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The future of crop protection in Europe

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The future of crop protection in Europe

The overall objective of the future of crop protection project is to present an overview of crop protection options for European farmers, which might enable them to work sustainably while securing food production, preserving biodiversity and supporting farmers' incomes. The policy options proposed are based on an assessment of current and emerging crop protection practices and their impact on the common agricultural policy (CAP) objectives. This overview shows that several crop protection practices are under continuous development and have potential to improve future crop protection in Europe.

The likelihood that policy options can be successfully implemented depends upon the extent to which they are consistent with the interests of stakeholder groups. These include farmers, suppliers, supply chain partners, consumers and NGOs defending societal interests. Furthermore, it is important that crop protection policy options are embedded in a systems perspective. This should include related areas, such as phytosanitary policy, the entire crop production system, the supply chain, and international trade relationships – which need to be in harmony with the crop protection policy.

For each of the crop protection practices, different policy options are proposed together with an impact assessment.

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Executive summary

The world population is growing continuously. It is expected that by the end of the 21st century, around 11 billion people will need to be fed. A corresponding increase in food production is required to sustain the future population. Growth in food production can be achieved with the use of more farmland and an increase in yield per hectare (ha). However, increasing land use for food production significantly contributes to loss of biodiversity, which is very undesirable from the point of view of sustainability. Consequently, the pressure to improve food productivity per ha increases.

One of the important means to bring about high yields per ha is the use of plant protection products (PPPs). Herbicides, insecticides and fungicides help to protect plants from harmful pests, diseases and weeds. However, the use of PPPs is subject to societal concerns, due to the risks to human health (of users, consumers and in some cases bystanders) and the environment (loss of biodiversity). A key question arises as to whether the use of PPPs can be reduced while maintaining or increasing yields. This question relates not only to global crop production with its wide range in yields, but also to the European Union (EU) with its generally high levels of productivity.

The Panel for the Future of Science and Technology (STOA) of the European Parliament commissioned this study as part of the future of crop protection in Europe project. The overall objective is to present an overview of crop protection options for European farmers which might enable them to work sustainably while securing food production, preserving biodiversity and supporting farmers' incomes.

Appendix 1 of the study reviews and assesses current crop protection practices as well as possible alternatives. The review shows that a number of crop protection practices are under continuous development and have the potential to improve crop protection in future. These developments are important, but will only be effective if they are implemented by farmers and accepted by other stakeholders. Appendix 2 describes the societal assessment that presents an understanding of stakeholders' interests, and how they can be addressed.

This report summarises the results of the two abovementioned reports and reflects on existing and emerging crop protection options for farmers. It provides an assessment of the impact of the various crop protection practices on the common agricultural policy (CAP) objectives. Policy options are proposed to support crop protection developments.

Chapter 2 discusses the importance of embedding crop protection policy in a systems perspective that relates to other relevant policy areas. The following other policy areas are addressed:

- Phytosanitary risk management, focused on preventing the introduction, establishment and spread of exotic plant pests and diseases;
- The entire crop production process. Crop protection is one area of attention in the production process. Other areas that need to be managed by the farmer or grower may be linked to crop protection, such as nutrient management and soil fertility;
- The entire supply chain. Changing crop protection practices may affect the costs of production. Farmers may be more likely to make changes if they are supported by wholesalers, retailers and consumers paying higher prices.
- International trade. Application of crop protection policy in the EU can create competitive differences with producers outside the EU. This can result in shifting domestic production to imports of products which do not comply with EU requirements, which would violate the CAP objective of ensuring a fair income for farmers.

Chapter 3 discusses seven categories of existing and emerging crop protection practices and their potential impacts on crop yield, farmers' income, biodiversity and pollinators, climate change, public health, food safety, food security and the competitiveness of EU farming.

Precision agriculture has positive impacts on all factors, with high impacts on crop yield and competitiveness. Plant breeding, biocontrol and ecological principles have positive impacts on multiple factors, such as crop yield and EU farm competitiveness. All impacts of biocontrol, induced resistance and ecological principles are positive or neutral; with biocontrol and ecological principles having high impacts on biodiversity and crop yield, although their impacts on farmer income are neutral.

Improved mechanical techniques can have a negative impact on climate change, due to increased damage to the soil biomass and increased use of fuels. Furthermore, the combined interactions of all the other new practices can be expected to reduce the overall need for PPPs in the future.

Chapter 4 presents a stakeholder analysis covering the following stakeholder groups:

- Customers (consumers, retailers and food processing industry)
- Producers (farmers and growers)
- Suppliers (crop protection industry and other suppliers)
- Society (citizens and NGOs)

Chapter 5 proposes policy options, including a 'do nothing' baseline option. The options are structured according the categories of crop protection practices discussed in Chapter 3 and shown in Table S1, together with their potential impacts on a range of indicators. Chapter 5 describes an analysis of the impact of the different crop protection practices on the major groups of agents that harm crop production: pests, pathogens and weeds. Chapter 5 also discusses different categories of crop protection practices in a systems perspective, which takes into account synergies resulting from interactions between practices when used in combination. It is argued that policy options based on a systems perspective should cover the whole supply chain and also international trade.

Chapter 6 presents the main conclusions on policy options for crop protection in the future.

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1. Introduction

1.1. Background

Crop protection, particularly the use of plant protection products (PPPs), is the subject of an intense and ongoing debate that concerns those with an interest in plant production, its supply chain and society. The debate centres around the (perceived) negative impacts on human health and biodiversity.

Crop protection is essential for the efficient production of crops and their products. It prevents crops from being harmed by pests, pathogens and weeds, with consequent reductions in yield and product quality. It contributes to food production and food security, which benefits consumers and society. And it supports farmers' incomes.

Chemical PPPs are currently the most important single method of protecting crops against pests, pathogens and weeds. However, the debate – as well as the desire of farmers to reduce their dependency on chemical PPPs – has increased the need for alternative crop protection methods. Recent examples of the debate include the herbicide glyphosate causing cancer, and the use of insecticidal neonicotinoids causing a significant decline in pollinator populations.

These concerns were the reason behind the STOA workshop 'Farming without agro-chemicals' held in March 2019. The aim of the workshop was to give participants a better understanding of the impact of PPPs on food production, and to explore the interests of different stakeholder groups.

Prior to the workshop, STOA requested researchers from KU Leuven to produce a scientific background report 'Farming without plant protection products' to explore the possibility of growing crops without using agro-chemicals. The report concluded that a policy to reduce the use of PPPs would, on its own, have negative trade-offs if the yield reduction was compensated by an increase in the area of land used for agriculture. This is because it would lead to an increase in the loss of biodiversity.

Despite the doubling of PPP use since 1980, the environmental impact has been significantly reduced by application of stricter registration policy, replacement of broad-acting PPPs by more specific PPPs, avoiding impacts on non-target organisms, and the use of more advanced application technology. Without the application of PPPs, including biopesticides, the food security of 11 billion people is threatened.

On the basis of the outcomes of the workshop and the scientific background report, the Scientific Foresight Unit (STOA) commissioned this study on options for European farmers to work in a sustainable manner while securing overall food production, preserving biodiversity and supporting farmers' incomes.

This study offers reflections and policy options for the future of crop protection in the EU. It summarises the detailed technical analyses and assessment which are published as two annexes to this report:

1. Overview of Current and Emerging Crop Protection Practices
2. Societal Assessment

The technical analysis (available as the first Appendix of this report) reviews and assesses current crop protection practices, as well as possible alternatives. It identifies drivers and enablers for implementing alternative crop protection practices, and describes relevant legislation.

The second part (available as Appendix 2) presents a societal assessment of crop protection practices. This includes a stakeholders analysis regarding crop protection, and analyses the stakeholders' opinions on the use of plant protection products (PPPs). Four scenarios were developed to explore potential future impact of possible courses of action in relation to other global developments regarding the economy, politics and society. The scenarios were then discussed in a brainstorming meeting with stakeholders and experts.

1.2. Objectives of the report

The objectives of this report are:

- to summarise the results of both previous reports prepared as part of this study;
- to reflect on existing and emerging crop protection options for farmers;
- to provide an impact assessment of possible options on the Common Agricultural Policy (CAP) objectives;
- to propose policy options to support crop protection developments, taking into account the systems perspective.

1.3. Report structure

This report is structured as follows:

After the introductory Chapter 1, Chapter 2 describes the systems perspective, presenting other areas related to crop protection that have to be taken into account in an overall production strategy.

Chapter 3 summarises existing and emerging crop protection practices and their impacts.

Chapter 4 presents the interests of different stakeholders in a stakeholder analysis.

Chapter 5 proposes policy options together with the legal perspective.

Chapter 6 presents the report conclusions.

2. The systems perspective

2.1. Introduction

Crop protection does not take place in isolation. Decisions on crop protection are embedded in an overall production strategy, which covers all inputs and measures required to optimise the crop production process.

All these other areas related to crop production have to be identified during the policy-making process, for two reasons:

Firstly, they may limit the potential for making crop protection more sustainable.

Secondly, they may indirectly influence the developments in crop protection.

This chapter describes other main areas of interest and how they relate to crop protection.

2.2. Phytosanitary risk management

Crop protection is not the only policy area oriented at safeguarding plant health. Whereas crop protection focuses on preventing damage caused by endemic weeds, pests and diseases; phytosanitary risk management is directed at preventing the introduction, establishment and spread of invasive plants, pests and pathogens.

