forward which can significantly reduce the risks associated with the application of synthetic PPPs by improving the targeting and timing of sprays thereby greatly reducing the volume of such products when they are used.

PA has mostly been used in arable farms. A successful example of PA is the use of Controlled Traffic Farming which confines field vehicles to a minimum area of traffic lanes which reduces energy use and minimises soil compaction. The benefits of the variable application of fertilisers and PPPs in relation to prior measurement of soil or

[165] Frederiks, C., Wesseler, J.H., 2019. A comparison of the EU and US regulatory frameworks for the active substance registration of microbial biological control agents: Comparison of regulatory frameworks for MBCA registration in the EU and USA. Pest Manag Sci 75, 87–103.

[166] Ecorys, 2018. Full reference in p.24.

[167] COMMISSION NOTICE concerning a list of potentially low risk active substances approved for use in plant protection (2018/C 265/02).

[168] Frederiks and Wesseler 2019. Full reference above.

[169] European Court of Auditors 2020. Full reference in p.33.

crop conditions are less clear[170]. PA can play various roles in crop protection, it can further increase the precision of identifying when and where to deploy PPPs, which to deploy and how, to maximise the protection of the crop whilst ensuring the least required quantity of the active substance is delivered to where it is needed most effectively. PA therefore optimises the use of PPPs. It is possible that the new developments in precision crop farming could bring forward a step-change substantially reducing the need for herbicides and perhaps fungicides which are the most heavily used PPPs in EU agriculture.

Developments are taking many forms. One approach is for small autonomous (maybe solar-powered) robots which continuously search out and identify weeds at an early stage, which can target spray them or physically remove them, reducing, or even eliminating, the need for herbicides. Meanwhile on the more conventional larger sprayers more sophisticated sprayer and sprayer nozzle control are becoming available to eliminate overlaps, reduce spray drift and tailor pesticide (and nutrient) application to soil conditions, pest infestation and yield potential. Spray application technology is a rapidly developing area, most with the purpose of increasing precision of application and minimising side effects on the environment. These developments include: automatic tank filling to avoid spillage, automatic dilution and sprayer cleaning, automatic boom height control to enable lower nozzle height and reduce spray drift, automatic GPS nozzle-control to eliminate overlaps, individual nozzle control for high precision dose rate. The ability to vary the dosage rate can be linked to soil organic matter content to control herbicide application; for plant growth regulators application rate can be based on the biomass present, for leaf desiccants based on the chlorophyll detected, and considerable work is underway for weed identification to allow selective spraying of contact herbicides. These technologies are still evolving and some aspects, such as the identification of weeds by the robot remain challenging[171], but in recent years a number of small tech companies are showing great advances in this area.

Currently PA is mostly being developed in the context of conventional farming systems, highly dependent on PPPs and mineral fertilizers. It focuses on improving the efficiency and reducing impacts of such products. Other advantages often mentioned for PA are reducing water use, reducing errors in the reading of pesticide labels[172] and offering reduction in GHG emissions by lower machinery use, and contribution to adapting agricultural management to changing climatic conditions.

However, PA is criticised for perpetuating a damaging system of food production, albeit with a reduced rate of damage. It is said to fall short of achieving healthy soil and crop ecosystems because it does not promote the adoption of more integrated farming systems[173]. Precision application of herbicides should reduce some unintended effects of these products on non-target organisms, but if it even more effectively eliminates all weeds in arable crops, this will still remove feed sources and shelter of numerous species with effects through the food chains of which they are a part. In this regard, the advantages of PA for organic farmers are currently related to digitisation, data sharing and the contribution of robotics to mechanical weed control using electric current and laser technologies. Although PA is often seen as opposed to sustainable agriculture, big data, GPS and satellite use could help decision making

170 According to a 2014 document commissioned by the EP www.europarl.europa.eu/RegData/etudes/note/join/2014/529049/IPOL-AGRI_NT%282014%29529049_EN.pdf

171 Slaughter, D.C., Giles, D.K., Downey, D., 2008. *Autonomous robotic weed control systems: A review.* Computers and Electronics in Agriculture-London 61, 63–78.

172 Electronic systems can read bar-code-label, prepare mixtures and reduce risk of human errors on misinterpretation.

173 https://ec.europa.eu/epsc/publications/strategic-notes/sustainability-now_en

in this sector. Tailored precision and/or autonomous machinery could be developed with the help of users to meet the specific needs of sustainable farming[174].

One of the challenges for the implementation of PA can be the investment costs that this often represents for farmers. Larger farms may be better placed to adopt precision agriculture than smaller ones if it demands large investment, but some of the technologies are operable at small scale (e.g. drone use in Japanese agriculture). Also, the development of machinery rings and shared contractors are ways to make such technologies more widely accessible. Small farms that cannot hire workers could benefit from such technologies. Some developments of PA rely on mobile connectivity and the availability of a broadband network, which is still not a reality in many rural areas around the EU. Inter-operability between machinery is also a technical issue to be resolved.

Big data is another rapidly developing field. By combining data on: (i) the *physical characteristics* of land, soil, hydrology and topography (highly detailed field-boundaries, land areas, soil type and other indicators such as pH, hedgerows and woodland), (ii) the *vegetation cover and development* in live time as it develops through the season and possibly the presence of pest organisms, (iii) *previous crop management* and yields, and (iv) current *meteorological* data, there is a prospect of radically changing crop management including crop protection. With the appropriate scientific steers and encouragement, indicators of ecological health could and should be embraced in such approaches. A number of systematic attempts are being made both to compile agricultural big data. The expectation is that data analysis and in the future artificial intelligence will be used to a much greater extent to help guide crop management which would include pest forecasting and control. It is not anticipated that most individual farmers will access such approaches unless they have a personal inclination for this kind of technology. Rather that this approach lends itself to a different business model in which companies see the opportunity to devise ways of capturing the value in such data to offer a service to farmers of identifying their least cost, most effective, and least environmentally damaging way of protecting their crops. At the heart of these approaches there are questions about data ownership which are currently being discussed and for which some initiatives have been put in place[175].

The EU is financing the development of PA through its research frameworks such as Horizon 2020 and with encouragement of programmes in the Rural Development Programme (RDP) within the CAP. Its implementation is financed through local, regional and national development programs within the MSs[176]. The importance of precision agriculture within EU agriculture is set to increase over the coming decade. Some countries have explicitly mentioned it as part of their future strategy to reduce the environmental impacts of the sector. An example is the Netherlands in their 2030 vision on crop protection[177].

174 Bellon Maurel, V., Huyghe, C., 2017. *Putting agricultural equipment and digital technologies at the cutting edge of agroecology.* OCL 24, D307.

175 A group of agri-food chain stakeholders worked together to develop a Code of Conduct on agricultural data sharing by contractual agreement https://copa-cogeca.eu/img/user/files/EU%20CODE/EU_Code_2018_web_version.pdf

176 www.schuttelaar-partners.com/news/2017/smart-farming-is-key-for-the-future-of-agriculture

177 The new 2030 Plant Protection Vision focuses on innovative plant breeding and precision or smart farming for crop protection.

4.5 Crop protection through breeding

Since humans started cultivating land more than 10,000 years ago, farmers have selected plants and animals with the most suitable characteristics for agricultural use. For plants, these suitable characteristics or traits, included crop varieties with highest yields, shortened growing seasons, increased resistance to diseases and pests, larger seeds and fruits, better nutritional content, better post-harvest conservation[178], and better adaptation to diverse ecological conditions under which crops were grown[179]. In conventional or traditional plant breeding, new varieties are developed either by selecting plants with desirable characteristics or by combining qualities from two closely related plants through selective cross-breeding . The key to this process is variability amongst plants. *Selective cross-breeding*[180] is based on sexual reproduction. Pollen from one parent plant is applied to the pistil of a flower of the other parent plant. By crossing two specific plants, a specific trait from one plant is combined with a trait of the other plant in the offspring.[181] This type of breeding is slow, it takes on average 12-15 years to produce a new crop variety, and for some traits and some crops, this period can be as much as 40 years[182,183].

Since the 1940s, plant breeders have also been able to increase the range of variation available by exposing seeds to chemicals or radiation to introduce new variants[184]. This type of breeding is called induced mutagenesis or random mutagenesis. This alters an organism's genome at multiple positions in a non-targeted way. To date, more than 3,200 different commercially available crop varieties have been developed worldwide using induced mutagenesis[185]. At a regulatory level, no distinction is made between crops that have acquired traits through this type of mutation breeding and classic cross-breeding products[186].

With the invention of *recombinant DNA technology* in the second half of the twentieth century, it became possible to cut and splice individual DNA molecules together to make entirely new ones[187]. The resulting Genetically Modified Organisms (GMOs) can be defined as organisms (i.e. plants, animals or microorganisms) in which the genetic material (DNA) has been altered in a way that does not occur naturally by mating and/or natural recombination. The technology is often called "modern biotechnology" or "gene technology", sometimes also "recombinant DNA technology" or "genetic engineering"[188]. The development of *transgenesis*, in which genes from other species are inserted into random locations in the subject plant's genome allows certain traits to be introduced into crops rapidly[189]. A number of genetically modified, or transgenic, crops carrying

178 Nowadays referred to as 'shelf-life'.

179 Wieczorek, A.M., Wright, M.G., 2012. *History of Agricultural Biotechnology: How Crop Development has Evolved*. Nature Education Knowledge 3, 9.

180 Ibid.

181 VIB, 2016. From Plant to Crop: The Past, Present and Future of Plant Breeding, http://www.vib.be/en/about-vib/Documents/vib_facts_series_fromplanttocrop_ENG.pdf.

182 Ibid.

183 Wieczorek and Wright 2012. Full reference above.

184 Border, P. and Walker, J., 2017. New Plant Breeding Techniques, POSTnotes POST-PN-0548 (UK Parliamentary Office of Science & Technology), https://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PN-0548.

185 HLG-SAM 2017. New Techniques in Agricultural Biotechnology. Explanatory Note 02. European Commission, Luxembourg.

186 VIB, 2016. Full reference above.

187 HLG-SAM 2017. Full reference above.

188 An accessible but technical explanation is Heimann, J. M. 2018. *Using Nature's Shuttle: the making of the first genetically modified plants and the people who did it.* Wageningen Academic Publishers.

189 Border and Walker, 217. Full reference above.

novel traits have been developed and released for commercial agriculture production[190]. These include[191], inter alia, pest resistant cotton, maize and rapeseed (mainly Bacillus thuringiensis or Bt[192]), herbicide (glyphosate) resistant soybean and cotton and viral disease resistant potatoes, papaya and squash. Eighteen[193] of the 27 EU Member States have either restricted or banned GMO cultivation in all or part of their territory[194]. Genetically modified crops have been cultivated in Europe since 1998, on approximately 150,000 hectares, mainly in Spain, but also in Portugal, Czech Republic, Romania and Slovakia[195,196]. Currently, 71 genetically modified crops[197] are approved in the EU, however only one genetically modified crop is approved for cultivation, maize MON810 which has a gene inserted to confer resistance to lepidopteran pests. The other 70 are approved for import include fourteen genetically modified cotton crops, thirty maize varieties, five oilseed rape crops, twenty soybean varieties and one sugar beet.

Following the development of traditional plant breeding and then GM technology, even newer methods are now under development, collectively known as New Breeding Techniques (NBTs), New Genomic Techniques (NGT) or some prefer Plant Breeding Innovations (PBIs). These are techniques that insert or remove whole genes, make small changes to the DNA, or change the activity of genes without modifying their sequence[198]. There are many such techniques[199] and the one regarded as the breakthrough technique is called CRISPR/Cas9[200,201,202]. In crop protection NBTs could be used to generate crop varieties resistant to pests and disease. Other potential agricultural applications include generating resilience to harsh weather conditions and enhancing nutrients in foods[203]. Few of the new breeding techniques have yet progressed through to commercial application[204]. The development of a gene edited

190 FAO 2012. *Genetically Modified Crops*, Part 4. www.Fao.Org/Docrep/015/I2490e/I2490e04d.Pdf.

191 Ibid.

192 A natural occurring soil-borne bacterium that has been used since the 1950s for insect control. Bt makes toxins that target insect larvae when eaten. In their gut, the toxins are activated. The activated toxin breaks down their gut, and the insects die of infection and starvation (Source).

193 Austria, Bulgaria, Croatia, Cyprus, Denmark, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Slovenia, the region of Wallonia, the French-speaking region of Belgium.

194 https://ec.europa.eu/food/plant/gmo/authorisation/cultivation/geographical_scope_en

195 www.europarl.europa.eu/news/en/headlines/society/20151013STO97392/eight-things-you-should-know-about-gmos

196 www.europabio.org/agricultural-biotech/faq/gmos-and-the-european-union/which-gmos-can-be-cultivated-eu

197 The EU Register of authorised GMOs, https://webgate.ec.europa.eu/dyna/gm_register/index_en.cfm

198 Border and Walker, 217. Full reference p.58.

199 Such as: Zinc Finger Nuclease technologies (ZFN-1, ZFN-2, ZFN-3), Transcription Activator-Like Effector Nucleases (TALEN), Oligonucleotide Directed Mutagenesis (ODM), cisgenesis and intragenesis RNA-dependent DNA methylation (RdDM), grafting on GM rootstocks, reverse breeding, agro-infiltration, and more recently RNAi techniques.