Prevention introduction is based on a zero-tolerance policy, meaning that all imported plants and plant products may not contain any pest or pathogen that has quarantine status in the country of destination.

Since endemic plants, pests and pathogens in an exporting country may have quarantine status in the country of destination, crop protection has to be applied in such a way that no living organisms will be present in plants or plant products involved in international trade.

This provision limits the application of crop protection options to those that cause the total destruction of pests or pathogens; biocontrol agents to meet this requirement.

Although both policy areas have the same goal, phytosanitary policy interferes with crop protection policy and complicates the search for sustainable PPPs. This tension has been recognized by the International Plant Protection Convention in their strategic framework 2020 – 2030 (FAO, 2019).

2.3. Entire production process

The discussion about the future of crop protection in the EU is part of a much wider discussion on the future of food production and the prevention of climate change.

The EU recently released the European Green Deal, the Farm to Fork Strategy and the Biodiversity Strategy. These contain plans to reduce Europe’s contribution to climate change significantly, to transform agriculture to sustainable levels of production and consumption, and to safeguard the environment and biodiversity.

Any policy options regarding the future of crop protection should therefore be consistent with these policy areas.

Buckwell et al. (2020) discussed crop protection in the wider context; it is embedded in a series of production processes oriented towards high yields, high quality and minimal environmental impact.

Other production processes also have impacts on the environment, climate change and human health. For example, the management of soil quality and nutrients is primarily undertaken to obtain high crop yields, but it is also important for plant resilience to reduce their vulnerability to pests and diseases.

It is therefore important that farmers' decisions on crop protection take into account the whole production process from societal and environmental, as well as economic perspectives.

2.4. Entire supply and trade chain

Farmers can be expected to select the most cost-effective crop protection methods from the point of view of their farm businesses. Selecting options that are less harmful to the environment may incur higher costs for the business for the benefit of all society.

In order to reward the farmer for this public good, farmers should be able to pass these costs down the supply chain to consumers, who would pay the 'true' price.

Policy considerations should, therefore, not be limited to primary production but include the entire supply chain, including wholesalers, retailers and consumers.

2.5. International trade

The EU has adopted WTO rules to facilitate free trade as much as possible. This is appropriate as the EU has an open economy and trades with nations all over the world.

For some plant products, such as bananas and rice, the EU is largely or wholly dependent on supply from other countries. Other plant products, such as citrus and animal feed ingredients, are supplied by both domestic production and EU imports. Crops such as onions and potatoes are produced in the EU and traded on the world market.

Implementation of EU policies to reduce the environmental damage caused by crop protection practices may change the competitive relationships between EU producers and those elsewhere.

EU farmers may be put at a competitive disadvantage with external producers who are not subject to stricter controls and still have full access to the EU market. This could affect domestic EU production.

Potentially, such a situation could violate the CAP objectives to ensure a fair income to farmers and to increase competitiveness. Furthermore, the policy measures may not achieve their intended sustainability objectives and instead just export the problems to the other countries supplying the products.

Therefore, policy options need to strike a balance so that EU producers are not disadvantaged; either by requiring that imported products meet equivalent standards, or by introducing import controls.

3. Existing and emerging crop protection practices

3.1. Introduction

Crop protection practices are continuously developing. Societal pressure and the needs of farmers create the demand for change.

Innovation by the industry, together with fundamental and applied research by universities and research institutes create the opportunities for improving crop protection techniques.

Chapter 3 discusses existing and emerging crop protection techniques to protect plants against damage caused by pests, diseases and weeds.

The use of conventional chemical pesticides provides a baseline to assess alternative crop protection practices.

The following categories of crop protection practices were assessed in Appendix 1 Overview of Existing and Emerging Crop Protection Practices, Chapter 3 of this study:

- Mechanical techniques;
- Plant breeding;
- Biocontrol;
- Induced resistance;
- Applying ecological principles in diversified systems;
- Precision agriculture (PA);
- Plant protection products.

Summarised extracts from this chapter are presented in the following sections. The summaries are followed by a description of the interactions between practices, and a conclusion on the impact of emerging practices.

3.2. Mechanical techniques

3.2.1 Existing practices

Mechanical practices are mainly used to control weeds. Different weed management tools can be distinguished by: a) their scale of operation (full field, inter-row, intra-row) and; b) their mode of action (mechanical weeders, electroweeders, thermal weeders).

The most important innovation for inter-row weeders is the development of guidance systems that take over the role of the driver. Physical guidance systems that follow the crop row are widely available and cheap. Automated guidance systems based on GPS are available and row or plant recognition has been developed.

3.2.2 Emerging practices

Intra-row weeding is the most challenging technique since the risk to crop damage is highest when removing weeds growing close to the crop plants.

Over the last two decades, two developments have led to major innovations in intra-row weeding: the combined use of cameras and computer vision; and the development of real-time kinetic global positioning systems (RTK GPS).

Computer vision technologies are able to recognise the crop row based on shape, colour and location; they steer the weeding device in the crop row to cut, uproot, burn or bury the weeds. The latest step is the development of autonomous robotic weeders with non-chemical actuation.

3.2.3 Potential impact

Weed control using mechanical techniques generally requires multiple passes to achieve the same degree of control as herbicides. The impact on biodiversity varies with the type of organism; the impact on fauna increases with the number of passes.

The side effects of mechanical weeding on soil dwelling insects are often indirect. The more efficient the weed management practice, the lower the amount of remaining biomass; the lower the biomass, the lower the population of beetles and spiders.

Due to the developments in precision agriculture, mechanical weeding will become more precise in future, which will reduce the remaining biomass. The expectation is that both the direct and indirect negative effects of mechanical weeding on beetles and spiders will increase.

Current full-field mechanical weed control techniques have a destructive effect on the eggs of farmland birds. To reduce the negative effect on birds and their nests, it is necessary to detect and protect the nests during weeding. Vision-based detection systems are under development (Steen, Therkildsen, Green, & Karstoft, 2015).

It is foreseen that the impact of improved mechanical techniques on crop yield will be similar to the impact of existing herbicides.

3.3. Plant breeding practices

3.3.1 Existing practices

Plant breeders use a variety of methods to create new cultivars. The simplest method is to select the best plants in a crop. Greater progress can be made by including plants from all over the world in the selection process to make optimal use of naturally-occurring genetic variation. A further step is the crossbreeding of different plants to combine their characteristics. There is a long history of selection breeding, crossbreeding and hybrid breeding.

The technique of mutation breeding (or mutagenesis) was developed during the 20th century. Random (or conventional) mutagenesis involves artificially changing a trait through chemical treatment or radiation to create a mutation.

Further developments in plant breeding since the 1990s include genetically modified organisms (GMOs) and gene transfer techniques.

Cisgenesis and intragenesis refer to the production of plants by genetic modification using only genes from the species itself, or from a species that can be crossed with this species using traditional methods.

In cisgenesis, genes are added as an extra copy and are natural variants with improved characteristics, for example providing disease resistance. In transgenesis, the genes inserted are from species outside the species' gene pool.

A cisgenic plant can, in principle, also be produced through traditional breeding, but this would require a much longer period of time.

3.3.2 Emerging practices

In recent years, a range of new plant breeding techniques (NPBTs) have been developed to provide a more efficient and precise adjustment of the genetic make-up of crops (Figure 1). These techniques include genome editing (or directed mutagenesis), which has made major progress since the introduction of CRISPR-Cas in 2012 (Cong et al. 2013). These new techniques will support plant breeders in improving important crop traits that have been difficult to improve by crossbreeding.

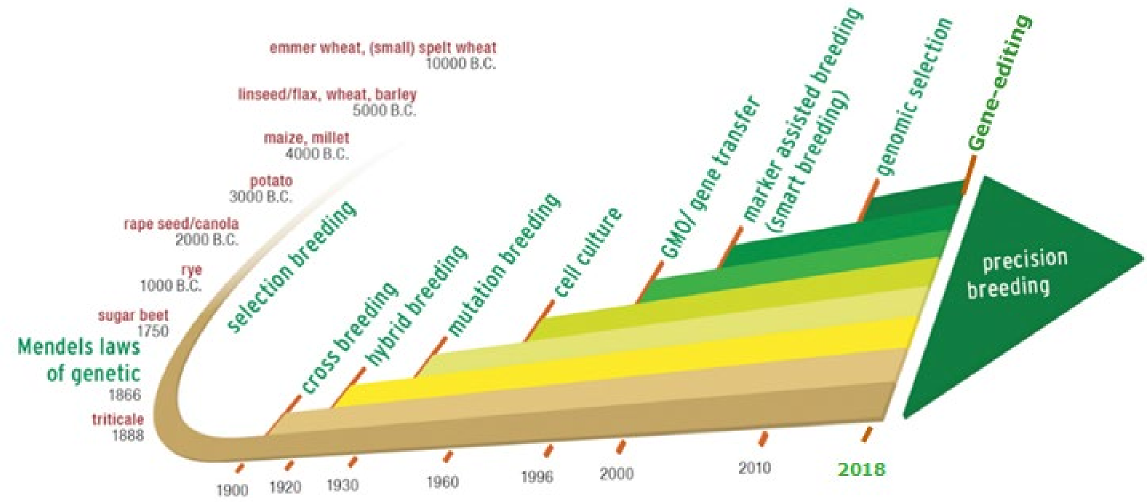

Figure 1 Milestones in plant breeding.