200 CRISPR stands for Clustered Regularly Interspaced Short Palindromic Repeats. Cas9 stands for CRISPR-associated Protein 9. CRISPR gene editing is a genetic engineering technique in molecular biology by which the genomes of living organisms may be modified. It is based on a simplified version of the bacterial CRISPR-Cas9 antiviral defense system. By delivering the Cas9 nuclease complexed with a synthetic guide RNA (gRNA) into a cell, the cell's genome can be cut at a desired location, allowing existing genes to be removed and/or new ones added *in vivo*.

201 Ali Razzaq et al. 2019. *Modern Trends in Plant Genome Editing: An Inclusive Review of the CRISPR/Cas9 Toolbox*, Int J Mol Sci 20(16): E4045.

202 Kok, E. et al. 2019. *Food and Environmental Safety Assessment of New Plant Varieties after the European Court Decision: Process-Triggered or Product-Based?*, Trends Food Sci Tech 88:24-32.

203 European Commission 2018 Statement by the Group of Chief Scientific Advisors, *A scientific perspective on the regulatory status of products derived from gene editing and the implications for the GMO directive*, 13 November 2018.

204 It seems that the first organism genetically modified with the CRISPR-Cas9 protein system to pass US regulation was achieved in 2015 by Yinong Yang who successfully deactivated 16 specific genes in the white button mushroom to make them non-browning.

plant with a desired trait will take approximately 4 to 6 years, compared to the creation of a genetically modified plant which requires 8-12 years[205]. One of the features of gene editing is that the plants are not distinguishable from plants developed from conventional plant breeding techniques, while for GM crops, tests can clearly distinguish them from non-GM varieties. This lack of distinction raises questions about ensuring compliance with regulations[206].

Another genomic development exploits understanding of RNA[207]. RNA interference (RNAi) is a process which stops, or silences, the production of vital proteins needed by the target insect in order to survive[208]. It was discovered in the 1990s and amongst many other applications it is under investigation for applications in crop pest control. There are two ways to exploit this pest control process. One is through topical application of the RNA trigger to plants, i.e. spraying, and the other is a transgenic approach to express the trigger within plants. Crops that has been modified in this way have already been registered in various countries and include among others non-browning apples, tomatoes that stay firm longer, or virus-resistant papaya, squash, plums, potato and beans. The exogenous applications are still in research or development, and there are still questions to be addressed about its efficacy, its degradation and its potential effects on non-target organisms when spraying in field conditions. Work is understood to be underway on topically applied RNA-based control of Colorado potato beetle, Varroa mite, Flea beetle, corn-root worm and soy stink bug. Potential benefits of the exogenous application are a high degree of target selectivity, and therefore increased safety for non-target beneficial insects, and a rapid degradation of RNA molecules in the soil. There are important questions about how to classify and regulate such technology. Is it biocontrol or a new genomic technique, or both? What is the most appropriate regulatory assessment for such technology? Currently, crops expressing RNA are regulated under the GM procedures and topical applications will be assessed by the authorities responsible for pesticides. As for any new approach the most appropriate risk assessment needs to be established and OECD has started to work on guidelines for the assessment of externally applied RNA-based pesticides.

The use of techniques of genetic modification in agriculture have attracted virulent opposition from environmental organisations and some MSs have decided to restrict or ban the cultivation of genetically modified organisms (GMOs) in their territory. As yet, there are no gene edited crops ready for commercialisation in the EU, but the issue of how they will be regulated is already open. Following a request from the French Conseil d'État[209] the European Court of Justice decided in July 2018[210] that organisms obtained by the new techniques of directed mutagenesis[211] are GMOs,

205 Ali Razzaq et al., 2019. p.46

206 The European Council has asked the European Commission for a report.

207 RNA stands for ribonucleic acid. It is a polymeric molecule essential in various biological roles in coding, decoding, regulation and expression of genes. A ribonucleic acid is a nucleic acid present in all living cells. Its principal role is to act as a messenger carrying instructions from DNA for controlling the synthesis of proteins.

208 www.sciencedaily.com/releases/2019/05/190502100849.htm

209 Who were prompted by an action brought by the French agricultural union Confederation Paysanne and eight other organisations.

210 https://curia.europa.eu/jcms/upload/docs/application/pdf/2018-07/cp180111en.pdf

211 Mutagenesis is a process by which the genetic information of an organism is changed resulting in (a) mutation(s). Random mutagenesis techniques, also called conventional or traditional mutagenesis techniques, are based on using irradiation or chemical treatment of organisms or cells to generate random mutations. Directed mutagenesis techniques, including genome editing, allow for making site-specific mutations in a targeted manner. Synonyms of directed mutagenesis are site-directed mutagenesis, precision mutagenesis and targeted mutagenesis (https://ec.europa.eu/info/sites/info/files/2018_11_gcsa_statement_gene_editing_2.pdf)

within the meaning of the Directive 2001/18/EC[212] on the release of genetically modified organisms into the environment, and that they are therefore subject to the obligations laid down by the GMO Directive. This means that in the EU, products based on gene editing techniques will be regulated under the GMO legislation. Some sectors of society including environmental and organic farming organisations welcomed this ruling, but others including EU Commissioners, scientists and industry claim that the judgement will harm future innovation in the sector[213]. Prompted by some MEPs, the European Council has asked the European Commission to produce a study on the status of new genomic techniques with options to update current GMO regulation. This comes after the group of chief scientific advisors to the European Commission in 2018 published a statement recommending "*revising the existing GMO Directive to reflect current knowledge and scientific evidence in particular on gene editing and established techniques of genetic modification*"[214]. These chief scientific advisers explained that new scientific knowledge and recent technical developments have made the GMO Directive no longer fit for purpose. Some scientists advise that it is a mistake to focus on the production technique, regulation should instead focus on the resulting products and then how they are farmed.