Source: Adapted from Europeanseed.com.

NPBTs include a diverse set of technologies for improving the efficiency and precision of plant breeding. They can shorten breeding programmes considerably – sometimes from decades to years – depending on the crop and the plant traits being targeted. Genetic modification is frequently used in these techniques, but only as a tool during the breeding process. No DNA from non-crossed species is present in the end product.

Genome editing (sequence-specific nuclease (SSN) technology) or directed mutagenesis allows DNA to be changed at precisely specified points in the plant genome. This allows the adjustment of plant traits in an accurate and efficient way.

Reverse breeding is a method designed to create homozygous parental lines from offspring of a heterozygous plant. This approach allows the rapid fixation of chromosome substitutions resulting from the heterozygous plant, which will facilitate breeding at an individual chromosome level.

Induced early flowering is a technique where a transgene induces fruit tree seedlings to flower years before they normally would. This enables fruit tree breeders to cross plants every year, allowing for the fast introduction and combination of desirable traits, after which the transgene is eliminated.

3.3.3 Potential impact

The objective of breeding – through either conventional or new breeding techniques – is to provide varieties with good characteristics. With regard to crop protection, this means developing crop varieties that are resistant against specific pests and diseases, or tolerant or suppressive to weeds, which reduces the need to control those pests and diseases by other means.

Compared to chemical pesticides, the introduction of resistant varieties contributes to safeguarding biodiversity and the protection of human health. Furthermore, it contributes to farmers' incomes by saving the costs of pesticide application.

The question of whether new breeding techniques will contribute to the competitiveness of EU farming largely depends on the legal situation on the use of the new techniques – both within the EU and elsewhere. The EU has, to date, been reluctant to allow the use of new breeding techniques, which could create a competitive disadvantage for EU farmers.

3.4. Biocontrol

3.4.1 Existing practices

Organisms that cause the damage to plants have natural enemies (or antagonists). These enemies exist naturally in any agricultural system. However, their numbers or effectiveness are often too low to contribute to crop protection.

Different types of natural enemies can be identified: microorganisms such as bacteria, viruses and fungi; and macro organisms such as insects and nematodes. Biocontrol entails all methods, tools, measures and agents of plant protection that rely on the use of beneficial organisms, as well as their natural mechanisms and interactions which steer the relationship between biological species in the natural environment.

Depending on the context, the term biopesticides is used for a variety of products and agents. In this report, the term is used only to refer to the use of arthropods, microorganisms, nematodes, viruses and products derived from these organisms for crop protection.

During the last decade, the rate of introduction of new biological products has exceeded that of conventional plant protection products worldwide[1]. Despite the recent rapid growth of the biopesticide market, less than 5 % of plant protection products currently sold worldwide are biocontrol agents (Buckwell, 2020).

In arable cropping systems, a limited number of biocontrol options are available to control the major pests, diseases and weeds Lamichhane et al. (2017).

More biocontrol options are available for protected cropping systems, such as vegetables, fruits and ornamental plants grown in greenhouses.

3.4.2 Potential Impact

It is generally presumed that biocontrol methods are inherently less risky for both human health and the environment as these products have originated and evolved in nature. There should be less concern about persistence, bioaccumulation and residues as they are generally quickly broken down and recycled. They should pose less harm to operators (Buckwell, 2020). However, these properties do not automatically apply, so such general claims must be scrutinised.

For farmers, the effectiveness of biopesticides compared to agrochemicals is the main consideration. Farmers are risk adverse and these products should have at least a reliable and adequate level of control if they are to substitute for synthetic products. Furthermore, it is important that schemes are developed in which these products can be used in combination with synthetic PPPs.

[1] https://croplife.org/wp-content/uploads/2018/11/Phillips-McDougall-Evolution-of-the-Crop-Protection-Industry-since-1960-FINAL.pdf

As shown in the tables above, the number of biocontrol tools developed for field crops is still limited and the combined use of biopesticides with synthetic PPPs can be expected. Today, biopesticides are seen by farmers as less efficient and reliable than synthetic products. Farmers need to gain experience with these types of products to build trust and acquire knowledge.

Biocontrol agents generally have a narrower spectrum of application of crop/pest combinations than chemical products. The use of several products in one crop can therefore be expected. This may be costlier to farmers than the use of conventional pesticides. Potentially, their costs of production may increase as a result.

3.5. Induced Resistance

The defence mechanisms of plants can be induced by a variety of biotic (living) and abiotic (non-living) agents. Applying induced resistance for crop protection is an emerging field of research (Borges et al., 2015) and has to date not been adopted as a commercial crop protection practice.

Induced resistance tends to be broad-spectrum and can be long-lasting, but is rarely completely effective. Most inducing agents reducing disease by 20-85 % (Walter et al., 2013).

In contrast to breeding for resistance, the genome of the plant is not altered by induced resistance. In most cases, elicitors are applied to plants as either foliar sprays or a root drench. A convenient way of applying crop protection treatments involves treating seeds. Seed treatments can be particularly useful, since they can provide protection to young plants during a vulnerable stage in their development (Walter et al., 2013).

3.5.1 Potential Impact

Since techniques to induce resistance are still in development, no potential negative impacts have been reported. Successful application, especially in early growth stages, with long-lasting effects will contribute to saving other crop protection measures with positive consequences for the environment, and saving costs and labour.

3.6. Applying ecological principles in diversified systems

A major ecological principle is that diverse systems are more stable and resilient to impertubations. This principle can be used to design new cropping systems that are more resilient with a reduced chance of a large outbreak of a pest or disease.

An emerging strategy to reduce damage from pests is to apply ecological principles to increase plant diversity in and around cropping fields. Biodiversity is critical for the functioning of natural ecosystems and is also a prerequisite for developing agro-ecological farming systems (Barot et al., 2017; Beilloun et al., 2019; Malézieux, 2012).

Biodiversity at the field level can be considered in three domains: temporal, spatial and genetic.

Temporal diversity includes crop rotation, which may be enhanced by including cover crops to provide green manure (i.e. organic material) to the soil. Including legume crops in a rotation also enhances soil fertility.

Spatial diversity includes extending and improving semi-natural habitats (e.g. hedgerows, flower strips) around field crops.

Genetic diversity includes various ways of mixing crops, including agroforestry.

While the impact of improving biodiversity on pest reduction may vary from year to year, or from field to field, there is a consensus that increased biodiversity in and around crops has positive effects (Martin et al., 2019).

On the other hand, enhancing plant biodiversity often comes at a cost. Land taken up by non-crop vegetation reduces the overall cropping area. Also, yields per hectare from the productive area of biodiverse systems have tended to be lower than from conventional systems (Letourneau et al. 2011).

However, Martin et al (2019) showed in a study covering 1 515 landscapes across Europe that landscapes with narrow fields (i.e. many boundaries relative to area) had 44 % more natural enemies and pest control increased 1.4-fold while maintaining high yields.

It can be expected that the effects of diversity actions will differ both within and between the three domains. For example, the use of variety mixtures in cereals can be expected to have a lower effect on pest reduction than crop mixtures such as wheat and pea (Iverson 2014). A crop rotation with inclusion of a similar crop under similar management (e.g. two winter cereals) will have a lower effect on weed reduction than using a crop with different timing and management (e.g. a winter cereal and a tuber crop that is sown in the spring) (Weisberger 2019). Similarly, narrow strips of potato can have a better disease suppression than wider strips (Skelsey et al., 2010).

3.6.1 Potential Impact

The potential impacts of ecological functions in agriculture can be both positive and negative. Farming systems based on ecological principles potentially require lower levels of fertiliser and PPP inputs and will therefore have a reduced impact on wider biodiversity, human health and environment.

There is a risk of lower yields when lower amounts of fertilisers and PPPs are applied. Meta studies of organic farming show yield penalties compared to conventional farming of between 5 % and 45 %, depending on the crop (Ponisio et al. 2015; Seufert et al. 2012). Unless the farmed area is expanded proportionately, food output would fall if most or all EU land was converted to organic systems. However, expanding the agricultural area could be highly damaging to habitats and biodiversity.

New systems that combine the best of conventional and more sustainable practices are needed. A recent meta study (Bellouin et al. 2019) showed that all diversification strategies benefit biodiversity. The majority of the studies indicate a positive impact of diversification on soil quality and also on productivity of the system.

The meta study shows that diversified systems can contribute to sustainability and production goals. The question is how to design alternatives to Europe’s high-input, high-output systems to grow the crops needed to meet dietary demands and quality standards.

3.7. Precision Agriculture and Decision Support Systems

Precision agriculture, or precision farming, is a modern farm management concept using digital techniques to monitor and optimise agricultural production processes.

The development and implementation of PA is enabled by various technologies: object identification, sensors, Global Navigation Satellite Systems (GNSS), connectivity and other information and communication technology, robotics, and autonomous navigation. A detailed description of the development of these techniques is given by STOA (2016).

Since 2004, farmers have been able to use GNSS on farm machinery in order to define precise routes ('tram lines') in the field. This prevents overlap or gaps in application, thus saving energy, water and agrochemicals.

Modern crop sprayers are able to vary application rates based on (near) real time data.