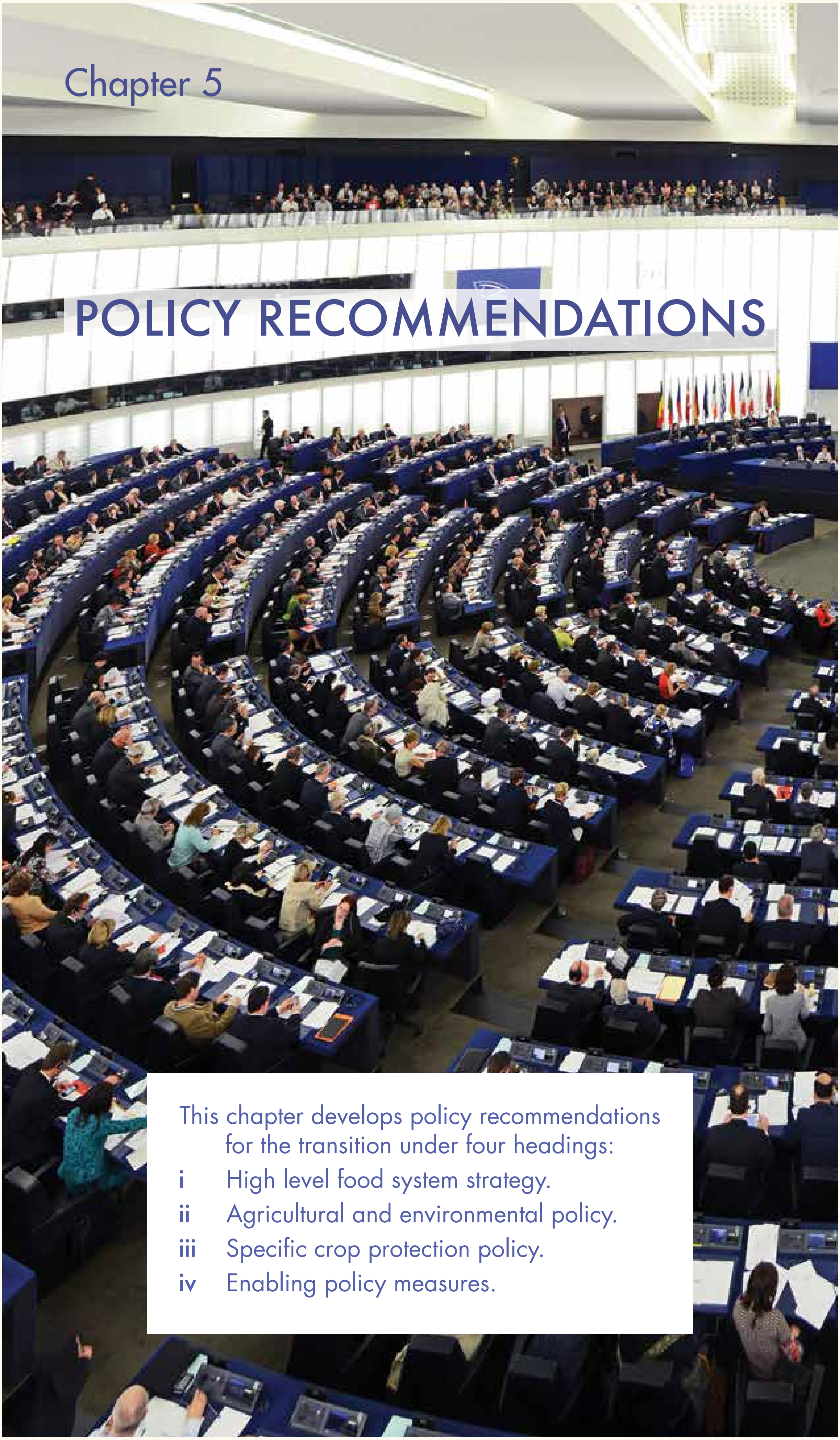
Regardless of the techniques used, crop breeding remains a central element of all systems of crop protection. Farmers whether they are conventional or any one of the numerous variants of sustainable farming, will always start by selecting crop varieties best suited to their soils and natural conditions including exposure to pests and disease. Breeding robust and resilient crop varieties will become even more crucial in the future to address the challenges arising from the impact of climate change on the distribution of pests and diseases[215]. Indeed, these represent just one aspect of how innovation in plant (and animal) breeding will be important in mitigating and adapting to climate change in the food system. Climate considerations introduce new goals for selective breeding: for drought and heat resistance, better carbon sequestration, reduced methane production, and of course the long-sought goal of incorporating nitrogen fixation into non-legume crops. Whether these suitable crop traits can be acquired in the EU through traditional or new breeding procedures will depend on critical societal choices which lie ahead. These innovations in molecular genetics will be transformative in medicine and will certainly be applied to agriculture in other parts of the world. The EU is currently reconsidering its stance on applications of genomics.

212 Directive 2001/18/EC of the European Parliament and of the Council of 12 March 2001 on the Deliberate Release into the Environment of Genetically Modified Organisms and Repealing Council Directive 90/220/EEC - Commission Declaration, OJ L 106, 17.4.2001, p. 1–39.

213 Euractiv. 5 December. www.euractiv.com/section/agriculture-food/news/eu-study-to-clarify-gene-editing-court-ruling-further-muddies-waters/

214 EC, 2018. Full reference in p.59.

215 Indeed there are important other ways in which breeding innovations will be important in mitigating and adapting to climate change.



Chapter 5

POLICY RECOMMENDATIONS

This chapter develops policy recommendations for the transition under four headings:

i High level food system strategy.

ii Agricultural and environmental policy.

iii Specific crop protection policy.

iv Enabling policy measures.

5.1 Drawing together the threads of the argument

The scientific approach to crop protection of the post war period set out to discover and understand the biology of disease-causing organism and pests, their life cycle, hosts, methods of entering or infesting and interfering with the physiology and growth of the crops and then working out strategies to defend the crop plant. The development in crop protection occurred alongside the growing understanding of plant nutrition, and plant breeding for high yield and resistance to disease and difficult growing conditions. These developments were fostered in public research institutes and universities as well as in the private sector. Their fruits were taken up and developed into commercial products and services by agri-business and then rapidly adopted by farmers who could see the benefits. For many farmers', the developments in crop nutrition, protection and mechanisation improved yields, reliability, consistency and quality of crops[216] and reduced the effort and uncertainties of production. Farm structures radically changed as these techniques of what is called conventional agriculture were adopted. These production systems were taken up world-wide under very different economic and policy regimes.

The twin goals of finding ways to enhance the productivity of crop plants and increasing total production seemed self-evidently necessary and a good thing at the time, and undoubtedly addressed the deep food security risks in Europe following World War II. However, it was subsequently discovered that these advances all came with a large environmental and societal cost. There is little to be gained in recriminating over whether the downsides of this multi-faceted approach to increasing yield and production, which have been flagged with increasing volume and evidence for many decades now, could and should have been recognised and more meaningfully acted upon earlier. It has required substantial losses in biodiversity and a global climate emergency to finally create the conditions in which the need to address the sustainability of our food and agriculture system is now frontally and frequently debated.

The proposition that current intensive production systems which are heavily reliant on mineral fertiliser and PPPs to produce high levels of output intensity per hectare are not sustainable is still contested by many farmer organisations and their upstream suppliers. Likewise, there are many amongst the science community who argue that further, albeit sustainable, intensification is still the correct strategy. All these groups acknowledge that environmental performance of agricultural systems must improve, but some argue that a way of achieving this is to further increase the productivity of the best agricultural land to release other, poorer quality, land for biodiversity, carbon sequestration and urbanisation. These interest groups are heavily invested in the current production systems intellectually, emotionally and of course financially. This shows in substantial investments right through the chain from education, research and development and of course in the supply industries and in the infrastructure of farming itself. A just transition process will therefore require time and assistance to help these groups adjust.