Spray application technology is a rapidly developing area, mainly with the purpose of increasing precision of application and minimising side effects on the environment. 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, and 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, the application rate can be based on the biomass present. For leaf desiccants, the rate can be based on the chlorophyll detected. Considerable work is underway for weed identification to allow selective spraying of contact herbicides.

Remote sensing may be used to detect and control weeds. Most studies have focused on detecting weeds between rows, which means detecting the rows and then the vegetation in-between. The detection is based on the geometric structure of the rows and the spectral contrast between vegetation and soil (Weiss et al. 2020).

PA technologies under development are sensor-based methods for the detection, identification and quantification of plant diseases (Mahlein, 2016; Hillnhütter et al. 2010; Mahlein et al. 2012a; Sankaran et al. 2010).

Decision support systems (DSS) are used to optimise crop management. Crop, weather and soil sensors enables the collection of real-time data on crop and environmental conditions. Connection of that information to the location of pests, diseases or weeds, and with the population dynamics of the target crop, will improve the application and efficacy of control measures.

3.7.1 Potential Impact

The Scientific Foresight Study "Precision agriculture and the future of farming in Europe" (STOA, 2016[2]) draws the following conclusions on the potential impact of PA:

PA can make a significant contribution to food security and safety:

- PA offers technology solutions that can aid to produce more with less inputs;
- PA will enhance food safety and plant health

PA can promote sustainable farming:

- PA technologies are already in use with positive impacts on the environment;
- PA will generate sustainable productivity gains

PA will trigger wider societal changes:

- PA will influence work practices and life conditions on farmland
- New farming business models are under development

Precision agriculture requires the learning of new skills:

- Technological skills
- Environmental skills

[2] https://www.europarl.europa.eu/thinktank/en/document.html?reference=EPRS_STU(2016)581892

- Managerial skills

Precision agriculture and decision support systems offer the potential to increase farmers' incomes through a range of applications. Precision technology and DSS can reduce the amount of agrochemicals needed; thus reducing both the cost of crop protection and the impact on the environment. They can contribute to food security, food safety and sustainable farming.

3.8. Plant Protection Products

Agrochemicals is a broad term and may include many substances. The term is used here to describe classical (or conventional, or synthetic) plant protection products including soaps/detergents, botanicals and nanoparticle-based micronutrient formulations. The term plant protection products includes agrochemicals and biopesticides.

The discovery and development of plant protection products was one of the major enablers of intensification of agriculture in the 20th century. Intensification has led to increased yields per hectare, which has been a critical development for food security at both the EU and global levels. Without intensification, more land would be needed for food production, which would have negative environmental impacts.

However, the intensification of food production has had undesirable side effects, including declines in biodiversity, soil and water quality, as well as concerns for human health.

As a result, it is necessary to regulate the use of PPPs at national and EU levels. EU regulation is based on the use of hazard-based risk criteria and risk assessments. This approach has led to the removal of a number of PPPs (both products and active ingredients) from the EU market.

Most PPPs are agrochemicals and new products are released continuously. The introduction of new working mechanisms in products is one of the means to prevent resistance development in target organisms. However, most new products today are reformulations using existing active substances. The discovery of new active substances is currently at a relatively low level

3.8.1 Impact

PPPs are regulated because of their potential risks to biodiversity and human health.

There has been a substantial decline in biodiversity – both above and below the ground – in agricultural ecosystems, as reflected in declining populations of farmland birds and insects in parts of the EU. As a result, the ecosystem functions that these organisms provide – including natural pest control – are endangered or lost as well.

Among other factors, pesticide use has been identified as an important cause of environmental impacts. Pesticides contribute to the pollution of ground and surface waters, and there are strong indications that long term exposure to PPPs can have a negative impact on biodiversity (Topping et al., 2020).

There is a multitude of factors – both within and outside agriculture – that can affect the environment. It is therefore difficult to isolate and assess the specific impact of PPPs. The complexity of interactions: between species; over (trophic) levels along food chains; above and below ground, makes distinguishing cause and effect very hard. Reduction in one species may interfere with habitat or food requirements of another species in another trophic level.

The impacts and potential risks of PPPs on terrestrial above-ground and water organisms are relatively well documented. Tighter restrictions and withdrawal of active substances with negative impacts on pollinators have contributed to a higher level of environmental protection (Buckwell, 2020).

Insects (particularly pollinators) and birds are the two most studied groups. The evidence on the potential impact of PPPs on soil functions and soil ecosystems is not consistent (FAO and ITPS, 2017)

In case of direct human exposure, PPPs can enter the human body in four ways: dermal exposure, orally, through the eye and via respiratory pathways. Buckwell (2020) summarises the accumulation of evidence about the impacts of PPPs on human health. Cancer, endocrine disruption, respiratory conditions, reproduction problems, and neurological and cognitive effects are all reported. However, causal relationships between active substances and a particular health risk are still not proven.

The recently REFIT study (Ecorys, 2018) shows that consumers are quite well protected from exposure since the introduction of legislation on maximum residue levels (MRLs) for agricultural products for food and feed. However, more attention can be paid to the exposure of farmers and operators applying PPPs.

3.9. Interactions between crop protection practices

Interactions take place between the various crop protection practices discussed in the previous sections. They can reinforce each other, have no interaction, or exclude each other. Information on these interactions is needed to assess the extent that crop protection practices can be combined for greater effect. Firstly, it is important to distinguish between preventive and control measures.

Breeding and induced resistance are preventive measures. If effective, there is no need to protect the plants against specific pests and diseases. Diversified systems that make use of ecological principles include both prevention and control measures. The emphasis is on prevention, but the provision of habitat for natural enemies in the direct neighbourhood of the cultivated crop can be considered as an element of control.

The application of biopesticides is a control measure, since they are intentionally applied to control pests or diseases. Plant protection products can be applied for prevention, but the vast majority of PPPs are applied to control pests, diseases and weeds.

Breeding and induced resistance do not conflict with other crop protection practices. The most conflict arises between the use of biopesticides and agrochemicals, since agrochemicals can have adverse effects on biocontrol agents. However, this problem has decreased since broad-spectrum pesticides have been replaced by selective pesticides. Furthermore, the use of both diversified systems and precision agriculture can reduce the conflict by location-specific pesticide application, if such control is necessary.

It is important to emphasise that the practices described in Chapter 3 are not applicable to all crop protection problems. The main problem categories are pests (e.g. insects, nematodes), pathogens (e.g. viruses, bacteria, fungi that cause diseases) and weeds. Mechanical methods are used to control weeds, whereas breeding contributes to the prevention of damage caused by pests and pathogens.

3.10. Conclusion on impact assessment

Table 1 shows the potential impact of new and emerging crop protection practices on crop yield, farmer income, biodiversity (including pollinators), climate change, public health, food safety, food security, skilled workforces, competitiveness of EU farming.

Table 1. Potential impacts* of new and emerging crop protection practices

	Mechanical practices	Plant Breeding	Biocontrol*	Induced Resistance*	Ecological principles*	Precision agriculture	PPPs
Crop yield	=	++	++	+	++	++	=
Farmer income	=	+	=	=	=	+	=
Biodiversity and pollinators	=	=	++	=	++	+	-
Climate change	-	+	=	=	+	+	=
Public health	+	+	+	=	=	+	=
Food safety	+	+	+	=	+	+	=
Food security	=	+	=	+	=	+	=
Competitiveness of EU farming	=	++	+	+	=	++	=

*The impact assessment is indicative, i.e. the available data and information is insufficient or inconclusive. The impacts are rated as Positive (+ or + +), Neutral/Unknown (=) or Negative (-)

Precision agriculture has positive impacts on all factors, with high impacts on Crop yield and Competitiveness. Plant breeding, Biocontrol and Ecological principles have positive impacts on multiple factors, such as crop yield and competitiveness of EU farming.
All impacts of Biocontrol, Induced resistance and Ecological Principles are positive or neutral; with Biocontrol and Ecological principles having high impacts on Biodiversity and Crop yield, although their impacts on Farmer income are neutral.

Improved Mechanical techniques can have a negative impact on Climate change due to increased emission of greenhouse gas from the soil and increased use of fuels.

It should be noted that Table 1 does not take into account the interactions between crop protection practices, as discussed in Section 3.9. For example regarding PPPs, precision agriculture and improved sprayer technology can be expected to improve application efficiency and therefore reduce the amounts of PPPs that are applied. Furthermore, the combined interactions of all the other new practices can be expected to reduce the overall need for PPPs in the future.

Table 2 rates the potential impact of the new and emerging crop protection practices on the control of weeds, diseases and insects. These ratings aim to give an indication of how well weeds, diseases and insects can be controlled when the use of PPPs is reduced or eliminated.

The table is based on the information found in peer-reviewed literature, together with expert judgement. The weighting of the impacts should be seen as indicative.

Table 2. Potential impact* of new and emerging crop protection practices on the control of weeds, diseases and insects

	Weed Management	Disease control	Insect Management
Mechanical practices	●●●	○	●
Breeding	●●	●●●	●●
Biocontrol	●	●	●●
Protection using induced resistance	○	●●	●
Diversified systems	●●●	●●●	●●●
Precision agriculture and decision support	●●●	●●●	●●●

*The weighting of the impact should be seen as indicative.
●●● high potential impact, ●● intermediate potential impact, ● low potential impact, ○ no significant impact.

It can be seen from Table 2 that Precision agriculture and ecological principles have high potential impacts on all three pests. Plant breeding follows with a high potential impacts on diseases, and intermediate potential impacts on weeds and insects.

Mechanical techniques have a high potential impact on weeds, but otherwise they, biocontrol and induced resistance have intermediate, low or no potential impacts.

Table 2 indicates that a combined approach employing most of these categories of practices is required to provide effective control of weeds, diseases and pests with reduced use of PPPs. The most critical categories are Mechanical techniques, plant breeding, ecological principles and precision agriculture. Biocontrol and induced resistance may become increasingly effective over time.

4. Stakeholder analysis

4.1. Introduction

The emerging crop protection practices and their impacts discussed in Chapter 3 provide a basis for developing new policy options concerning crop protection.

In order to propose policy options, it is necessary to understand the interests of the most important stakeholders who will be affected by new crop protection practices. Four groups of stakeholders can be identified:

- Customers (consumers, retailers and food processing industry)
- Producers (farmers and growers)
- Suppliers (crop protection industry and other suppliers)
- Society (citizens and NGOs)

4.2. Customer group

4.2.1 Consumers

Many consumers have varying views on crop protection and food supply, which depend on the circumstances. In times of uncertain or scarce supply, consumer interest focuses on ensuring food security. On the other hand, if high quality food is readily available at reasonable prices, consumer interest in food security receives little attention.

However, consumer interest in crop protection and the use of PPPs mainly relates to pesticide residues and toxicological risks in food, and how this aligns with their risk perceptions on food safety (Frewer, 2017).

This interest in food safety also applies to food retailers, as they are vulnerable and responsive to consumer concerns (Levidow & Bijman, 2002). Retailers want to give consumers a safety guarantee, particularly for fresh produce, which is an important product category as it provides good opportunities for strengthening company identity and customer loyalty.

In general, consumers show a willingness to pay premium prices for products with no or low use of pesticides. However, other factors including: individual and regional differences, the role of food labelling and marketing, and; other food choice motives including taste, should be taken into account when looking at their interests in crop protection.

4.2.2 Retail

With the rise of private labels, retailers increasingly "find themselves absorbing more responsibility and risk in the maintenance of food quality" and became more vulnerable and responsive to consumer concerns (Levidow & Bijman, 2002).

As a result, retailers have developed common practices or criteria for lower-pesticide products with the following aims (Levidow & Bijman, 2002, p. 42): "to maintain consumer confidence in product quality, to establish Europe-wide supply chains which meet common or minimum standards, to make supplies interchangeable, and to avoid competition for low-pesticide products defined in various ways."

Retailers have set up their own quality and safety control systems for their supply chains, including requirements for the use of inputs like seeds and pesticides. To avoid becoming too dependent on particular suppliers, retailers are seeking to develop quality standards that can be broadly implemented by numerous suppliers in Europe (Brouwer and Bijman, 2001).

4.2.3 Food processing industry

Food processing companies have also addressed consumer concerns. Regarding pesticide reduction, some companies have funded research on pest-resistant seeds and alternative chemical agents; some have also promoted precision (rational) agriculture methods, as distinct from Integrated Pest Management (IPM) and Integrated Crop Management methods.

At the same time, food processors have relatively greater interest in differentiating their products from those of competitors in other respects. Unlike retailers, they search for novel seeds which may provide consumer benefits and gain public acceptability, while seeking exclusive control over such products.

4.3. Producers

Farmers and growers have a dual relationship with PPPs. On the one hand, they benefit from crop protection as it prevents yield losses and safeguards product quality; their income depends on both. On the other hand, farmers are directly exposed to these products when they mix, load and spray the pesticides, sow pesticide treated seeds, weed and harvest sprayed crops, and clean and dispose of containers. Moreover, other members of rural communities may suffer indirect exposure, including family members and people living in rural areas where there is an intensive use of pesticides (Tago et al., 2014).

Farmers recognise the need to reduce their dependency on agrochemicals. They are aware of public concerns about PPPs and the consequences for their “licence to produce”. Nevertheless, they are often reluctant to switch to alternative crop protection practices as, in many cases, alternative methods are not as efficient as chemical control. There may not even be suitable alternatives for particular circumstances.

Essentially, farmers rely on PPPs as they are effective and cost-effective; these benefits are easily seen, and they provide a rapid return on the investment (Buckwell et al., 2020).

An important factor regarding alternative crop protection strategies is the cumulative benefit from combining various practices for optimum efficacy. However, convincing farmers to re-design their farming systems to adopt combinations of preventive measures for pest management is a difficult task as it requires behavioural change.

Farmers are increasingly pressurised to reduce their use of conventional (chemical) pesticides. Firstly, they are required by the EU regulations. According to Bonanno et al. (2017), EU farmers face a challenge since the number of newly approved active ingredients for herbicides has declined and is expected to decline further still. This is due to more stringent pesticide regulations, and to the slowdown in the development of alternative solutions caused by the stringent regulation.

Secondly, food retailers and processers exert pressure on farmers to reduce pesticide use. As a result, farmers’ organisations are advising their members to adopt non-chemical crop protection methods without necessarily having sufficient information, knowledge and an adequate range of suitable products. According to the RISE report (Buckwell et al., 2020, p. 15), these organisations 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, more volatile yields and reduced

EU agricultural outputs and higher risks of microbial contamination of foods impacting human health, and; (iii) reduced competitiveness of EU agriculture with less viable farm businesses.

4.4. Suppliers (crop protection industry and other suppliers)

Supplier interests cover four sectors: the crop protection industry, the biocontrol sector, plant breeding companies, and the agricultural machinery industry:

4.4.1 Crop protection industry

The use of PPPs is clearly in the interest of the crop protection industry, as they want to sell their products. The global market for agrochemical pesticides has grown steadily since 2006, although sales in Europe remained relatively stable. Simultaneously, leading agrochemical companies have entered a period of significant consolidation through mergers and acquisitions.

Due to rising research and development costs to meet the growing demand for safer agrochemicals, and tightening of regulations by the authorities, major crop protection companies have diversified their regular businesses. For example, they have focused more on plant breeding and genetically modified seeds, and this newer sector has grown to account for a considerable proportion of their total sales (Nishimoto, 2019).

More recently, these companies have started exploring new fields (e.g. precision agriculture and crop stress management). They have also accelerating the product development process by introducing novel technologies to further improve agricultural productivity (e.g. genome editing) (Nishimoto, 2019). Increasingly, the big companies in the crop protection industry also focus on biocontrol.

The supply industry sees itself forced into a defensive position by increasing societal pressure to substantially reduce the use of PPPs. They argue that PPPs can be safely used within responsible limits, they contest the contribution of PPPs to biodiversity decline, and they claim that health and the environment are now sufficiently protected from impacts of PPPs by a stringent regulatory system (Buckwell et al., 2020; Parker, 2015).

Nevertheless, the crop protection industry is confronted with regulations that have been tightened over the past years. In the European Union, the criteria for safety and environmental impact assessment were switched from risk-based to hazard-based in 2011, leading to a decline in the number of registered chemical products (Nishimoto, 2019). Industry representatives argue that the hurdles have been raised higher every year with the need for initial registration and then re-registration of the active ingredients of agrochemicals.

The industry would prefer environmental impact assessment to be based more on probabilistic risk assessment rather than being hazard-based. The hazard-based approach is criticised for its lack of scientific basis (Hunka et al., 2015).

Another issue is that the reduced number of registered active substances leads to greater use of a smaller set of products. A limited set of PPPs increases the risk of weeds, insects and pathogens developing resistance to these products, which reduces their effectiveness. As the industry currently sees no viable alternatives to agrochemicals, this situation leads to lower crop yields and product quality (Buckwell et al., 2020; Seufert et al. 2012).

In addition, the PPP industry is concerned about the rising cost and time to get product approval under stricter EU regulatory process. This restricts the industry's ability to develop more sustainable alternatives for the European market (Buckwell et al., 2020).

Although it is critical towards societal pressure and the regulatory system, the crop protection industry is committed to responding to societal demands: to make safety data more accessible to the public; to provide greater transparency, and; to increase trust in the approval process. For example, the European Crop Protection Association (ECPA), CropLife International and their member companies have launched their own transparency commitment to ensure that more data related to the safety of their products are made publicly available (Blake, 2019).

4.4.2 Biocontrol sector

As well as the 'traditional' crop protection industry, other suppliers also have an interest in crop protection. First and foremost, new players have entered the market with a focus on biocontrol technologies. The biopesticide industry supports sustainable agriculture, enabling farmers to grow healthy and environmentally-friendly crops.

The biocontrol sector is also critical of the current regulatory system; labelling it as limiting the uptake of biocontrol methods for crop protection. For example, the International Organisation for Biological Control (IOBC) identified the following limitations to biocontrol uptake: risk averse and unwieldy regulatory processes; bureaucratic barriers to access biocontrol agents; insufficient engagement and communication with the public, stakeholders, and growers of the benefits of biocontrol; and fragmentation of biocontrol sub-disciplines (Barratt et al., 2018).

Given this unsatisfactory situation, the biocontrol industry strongly argues that Regulation (EU) 1107/2009, which was designed for synthetic active substances and products, is not appropriate for the approval and authorisation of biological plant protection products (Ecorys, 2018). The industry requests a separate process for the approval of biological active substances and PPPs. It argues that the criteria for biological substances are often too stringent for products of natural origin.