Although the subject of this report might on the face of it seem to concern just one specific technical aspect of EU agriculture, in fact **the predominant system of crop protection adopted is an integral part of the whole ethos of current production**. It has become a totemic issue in the debate about the correct farming system for the challenges faced this century. But, important as crop protection is, it makes no sense

[216] It is acknowledged that there are at least two aspects of quality of concern. The emphasis in the food chain has been on outward measurable qualities such as consistency, uniformity, size, colour and contaminant-free and blemish-free product. Many argue that the process of successfully delivering these has sacrificed nutritional quality and taste.

to focus narrowly on the specific list of chemicals permitted as active substances and PPPs. Regaining system resilience by restoring more natural ecosystem functioning requires us to confront a much wider change in farming systems. These in turn, as was argued in Chapter 3, will require wider changes in the food system, including consumer prices, and behaviour, social welfare and trade policy. Therefore, to bring about such system change will require a broad set of policy changes. To move in the directions argued in chapters 3 and 4 the first requirement is that the case for the system change suggested is accepted at the top political levels in the EU Member States and the EU institutions with full participation of stakeholders. Only then will it be possible to bring about the necessary policy reforms. This is work in progress, the December 2019 announcement of the European Green Deal was a very important first step but this must now be developed into concrete policy actions agreed by the European Council and Parliament. Until it is achieved it is not possible to spell out detailed policy changes beyond the broad categories of actions which will be required.

What are the actions and policy reforms needed? Because the new strategy requires a system change, not simply adjustments within the agricultural sector, these will be required at four levels. First, the high-level case for the suggested changes in the food system and its feasibility have to be robustly demonstrated showing how food consumption and trade will have to adjust as well as agricultural production. The broad policy approaches for this have to be considered. Second, two critical sets of policy instruments to induce changes in agricultural production systems will be the EU's Common Agricultural Policy and its suite of environmental policies. Third are the changes in specific arrangements for crop protection, the licencing of PPPs and the Sustainable Use of Pesticides Directive. Fourth is a set of enabling and consequential policy measures to assist the transition and monitor its progress especially regarding crop protection. These are discussed in turn below.

More specifically on crop protection this report advocates a strengthening of the goal of EU crop protection ***to re-establish ecosystem functions on agricultural land to provide nature-based solutions for pest, disease and weed threats, increase system resilience and to utilise all means to eliminate harms caused to health and environment by use of PPPs***. Five actions to lead towards this goal were discussed in Chapter 4. The policies which can encourage these actions are considered in the following.

5.2 Policy recommendations

5.2.1 High level food system strategy

The debate on crop protection is concurrent with the recently invigorated debate on climate change towards Net Zero emissions by 2050, widely supported by virtually all Member States, and in the new Green Deal proposed by the European Commission. To date, these debates have been running along parallel lines rather than in a single integrated strategy. It remains to be seen if the proposed new Farm to Fork strategy which is a component of the European Green Deal will correct this. There can only be one system change, and so this must safeguard society's broad array of objectives for its food system embracing consumption as well as production. For food consumption, citizen well-being requires high nutritional quality of food and healthy dietary patterns of citizens. On the production side, the objectives concern security of food supplies, based on protecting the long-run capacity to produce from viable farming systems working with fertile, resilient soils and functioning ecosystems and in conditions of climate stability. The biggest long-run threats to this food system currently come from over-consumption of calories and protein and associated ill heath on one side, and depleted soils and biodiversity and from the threat of climate change on the other. Studies investigating combinations of measures to tackle these challenges have been emerging, but much more research is required to understand the combinations of consumption and production changes and how to bring these about. The output of such research will not be a single blueprint to optimise farming systems and land use to achieve these multiple objectives but a better understanding of the broadly feasible production sets and trade-offs. In any case Europe will always have a wide mix of farming systems with different combinations of crops and livestock, according to the differing soils and climatic zones, and based on the farming structures and production systems which have evolved under quite different historic, social and economic circumstances.

Analysis is required to discover the balances along five broad dimensions: (i) between EU domestic consumption and production and international trade; (ii) the allocation of land between agriculture, settlement[217], habitat restoration, bioenergy, forestry and other means of increasing carbon sinks; (iii) between crops and animals; (iv) between red meat (and thus grasslands) and white meat (currently heavily dependent on imported feeds), and (v) between reducing intensity of production for some systems and increasing intensity in others. An example of reducing intensity is to rebuild soil fertility, biodiversity and ecosystem function by moving towards sustainable farming. This might suit some crop systems and regions, but not others. Increasing intensity might be the way to ensure maximum resource efficiency for example through precision crop production to reduce emissions per unit of production in other systems, or by containing production for example of specialist salad and high-value crops in glasshouse or vertical farming units.

Much more systematic analysis of these possibilities and trade-offs is required. This has to be conducted at both EU and Member State level as the balances struck are likely to be different across the MS and regions of Europe. Until there is a good understanding of the feasible mixes along the five dimensions listed above it will not be practical to design the detailed policy inducements required to bring about Europe-wide system change. To illustrate, the land use changes from agriculture towards habitat, forestry or peat restoration will be very different across the Member States as some already have a very high proportion of their land under forestry, and some have a high proportion of peat-rich soils whilst others have very little. The system change envisaged towards sustainable farming is so profound that there is much more to consider than just land allocation and farming practices. If a significant portion of EU agriculture is to be farmed more extensively then the economic implications at farm and market level and the implications for international trade have to be modelled and worked through. **A central question will be, who bears the economic burden of adjustment?** Is the less environmentally damaging, and perhaps higher nutritional quality food[218] to be paid for by consumers in food prices or helped by the taxpayer through agricultural policy? Higher consumer prices are consistent with higher standards,

217 This refers to the land used for housing, commerce, manufacturing and all the associated infrastructure for health, education, security, transport and communications, sometimes referred to as developed, or sealed land.

218 The nutritional quality of food is another contested issue. It is frequently claimed that there has been a decline in content of micronutrients such as vitamins and minerals of fruit and vegetables over a long period and the cause is thought to be the depletion of soil fertility: an example is, www.scientificamerican.com/article/soil-depletion-and-nutrition-loss/. However other studies refute this claim, www.sciencedirect.com/science/article/pii/S0889157516302113. At a recent meeting organised in the European Parliament by its office for STOA Bernhard Watzl, from the Max Rubner-Institut in Germany said that "There is a lack of evidence of organic crops having more significant nutritional value than conventional ones." Axel Mie from the Swedish University of Agricultural Sciences, and Johannes Kahl, from The Netherlands Food Quality and Health Association, pointed out that people who buy organic food tend to consume more fruit, vegetables, wholegrains or nuts than non-organic consumers, which benefits their health. The role of the food industry in formulating processed and convenience foods is a further complicating factor in such assessments. www.europarl.europa.eu/news/en/headlines/society/20151116STO02882/organic-food-healthier-than-conventional-food

internalising externalities and encouraging less profligate consumption but, in turn, may require border protection. This inevitably introduces trade policy conflict if it infringes accepted WTO rules. Furthermore, these considerations raise distributional issues which may require changes in social welfare. These are tricky matters to resolve as the EU single market demands a common approach to standards, agricultural prices and trade, but welfare policy is a Member State competence.