4.4.3 Plant breeding companies

Plant breeding companies are focusing on developing new plant breeding techniques. These techniques can provide more efficient and precise methods of modifying the genetic structure of plants. They include genome editing, which has made tremendous progress since the introduction of CRISPR-Cas in 2012 (see Section 3.3). Companies working in this area support plant breeders in improving important crop traits that always have been difficult to improve by traditional cross breeding.

Breeders consider that plant breeding helps to produce 'more with less' through efficient use of resources and reduced pressure on the environment. Accelerating genetic improvement through the development of new germplasm technologies is critical to achieving sustainable increases in productivity.

4.4.4 Agricultural machinery industry

The agricultural machinery industry has a growing opportunity to develop and provide new technologies that improve the efficiency and effectiveness of crop protection practices.

The new technologies can be divided into: i) precision agriculture 'hardware', including object identification, sensors, global navigation satellite systems, connectivity and other information and communication technology, robotics and autonomous navigation, and; ii) 'software' in the form of decision support systems (See Section 3.7).

This industry supports the development and use of precision agriculture techniques that contribute to sustainable use of pesticides, since this provides a significant and growing source of income.

Since the traditional crop protection industry increasingly diversifies, developing activities in biocontrol, breeding and precision agriculture, perspectives are created to develop crop protection strategies that consist of crop protection techniques, supplemented with extension services.

4.5. Society

The use of PPPs is subject to societal concerns because of their possible impacts on human health (of producers, consumers and in some cases bystanders) and the environment (through loss of biodiversity and pesticide resistance).

According to Frewer (2017), there are two issues which need to be understood in relation to societal response to pesticide use. The first relates to the safety of pesticide residues in food, and whether this aligns with toxicological risk assessments, as well as the risk perceptions of citizens. This has been discussed in section 4.2.The second focuses on contamination of the environment (air, soil and water) from pesticides, which may have negative environmental and agronomic impacts (for example, on biodiversity and the emergence of pesticide resistance).

The RISE Foundation report (Buckwell et al., 2020) found that most environmentalists and many scientists are concerned that the EU is not acting sufficiently strongly or rapidly to reduce biodiversity loss by what they see as a necessary system change in farming methods. Environmentalists argue that the current food production system with its high degree of dependence on synthetic PPPs is unsustainable, and they advocate stronger actions to reduce or abandon their use. However, the multiplicity of organisms potentially affected by PPPs and the complexity of their interactions with each other and with all other aspects of human activity involved in food production make it hard to determine the actual impact of PPPs.

The lack of scientific consensus on the effects of pesticides on human health and the environment has a negative effect on public support for policies on their use (Aklin and Urpelainen, 2014). Frewer (2017, p. 688) observed that “the scientific controversy associated with the possible impacts of pesticides potentially signalled that their use may be ‘out of control’, and thus human health and environmental impacts may be unanticipated, unintended and unpredictable. Affective factors influence peoples’ acceptance of pesticide use, disgust being an influential factor associated with consumer decision-making across different applications of agrifood technologies.”

Dismissing affective (i.e. emotional) responses by citizens as irrational has further fuelled public distrust in regulators and the associated industries, and, as a consequence further communication about the topic is likely to be disregarded (Frewer, 2017).

4.5.1 NGOs

A number of NGOs represent the concerns of citizens. Some NGOs can be more or less activist, and often focus on single societal issues like human health or environmentalism.

Environmental NGOs are particularly concerned about crop protection. They include the Pesticide Action Network (PAN) and organic groups such as the UK Soil Association. These NGOs often support or demand more stringent regulations to increase the pace towards a pesticide-free Europe (Hillocks, 2012).

The NGOs report that health and environment are inadequately protected by the current system because: the impacts of PPPs 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 (Buckwell et al., 2020). As a consequence, they urge consumers to avoid products from crops grown with the aid of pesticides, and encourage the development of alternatives (Friends of the Earth (2012), and others).

5. Policy options and legal fit

5.1. Introduction

Previous chapters have described the technical developments in crop protection, their impacts, and stakeholder interests. This chapter proposes policy options to support farmers and growers adopt the most suitable crop protection strategies consistent with EU objectives. The envisioned support may be provided by public bodies, and particularly by the European Union.

The policy options have to be considered within the context of the CAP objectives and also the wider context of the future of food production, and climate change. The demarcation of responsibilities between the EU and Member State levels also has to be considered.

Firstly, the policy options have to serve the nine CAP objectives:

1. To ensure a fair income to farmers
2. To increase competitiveness
3. To rebalance the power in the food chain
4. Climate change action
5. Environmental care
6. To preserve landscapes and biodiversity
7. To support generational renewal
8. Vibrant rural areas
9. To protect food and health quality.

Secondly, the wider context of the future of the food production and climate change is affected by the supply chain and international trade. Competition may both limit policy options and indirectly provide policy options (see Chapter 2). It is therefore important to apply a systems perspective for policy development, taking into account other areas related to crop production.

Thirdly, crop protection policy options may be developed for implementation at EU level or by delegation to Member States. In the first instance, both objectives and means of implementation are defined at EU level. In the second instance, the objectives are defined at EU level and Member States choose their own means of implementation.

Furthermore, policy options must include research and development of the methods and means of implementation, including at the practical level. Policy instruments may range from mandatory to voluntary options.

The following sections focus on the policy options to support the crop protection practices presented in Chapter 3. The practices are considered individually, and also in ways that they may interact in a systems approach. The possible impacts of the policy options are also explored.

5.2. Policy options

5.2.1 Retaining the current legislative framework

The baseline policy option is to do nothing. This implies that the existing policies will continue, including the legal framework. The main instruments are Regulation (EC) 1107/2009 concerning the placing of plant protection products on the market and Regulation (EC) 396/2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin. These regulations will be revised according the REFIT study recommendations. The criteria for registration of PPPs and for setting MRLs will remain unchanged. Developments in breeding, biocontrol and precision agriculture will continue, based on private sector initiatives.

Consequences. Under this option little progress is likely on protecting the environment and biodiversity, and negative effects will continue. The income and competitiveness of European farmers will not improve. Crop protection will continue to depend largely on PPPs. The approval and introduction of new PPPs is uncertain, since the EU is not an attractive market for the PPP industry, and current registration procedures take a long time, with an uncertain outcome. The competitiveness of EU farmers will deteriorate if producers outside the EU are able to innovate and improve their production processes, including new techniques for crop protection.

Implications for farmers. For farmers, this policy means a continuing dependency on chemical PPPs. Agriculture will not be seen as an attractive career due to limited technological development and innovation compared to other economic sectors. Farmers will struggle to compete with other countries that make greater progress in developing new crop protection practices. Those who wish to adopt new production practices will receive little encouragement or support.

Implications for consumers. Since there is evidence that consumers are already adequately protected against PPP residues, it is likely that this level of protection will continue.

Implications for PPP industry. This scenario is positive for the PPP industry in the sense that reliance on PPPs will remain high. However, the opportunities for innovation will be limited by the size of the EU market; the high approval criteria relative to other countries, and; the length of time and uncertainty around getting approval. As a result, the number of requests for authorisation, and the introduction of new PPPs, is likely to fall behind that of other countries.

Implication for NGOs. Since little progress will be made in protection of the environment and biodiversity, NGOs will remain active in challenging governments and the EU, and convincing citizens, on the need to switch to more sustainable plant protection practices.

5.2.2 Removing legislative barriers to new breeding techniques

The development of new breeding techniques can be supported by increasing investment in fundamental research, which will enhance the speed of innovation.

However, at present, the most important constraint to the development and uptake of new varieties is a number of drawbacks with the current legislation (See Section 5.2.3 in Appendix 1).

To resolve this situation, the European Commission Group of Chief Scientific Advisors (European Commission, 2018) have concluded that 'the GMO Directive should be revised to reflect current knowledge and scientific evidence, and as part of a broad dialogue with relevant stakeholders and the public at large'.

The Scientific Advisors also conclude that regulatory framework should 'put much more emphasis on the features of the end product, rather than on the production technique'.

Using a product-based approach implies that the breeding techniques should not be the main criterion for determining whether new varieties can be placed on the market. Instead it should be the genetic composition of the end product. If DNA in a new variety comes from the species being improved, or from a species that can be crossed from this species using traditional methods, then it is argued that the technique used should be exempt from GMO legislation.

It follows that a rational policy option is to adjust the legislation to take the latest breeding techniques into account.

If the EU legislation is not adjusted, a policy option is to close the EU borders to products from varieties that are classified as GMOs, because they are produced by a technique that is not allowed in the EU.

Consequences. The potential of innovative breeding techniques will only be fully realised if the resulting new varieties are authorised for commercial production. Adjustment of the EU legislation from a process to a product-based approach will enable this uptake.

Use of new breeding techniques will enable a more targeted development approach, and can significantly improve the speed of introduction of new varieties with better resistance against pests and diseases. More resistant varieties will lead to lower use of PPPs.

Closing the EU borders for products from varieties that are classified as GMO according to EU legislation will contribute to a level playing field with exporting countries for European farmers.

Impact for farmers. If resistant varieties become available, the use (and cost) of PPPs will reduce and the resistant varieties will contribute to yield stability. There will continue to be some use of PPPs, as farmers will still need to control pests and diseases in varieties that do not have resistance.

Costs of plant material can be higher than from non-resistant varieties. However, there will be an overall positive impact on farmers' incomes, and their competitiveness, through cost savings.

Reduced PPP use lowers health risks for farmers and farm workers.

Reduced use of chemical PPPs use also facilitates the use of biocontrol agents, if applied.

The creation of a level playing field between EU and non-EU farmers will also support the competitiveness of EU farmers.

Impact for consumers. Reduced use of PPPs lowers the overall risk of maximum residue levels being exceeded, potentially benefitting consumer health.

On the other hand, consumers may consider new plant breeding varieties and their products to be GMOs, which may cause them to reject them as being 'unnatural'.

Impact for supply industry. Legislative changes to support new breeding techniques would stimulate the market for new varieties and plant breeders would invest in further development. Over time, a widespread introduction of new varieties would be expected, since the new breeding techniques can also be applied to other plant properties.

Producers and suppliers of agrochemicals would see their sales fall. Producers of biopesticides could profit indirectly, since the reduction of PPP also lowers their threat for biopesticide agents. Closing the border for products classified as GMOs would indirectly support the PPP industry, as it would profit from the increased competitiveness of European farmers.

Impact for NGOs. NGOs representing citizens with concerns about GMOs would be disappointed if new breeding techniques are permitted. This would probably still apply even if new varieties contain species-specific DNA.
NGOs supporting a healthy environment and biodiversity will welcome resistant varieties, since the reduction in the use of chemical PPPs will benefit the environment and biodiversity.

5.2.3 Developing and promoting the use of biocontrol

To enhance the development and uptake of biopesticides, the EU may consider the following policy options:

1. Increase investment in fundamental and applied research to develop new biocontrol agents;
2. Prepare separate legislation for the placement on the market of biocontrol agents, oriented at ensuring the same level of safety, but different procedures and endpoints, compared to chemical PPPs;
3. Biocontrol agents may not control pests or diseases completely. As a result some pests or diseases may be present on the food products. Biocontrol agents are often themselves macro or microorganisms, and it can be expected that they may also be present on food products. The appropriate policy option would be to tolerate low levels of micro and macro organisms on fresh food products, providing that they do not pose a threat to human health or biodiversity. Such a policy option would need to be linked to phytosanitary policy. Applying an equivalent option to other countries exporting to the EU would mean the EU having to accept increased risks of introducing quarantine organisms.
4. Stimulate the creation of experimental farms and farmers' networks to develop and implement biocontrol on farms. Provide support from knowledgeable extension workers and suppliers of biocontrol agents for farmers to learn new techniques and learn from each other to improve sustainability for the overall benefit of farming communities.

Consequences. Developing a wide range of biocontrol agents will take a significant amount of time. Separate legislation for biocontrol agents could increase the speed and ease of registration..

Reviewing the zero tolerance requirement for pests and diseases on fresh food products would increase the scope for using biopesticides. Adopting them requires new knowledge and skills for farmers and workforces, and education and training would therefore be needed.

Impact for farmers. All the proposed policy options would potentially contribute to the availability and successful implementation of new biocontrol agents and practices. They would also contribute to integrated pest management techniques.

The adoption of biopesticides does not directly contribute to a farmer's income or competitiveness. This only occurs if alternative methods to control specific pests or diseases are not available, or suitable. The cost of biocontrols can be higher than that of chemical PPPs. However, biopesticides lessen the health risks for farmers compared to chemical PPPs.

Impact for consumers. Replacing chemical PPPs with biopesticides would benefit consumer health by reducing the risks of exceeding maximum residue limits for chemical PPPs, providing that the biocontrol agents do not pose a risk to human health. The issue of health risks from biocontrol agents needs to be investigated.

Impact for suppliers. The development and implementation of biocontrol agents benefits the income and competitive position of the producers and suppliers. Producers and suppliers of chemical PPPs that do not extend their product range to include biopesticides will be threatened. However those that do extend their product range will see their income and competitive position largely unchanged.

Impact for NGOs and citizens. NGOs and citizens will generally welcome the use of biopesticides that replace harmful chemical PPPs. This will be especially the case when biocontrol agents are indigenous to the ecological area. If they are introduced from other ecological areas, there is risk that they become invasive alien species. Such potential risks would need to be investigated.

Funding research and training on crop-induced resistance

The development of techniques for inducing resistance through the use of biotic and abiotic agents has a short history. Commercial products are not yet available and more research is needed. One policy option would be to increase investment in fundamental and applied research.

It is expected that successful practical implementation will require further development to find the most effective application methods. Another policy option would therefore be to invest in the education and training of extension workers and farmers in plant propagation and cultivation.

A further option would be to create farmers' networks to share experiences and insights for the benefit of all.

The review described in Appendix 1 of this study did not find any negative impacts from the use of substances to induce resistance (as shown in Table 4 of this report) and there are no regulatory requirements specifically concerning induced resistance. Nevertheless, it may be necessary to consider authorisation for placing biotic and abiotic agents on the market. The purpose would be to prevent misuse of this category of substances as an easy route for placing PPPs on the market.

Consequences. Successful commercial implementation of biotic and abiotic elicitors to induce crop resistance to pests and diseases would reduce the need for chemical PPPs. Formal regulation of placement on the market of both biotic and abiotic agents would safeguard against environmental and health risks, and prevent the sale of agents that are ineffective.

Impact for farmers. It can be anticipated that further research will help to generate a range of agents for commercial use as an alternative to chemical PPPs. Farmers would be able to save on the cost of PPPs while maintaining yields and product quality. Training, extension services and farmers' networks will contribute to successful implementation. Regulation of placement on the market will enable farmers to select effective and safe agents. However, it is too early to assess the impacts on farmers' income and competitiveness.

Impact for consumers. The impact on the health of consumers will be negligible. The chemical PPPs that are replaced are those applied in the early stages of crop growth, which presents a relatively low risk for consumers.

Impact for suppliers. The development of agents for inducing resistance opens new market opportunities for producers and suppliers, although this will result in lower sales of chemical PPPs. In the event that existing producers and suppliers of chemical PPPs extend their businesses to include agents inducing resistance, the effects on their overall business will be negligible.

Impact for NGOs and citizens. NGOs are likely to support a transition from chemical PPPs to biotic and abiotic agents as they have little or no risk to human health or the environment.

Promoting genetically diversified cropping systems

The development of diversified systems can be supported by the following policy options:

1. Applied research to develop practical options for farmers to increase the level of (genetic) diversity in their cropping systems;
2. Stimulate the creation of experimental farms and farmers' networks to develop and implement biocontrol on farms. Provide support from knowledgeable extension workers and suppliers of biocontrol agents for farmers to learn new techniques and learn from each other, to improve sustainability for the overall benefit of farming communities.

Consequences. Diversified systems span a wide range of cropping practices which increase genetic diversity and resilience to abiotic and biotic stressors.

Once the diversification is successful in controlling pests and diseases, there is less need – or no need – for pesticides, and there is a corresponding reduction in the negative impacts of PPPs on the environment and biodiversity. Diversified systems that increase diversity at field, farm and landscape level will not only contribute to functional agrobiodiversity, but also to wider biodiversity.

Diversified systems can have positive impacts on crop yields, benefitting farm incomes. However, diversified systems can also lead to increased costs and less overall income than conventional cropping, particularly monocultures. For example, crop rotations may include cover crops which provide green manure but no sales revenue; and some crops in a rotation may provide less income than others.

Impact for farmers. Application of diversified systems will benefit farmers' incomes by reducing the cost of PPPs. On the other hand, other costs may increase and revenues decrease through less intensive land use and additional inputs. It is therefore unclear, at the present time, what the balance between costs and revenues might be under different diversified systems and varying circumstances.

Impact for consumers. Consumers will benefit from reduced use of chemical PPPs as the overall risk of exceeding maximum residue levels will decrease. Products that benefit the environment and biodiversity may also have added value for consumers and attract premium prices.

Impact on supply industry. The reduction in use of chemical PPPs will harm agrochemical companies, unless they diversify. Producers and suppliers may be compensated by providing inputs related to diversified cropping systems.

Impact on NGOs and citizens. Lower use of chemical pesticides and fertilisers will have positive impacts on the environment and biodiversity. However, any increased land use, as result of lower yields from diverse systems, will harm biodiversity. Therefore, it is important that yields and crop production from diversified cropping systems are similar to (or only slightly less than) those of conventional farming systems.

Supporting precision agriculture

The development of precision agriculture is likely to have an increasingly large impact on both conventional and alternative farming systems in the future. Political decision-making is necessary to make best use of the potential it offers. Precision agriculture is relevant for all areas of agriculture. It concerns the optimisation of all inputs, such as labour, fertilisers and the use of machinery.

Regarding crop protection, the following policy options may be considered:

1. Enhance the use of PA technology for monitoring crop pests and diseases (detection, identification and quantification);
2. Enhance the use of PA technology for selective weed control;
3. Enhance the use of precision spray application techniques to optimise the amount of PPPs applied and to reduce drift;
4. Use automised data collection for recording: pest and disease incidence; the use of control measures; and the effectiveness of measures that are applied, to optimise crop protection strategies. The data can provide information at individual farm level (time-series data) or between farms (cross-sectional data);
5. Invest in improving the technological, environmental and managerial knowledge and skills of farmers and their employees with respect to precision agriculture;
6. Establish an open data approach throughout the food chain, with adequate standards that facilitate data exchange. Provide tools to control the flow of farmers' data to other stakeholders;
7. Include site-specific use of PPPs in legislation.