5.2.2 Agricultural and environmental policy

The Common Agricultural Policy (CAP) together with the EU's Common External Tariff (CET) are the principal vehicles through which EU agriculture is steered. They will have to provide the framework of policy instruments for the system change proposed. Through the first half-century of development of the CAP it has shown remarkable capacity to transform its principal instruments of support from systematic manipulation of commodity markets towards direct payments to farmers with an accompanying programme of environmental and social measures. This has been achieved within the original 1957 treaty-bound objectives. If the political will exists, the current five objectives of Article 39 of the Treaty of the Functioning of the European Union could, no doubt, be further stretched to accommodate the system change envisaged towards sustainable agriculture. The last four of these objectives to: safeguard the standard of living of those engaged in agriculture, stabilise markets, secure food supplies and ensure reasonable prices, do not pose a problem. **It is the interpretation of the first objective of the policy, to increase the productivity of agriculture, that has to change.** When it was drafted it referred to promoting technical progress and ensuring the optimum use of the factors of production, in particular labour. Labour, and indeed total factor, productivity was extremely low at the time with direct consequences for farming incomes and food availability, the objective was to raise farming outputs per hectare and in total. This was achieved with well-known consequences including switching the EU from being a net food importer to a net food exporter.

Any new interpretation has to widen the definition of productivity. Green or natural capital accounts require productivity measurement to embrace *all* the services and outputs of agriculture. This should include both the marketed outputs of food and fibre and the non-marketed positive (building soil fertility and resilience, cultural landscape and semi-natural habitats) and negative (water, air and atmospheric pollution and biodiversity and soil degradation) outputs and services[219]. If this interpretation was accepted then, in principle, the resources and broad structures of the CAP regulations could be redrafted to bring together the set of measures necessary to assist farming to make the transition described in the previous chapters.

Whilst the instrument set of the CAP has been radically changed since the mid-1990s, and environmental considerations are now much more visible than previously, the policy has not set out to achieve system change. More concerning is that the open-ended enshrining of direct payments to individual farmers as a core of the policy and the consolidation of these payments using the language of 'entitlements', has created an obstacle to transition, rather than a vehicle for achieving it[220].

219 Note that the broadening of the definition of productivity does not diminish the need to improve productivity in the narrower sense. If two farms have identical environmental impacts but one has far higher crop or animal productivity as conventionally measured, there is no less reason under green accounting to seek to improve the productivity and thus reduce the resource inefficiency of the poorer performing farm. The key is to take explicit account of any worsening in environmental performance of the more efficient farm if it decided to push its resources harder.

220 This has been argued for a very long time. In: RISE Foundation, 2017. *CAP: thinking outside the Box.*, it is explained how the current direct payments system is not performing the function it could and should.

Purists might argue that as the circumstances and challenges facing agriculture are completely different from the 1960s the Treaty CAP objectives should now be rewritten. **CAP objectives for the next half-century would describe the prime goals as: contributing to climate stability and ecosystem functioning alongside food security, viable farming and thriving countryside.** These are the purposes of the system change. A very important aspect of this will be that the policy should widen its scope for some purposes beyond purely agricultural land to embrace *all* rural land management including forestry and management of nature on farms. However, opening the Treaty of the Functioning of the EU is such a big step that it becomes a high-level political issue that is unlikely to be triggered solely by the need to modify the orientation of the CAP. These issues go well beyond a report focussed on crop protection.

The willingness to devote a significant share of EU budgetary resources to rural land management through the CAP has survived the enlargement of the EU and large transformations of the policy. It therefore seems safe to assume that this will continue. Repeated reports have concluded that the land management sector should be helped to make the systemic transition towards sustainable farming. The array of interventions needed for the new CAP which promotes a just transition will include many if not most of the instruments already available in the CAP and familiar to farmers.

Transitional payments to farmers to assist them change their farming systems will be required. To be effective this assistance will have to navigate a sensitive course between three modes: supporting the adoption of defined sustainable farming systems (i.e. along the lines organic conversion and maintenance schemes), supporting the uptake of specific farming practices, and rewarding the achievement of specified environmental outcomes (result-based payments). There are pitfalls with each of these three approaches, none can be the sole approach. Encouraging new sustainable farming systems alongside organic farming risks undermining the market and the critical price premium of the latter. Offering inducements for adoption of specific practices risks cynical and token responses which would deliver little benefit. Not all outcomes, or results, lend themselves to specific payments. Hence a mix of all three will be necessary. Some supports will be transitional, others will be enduring such as payments for delivering environmental and other public goods and services to secure carbon sequestration, flood and fire protection, biodiversity restoration and green infrastructure.

To be more specific, to discharge the CAP objectives suggested above and the new suggested objective for EU crop protection strategy the justification for the major part of the current CAP namely the pillar 1 direct payments will have to be redirected for two purposes. These are first to assist change in *farming systems* from conventional towards sustainable farming, and second, to induce the necessary *land use changes* from agricultural land to forestry, agroforestry and peat restoration for the purposes of carbon sequestration[221]. Because the purpose of the interventions will therefore be quite different to the current payments especially those in Pillar 1, so the character and the distribution of the payments – between Member States, regions, and farms – will also have to change. Payment distribution has to follow purpose. There is no sense in pursuing (internal or external) convergence of payments as a goal in itself[222].

The details of such payments, whether they are constant or tapering, annual payments or capital grants, the payment basis and how payments are scaled, whether they come with compliance conditions, and whether they can be coordinated at a landscape/river basin level, are all very important questions, but beyond the scope of this report. Similarly, whether the supports for change in farming systems and land use build on, or replace, the current Pillar 2 agri-environment and climate measures or the Pillar 1 eco-schemes is a further important detail which can only usefully be considered when

221 Some consider bioenergy as part of these changes but it´s disputed by others.

222 As unfortunately has been the case since the 2013 CAP reform.

the debate has progressed further. Indeed, the necessity for and appropriateness of the current apparatus of the two-pillar structure of the CAP is another second order consideration. The key point is that a common policy, with clear objectives and sufficient resources distributed amongst the Member States in a rational way will be a critical policy to steer EU agriculture down its development path for the next half century.

Turning specifically to crop protection, there should be much more explicit cross-linking to the Sustainable Use of Pesticides Directive and the take-up of Integrated Pest Management. Although recital 35 of the pesticide regulation 1107/2009 said that 'the principles of integrated pest management, including good plant protection practice and non-chemical methods of plant protection and pest and crop management' should be included as one of the statutory management requirements in the cross compliance for CAP pillar 1 payments, this was never adopted. This should be rectified as a condition for any future CAP assistance. In particular, ways must be found both to use CAP supports to stimulate take-up of ago-ecological principles and practices of soil management and crop production to restore ecosystem function. Lessons must be learned from the failure of the 'three greening measures' in the 2013 Çiolos reform of the CAP. The good intentions behind those measures to encourage wider and longer crop rotations, to manage field boundaries, corners and other less-productive areas for habitat creation and to include and retain grass and legumes in rotations are still highly relevant. However, the strategic case for such measures was not sufficiently made and certainly not accepted by farming organisations. The implementation of greening measures was systematically watered down and rendered ineffective. Their introduction has been acknowledged as a failure. The same is likely to happen again if the above high-level food system strategy is not accepted.

Whatever the carrots or sticks devised to motivate the system change, it will be necessary to raise awareness and provide education, training and advice to producer groups. The assistance for training should extend beyond farmers to include training of advisors and funds to enable the facilitation of knowledge transfer. There may also be some need to help farmers make new investments. Likewise, assistance for improving productivity (but redefined as explained above), risk management, marketing, diversification and restructuring will also all be required. The training should cover the principles and practices of IPM and specifically encouraging substitution of synthetic PPPs by biocontrol products. Farmers can also be encouraged to adopt precision farming, robotics and utilisation of big data. However, it should not be necessary to offer financial incentives for the adoption of these techniques as the private economic benefits should be enough for this. Public assistance to help with such techniques can only be justified through environmental benefit by improving the precision of use of PPPs and minimising the amounts required for effective use, and by demonstrating that other measures to stimulate better ecosystem functioning are in place. Integrated pest management must be seen to be truly integrated. Such public assistance should also where possible specifically allow for coordination across farms within a locality, river basin or landscape.

There is an important interplay between agricultural and environmental policy which will have to develop further in the new transition. First, the agricultural and land use aspects of climate policy will have to be more fully engaged in the CAP. This is inadequately done at present. This in turn means that the definition of agriculture for the purposes of receiving CAP supports must widen so that it does not exclude on-farm habitat restoration and management, tree planting, agroforestry and rewetted peat for example. Second, the new transition necessitates another look at the principles which underpin enforcement of environmental policies such as the birds, habitats, nitrates, water framework, and drinking water Directives. The aim should be that the destination of the new transition is to reach the position where the land management sector is able to accept that the polluter pays principle is fully operational. Assistance, including financial help, to get into that position through measures under the CAP is well established, but as farming is better tuned to nature, the need for this should ultimately fade away. Agriculture cannot sit outside this principle in the long run. It should also be recognised that in view of budget limitations, additional funding sources will be required to support this systemic transition. In view of this, private sources of funds should be promoted through regulations and in other ways such as: carbon credits, rural development bank loans and habitat banking.

5.2.3 Crop protection policy

It will be clear by this point that the language surrounding crop protection can be imprecise and confusing. This report has tried to be consistent in referring to PPPs (not pesticides unless a source cited used that word) and to follow the definitions based in legislation where possible as explained in the Glossary and in the Appendix. PPPs include synthetic products, biologicals (microbials), semiochemicals, natural and basic substances. PPPs are regulated under 1107/2009, but macrobials are not. Some PPPs are permitted for use in organic farming, most are not. Some PPPs are referred to as low risk, currently 18 of them, most synthetic PPPs are not. When targets are set for PPP reduction, it would be helpful if it is made clear which categories of PPPs are referred to. It is presumed that such targets will usually refer to synthetic PPPs excluding those classed as low risk.

To this point, the suggested policy emphasis is to use agricultural policy to offer transitional help and inducements to bring about system change which incorporates progress to the proposed strategic objective of crop protection policy. It is judged that this is more likely to be an approach which could be accepted by stakeholders and adopted through the complex ordinary legislative procedures of the EU[223]. The alternative in the more straightforward, but contentious, option of enforcing the polluter pays principle by taxing PPPs. Denmark and France have already acted in this way by introducing pesticide taxes, though in the latter case without success to date. It is possible that until farmers are ready to embrace wider change in their farming system, they feel locked-into the conventional model and may tolerate higher priced PPPs with little change in usage. Effectiveness dictates that such taxes should be risk-adjusted to encourage switch to low risk products, and the Danish model shows some success in this regard. Fairness in the single market would suggest that any such taxes should be EU-wide. This becomes a high-level political decision.

At the time of going to print, the evaluation of the current regulations (1107/2009) on the placing of PPPs on the market and (396/2005) on maximum residue levels is not yet complete as the response of the Commission to the REFIT report is awaited. Current indications are that no major overhaul of these two regulations is envisaged. Amendments could certainly be made to improve the workings of Regulation 1107/2009 by following the suggestions of the independent review conducted in the REFIT appraisal. Part of the problem of the slow progress in the approval process is the lack of resources allocated to the process and this is partly a matter for the Member States. Meanwhile although the PPP and farming industries are far from satisfied at the workings of the regulation, they are not demanding a reversion from hazard back to a risk-based approach. They fear that a reopening of regulation 1107/2009 will invite even more stringent evaluation of active substances increasing the cost, time and uncertainty of getting approval. There are however suggestions from some in the science community that risk assessments do not include the latest state of scientific knowledge. Prof van der Sluijs[224] stated in his evidence at a public hearing on environmental impacts of

223 This comprises proposals made by the European Commission and co-decision by the Council and Parliament.

224 Prof J P van der Sluijs evidence to the preparatory questions for the public hearing on 'Environmental impacts of pesticides, including mitigation measures at Member State level" and "Stakeholders' recommendations on the current EU regulation on the approval of plant protection products" PEST committee meeting 6 September 2018.

PPPs that assessments ignore cumulative effects of the same substance used on other crops in the same area, the cumulative effects of different products which have the same mode of action, the cumulative effects from exposure to other PPPs, and the effects of other stress factors. This latter point is endorsed by Topping *et al*[225] who suggest that environmental risk assessments are not taking sufficient account of stressors in the environment such as climate change, habitat destruction and landscape homogenisation which can aggravate the effects of PPP in nature It is important that assessments adapt in step with scientific knowledge.

The congestion and slow processing in the EU approval process for PPP active substances could also be approached by removing approval of biocontrol tools (also called bioprotectants) from regulation 1107/2009 to a new and separate regulation. The manufacturers of these products advocate this approach[226]. They justify it because of the intrinsic differences between biocontrol and synthetic products. Part of the process of drafting a new regulation for biocontrol products would be to define which products are included under this heading. This would serve a useful purpose in its own right as there are differences in the way the terms are used amongst the Member States. Of course, the public must be assured that the standards of safety with respect to health and environment are no different for biocontrol agents than any other PPPs. The data requirements appropriate to the various categories of biocontrol tools are different and the approval process should reflect this. A 2018 note from the EC explains that guidance documents are being discussed by an expert group on biopesticides to develop '*common understanding of risk assessment approaches amongst applicants, competent authorities and EFSA*'. At present EU produced biocontrol products are at a competitive disadvantage to those being produced in the Americas which come onto the market earlier because of their more streamlined approval regimes.

Asking for different requirements from biological substances and products would not be totally new. The authorisation process for low risk substances is already faster (half the time or even more) than for those that are not low risk in several MSs[227]. The 2018 note from the EC regarding the progress on increasing availability of low risk PPPs and implementation of IPM in MSs highlights that a 'fast-track procedure' for low risk and basic substances by exempting them from the need to set maximum residue limits. It is noted that PPPs based on low risk active substances may themselves not be classified as low risk PPPs if at least one of their co-formulants is not classified as "of no concern"[228]. Further, a distinction is made between low risk and biological since they do not always coincide and some synthetic PPPs may also fall under the term low risk.

Another regulatory instrument to strengthen the crop protection strategy is by reinforcing the Sustainable Use of Pesticides Directive. There are three possibilities of how to progress this. First it could be strengthened by modifying the existing Directive especially to strengthen and make more specific the requirements on Member States to set targets and monitor progress in implementing IPM through their National Action Plans. Second, if it is judged that the Directive gives too much scope to the Member States to pay lip service rather than implementing it with vigour, the Directive could be reformulated as a Regulation to enforce, rather than just promote uptake of measures by MSs. This would place greater responsibility for implementation on the Commission and would demand considerably more Commission resources to ensure it is followed into practice. Very little Commission resource is currently allocated to oversee implementation of the SUD. This approach could also give the opportunity to clarify

225 Topping, C.J., Aldrich, A., Berny, P., 2020. *Overhaul environmental risk assessment for pesticides.* Science 367, 360–363

226 IBMA 2018. *New EU Regulatory Framework for Bioprotection Agents*

227 European Court of Auditors 2020. Full reference in p.33.

228 Ibid.

and define targets for Member State National Action Plans and to enforce the actions required for implementing Integrated Pest Management. A third approach, given that to date the CAP has offered little help to ensure the SUD prescriptions are followed through, is to consider whether the functions of the SUD could be incorporated within the new framework for the CAP. The proposal in section 5.2.2 above which places the restoration of ecosystem function in soils and crop systems at the heart of the CAP suggests going one step further and fully integrating all the provisions of the SUD within this framework. This would certainly go beyond the current proposals for the 2021-2027 CAP which merely suggest including certain obligations under the Sustainable Use of Pesticides Directive in cross compliance conditions for direct payments, but not a requirement on farmers to apply Integrated Pest Management.

A further regulatory issue which could release a new line of development in EU crop protection is the status of new genomic techniques. This has been discussed in detail in section 4.5.

5.2.4 Enabling policy measures

In addition to the general, agricultural and crop protection policy changes outlined above, there are a number of cross-cutting and practical policy steps which are essential to enable barriers to the new transition to be overcome and to measure its progress. These are described under three headings: broad definitional and educational tasks, some specific crop protection related tasks and finally research gaps.

Some broad definitional and educational tasks

- The new transition has been variously described as 'moving towards sustainable agriculture', 'adopting nature-based practices' and 'restoring agro-ecosystem function'. Progress in this direction demands clear definition of the principles and practices which qualify under these headings.
- The relationships between these practices and the existing certification schemes of sustainable agriculture such as organic farming and integrated farm or crop management should be spelled out. There is also need for clear definition of biocontrol and bioprotectants, and clear unambiguous language to describe policies which aim to "reduce pesticides".
- The principles and practices of sustainable agriculture must also become core parts of the curriculum in agricultural universities, colleges and training schemes.
- It will also be necessary to provide training and restructuring in many Ministries of Agriculture to understand how the transition is intended to mainstream principles which may have been siloed in the 'organic' section of such organisations.
- It is important to develop indicators of ecosystem function which can be used both at policy level to measure progress and at farm level.

Specific crop protection related tasks

- Based on progress in identifying ecosystem function indicators, the next task is to open discussion of how to improve the capacity of the PPP active substance approval process to identify the longer-term impacts of PPPs on ecosystem function.
- Improving the collection and pooling of PPP use statistics by product categories, crops and Member States. The assessment of progress in reducing risks from PPP use is severely hampered by the fact that there is little comparative data across the EU Member States on what products are being used and how.
- Further development of the harmonised risk indicators, including the weighting factors, to assess in which crops/spheres most adjustment could potentially have most beneficial effects.

- Seeking ways to increase the transparency and independence of risk assessments (tests are now performed by the companies themselves) as well as accounting for multiple applications of the same active substance through different compounds and taking into account of "*cocktail effects*" and interactive effects of environmental stressors.
- Investigating how farmers can be helped gain access to independent Farm Advisory Services. If farmers continue to get their primary advise on crop protection from salespersons of the products, or even independents for whom the least risky advice is to reach for the sprayer the system will resist change.

Research gaps

- Modelling the interactions between changes in EU consumption, changes in EU production through various modes of transition and climate policy-induced changes in land use, and the repercussions for international trade.
- Analysis of the farm level and market level adjustments consequent to significant parts of agriculture moving towards lower intensity sustainable systems.
- Identification of the adjustment challenges for crop protection during the transition in farming system.
- Characterising and modelling developing metrics of ecosystem functioning and establishing the evidence base for farm system impacts on these metrics.
- Understanding the role of soils and soil organisms in ecosystem functions in order to provide adequate protection measures at EU and MSs level. The RISE´s Foundation´s next report will place its focus on this topic.

This report set out to better understand the tensions surrounding the way agricultural crops are protected in the EU and to suggest how these tensions might be relieved. It has concluded that the food system has become out of balance with nature and has to change. Moving crop protection away from heavy reliance on synthetic plant protection products and towards biological approaches including the bolstering ecosystem functioning in soils and around crops is an important part of that change. But such transition in crop protection techniques is just one component of a wider food system and land use change which will have to embrace food consumption and waste, food pricing which reflects true social costs of production, and welfare and trade policy too. It is encouraging that the European Green Deal has recognised the breadth and scale of change required to rise to the challenge of the climate and biodiversity crises. The report spells out some of the key actions to bring about the required transition.

Thank you

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Readers should note that the views and opinions expressed in this RISE report are solely those of the RISE Foundation and do not necessarily represent those we thank below.

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THIS REPORT SETS OUT to better understand the issues surrounding the way agricultural crops are protected in the EU. EU agriculture relies heavily on the use of synthetic chemical plant protection products to combat pests and diseases. Whilst EU regulation aims to encourage the uptake of non-synthetic crop protection methods to reduce harm to human health and the environment, the strategy is not working. Available data show no significant overall change in the use and associated risks of plant protection products during the last decade. A transition in the way crops are protected in the EU is needed. We propose one which aims to re-establish ecosystem functions on agricultural land to provide nature-based solutions for pest, disease and weed threats, and to utilise all means to enable a substantial fall in the harms caused to health and environment by use of PPPs. This transition cannot be disassociated from the wider food system and land use changes which will have to embrace food consumption and waste, food pricing which internalises the true cost of production, and welfare and trade policy. The report spells out some of the policy changes and key actions to bring about the required transition.

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