Consequences. The use of PA technology in crop protection reduces the use of PPPs for the following reasons:

In the first place, PA observation technology supports the early detection of pests and diseases, enabling the farmer to intervene early.

In the second place, it enables the farmer to reduce the amount of PPPs applied, by treating only the affected spots.

In the third place, environmental emissions can be reduced by adjusting the treatment to the specific circumstances in the field.

A further benefit is that PA technology contributes to the protection of non-target organisms.

Impact on farmers. Farmers applying PA technology for crop protection can save costs by reducing the use of PPPs. Also, early detection can contribute to higher yields.

On the other hand, the use of PA technology requires significant investment and skills, which can be too high for small-scale farmers who do not benefit from economies of scale. It may be more economical for small-scale famers to use specialised contractors, who are highly skilled and are able to spread the investment cost of machinery over larger areas. As PA technology requires high investment and high skills, it leads to an increase in large-scale farming and may put smaller-scale farmers at a disadvantage.

Impact on consumers. It is unlikely that precision agriculture will have direct impacts for consumers, although there will be a benefit from reduced use of chemical PPPs, as the overall risk of exceeding maximum residue levels will decrease.

Consumers may indirectly gain from the provision of more information about their food purchases.

Furthermore, if the power balance within the supply chain due to the scale dependency of the applied PA technology changes significantly, this can have an impact for consumers, if food prices change.

Impact on supply industry. Large scale application of PA technology will reduce the use of chemical PPPs, with a corresponding negative impact on the agrochemical industry and suppliers of PPPs. On the contrary, suppliers of agricultural machinery and the necessary software will profit from PA developments.

Impact on NGOs and citizens. The reduction in the use of chemical PPPs and emissions will reduce environmental pollution and benefit biodiversity. Should the uptake of PA lead to increases in the farm size, it is possible that there will be an indirect effect in the form of changes to the landscape.

Restricting the use of chemical PPPs

Changes in the composition and use of pesticides, particularly agrochemicals, and the widespread adoption of alternatives are critical factors for the future of crop protection.

All crop protection options discussed in previous sections potentially have positive impacts on the environment as they reduce the need for agrochemicals. Policy-makers also have the possibility to shape the negative impacts of chemical PPPs directly, which is the subject of this section.

The following policy options are identified for discussion, although this is not a complete list of possible options:

1. Prohibit the use of chemical PPPs completely;
2. Adjust the criteria for approval and registration of active ingredients or PPPs, for example by reducing the concentration of active substances;
3. Limit the number of emergency authorisations;
4. Adjust the rules for applying PPPs, including those relevant to PA technology;
5. Make PPPs more expensive by adding levies to the cost price.

Consequences. Prohibiting the use of chemical PPPs will significantly affect crop yields per hectare, as is evident from organic agriculture. This will result in an increase in the area of land under cultivation in order to maintain or increase food production in the EU. Extending the land area under cultivation will harm biodiversity. It is therefore necessary to increase efforts to develop sustainable alternatives to chemical PPPs that do not result in lower crop yields, in order to limit any long-term increase in the area of land under cultivation.

Adjustment of the approval and registration criteria will have consequences for the availability of PPPs. Stricter criteria will increase the costs for development, as well as for approval and registration. This will also lead to higher prices for PPPs and possible additional financing costs. Higher costs may reduce PPP use.

Adjustment of the rules for applying PPPs (for example, regarding wind speed) to suit the available technology may lead to reduced used of PPPs, due to more precise application.

Higher prices for PPPs may lead to their reduced use, if acceptable alternative crop protection measures are available, or to higher costs if this is not the case. Farmers will adjust their use to maximise the financial return.

Levies may be justified by using the proceeds to compensate for the negative impacts of PPPs, for example by improved protection for human health, the environment and biodiversity.

Impact for farmers. Policy options directed at reducing the use of PPPs will stimulate farmers to seek alternatives. Alternative methods that achieve similar levels of crop yield and quality are likely to be the most attractive.

At present, the use of integrated pest management (IPM) for low pesticide use may be the most cost-effective means of pest and disease control that is readily available to many farmers. In this case, the adoption of alternative crop protection measures will lead to higher costs or reduced revenue, at least in the short-term.

Farmers who currently do not use IPM may be able to reduce their use of pesticides with consequent cost savings.

If alternative crop protection options that achieve similar crop yields and quality are not available, additional restrictions on the use of chemical PPPs will result in lower crop yields and quality. Such a situation would weaken the competitive position of EU farmers compared to farmers elsewhere who do not face such restrictions. There would, however, be positive impacts in terms of lower risks of damage to human health, biodiversity and the environment from reduced used of PPPs.

Impact for consumers. Consumers and society will benefit from lower risks to human health resulting from reduced use of pesticides.

On the other hand, consumers may suffer from higher prices for food produced in the EU when the use of pesticides is restricted, unless alternative crop protection methods are available that do not depress yields or product quality. As production costs are a small proportion of consumer prices, it may be that price increases can be absorbed by the food chain or will be minimal, particularly when competing products are available from outside the EU.

Impact for the supply industry. Any policy option oriented at reducing the use of pesticides harms the interest of producers of agrochemicals. It leads to higher costs for development of active ingredients and PPPs, higher costs for approval and registration, or reduced sales.

Companies that also have interests in plant breeding and the development of biocontrol agents, would have options to compensate for loss of sales of chemical PPPs. Producers specialising in alternative crop protection methods would benefit from reduced use of chemical PPPs.

Impact for NGOs and citizens. It is likely that a reduced use of PPPs will have positive impacts on the environment and biodiversity, if there is no increase in the area of land under cultivation. Increasing land use to compensate for yield reductions would have negative impacts on biodiversity and the environment.

5.3. The systems perspective

Section 5.2 discusses policy options that focus on individual categories of crop protection practices.

However, in Chapter 2 it is argued that it is important to adopt a systems perspective, which takes into account synergies resulting from interactions between practices when used in combination.

Furthermore, it is argued that policy options based on a systems perspective should cover the whole supply chain and international trade. This opens the way to combining direct and indirect policy options at different stages and levels of the supply chain.

Chapter 3 presents various practices to protect crops against pests, pathogens and weeds. However, these practices are not equally applicable to all three groups of agents that harm crop production.

The most effective crop protection strategies are therefore those that combine practices to optimise the control of each group of agents. Table 2 (Section 3.10) shows the impact of each crop protection practice on the three groups of agents.

An example of a weed control strategy might comprise mechanical weed control (e.g. inter-row weeding) together with selective herbicides applied by precision technology that recognises weed species.

Pests and pathogens can be controlled partly by breeding resistant crops, and partly by biocontrol agents applied in diversified growing systems. Precision agriculture is also beneficial in this strategy.

Policy options should therefore differentiate between the three groups of agents.

Regarding the various crop protection practices, policy-makers have the possibility to stimulate research and development targeted at the individual practices.

They can stimulate uptake and application of those practices with a range of instruments including financial incentives, advertisements, educating extension workers, and setting up experimental farms. The stimulating measures can be accompanied by limiting measures, such as more stringent criteria for placing chemical PPPs on the market, or prescribed use of certain technologies.

These measures can be embedded in a policy oriented at consistency at farm level. This means that requirements for crop protection measures are balanced with requirements for other production processes and inputs. An example is the support of diversified systems, accompanied by a policy with the objective to improve soil fertility and resilience, and to reduce the input of artificial fertilisers.

Paying attention to all CAP objectives will prevent trade-offs between policy goals. This could be the case if a strict crop protection policy resulted in lower yields and increased land use for agricultural production, which would be harmful for the wider environment.

Crop protection policy can be strengthened by taking into account the trade and sale of crop products in addition to production on the farm.

Instruments may include: a requirement for product labelling to provide information on the sustainability of the production process, or; setting minimum sustainability requirements for producing different crops, irrespective of whether they are produced inside or outside the EU.

Such measures would protect EU farmers against unfair competition from imported crop products that do not comply with EU standards.

6. Discussion

This report proposes policy options for crop protection in the future. The options take into account different combinations of technologies within a systems perspective that extends along the supply chain to the consumer.

This perspective is in line with proposals made by the European Commission in 2019 and 2020. These include the European Green Deal, an action plan: 1) to boost the efficient use of resources by moving to a clean, circular economy, and; 2) to restore biodiversity and cut pollution.

Regarding agriculture, the proposals have been elaborated in the Farm to Fork Strategy to realise a fair, healthy and environmentally-friendly food system. This provides basic principles for development and implementation of a future crop protection strategy.

The geographical focus of this vision is the European Union of 27 Member States. The guiding objectives are the nine CAP objectives.

It is argued that international trade should be part of the systems perspective. However, this approach ignores the possibility of unintended consequences occurring outside the EU. For example, a requirement that plant food products imported into the EU will be subject to minimum sustainability standards may be difficult for producers in developing countries to meet. They may be unable to export to the EU, which would take away this source of income and prevent them from making their agriculture more sustainable. Another example would be lower yields from alternative crop protection practices. Farmers in other countries may compensate for the loss in production by converting natural areas for agricultural production.

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The overall objective of the future of crop protection project is to present an overview of crop protection options for European farmers to enable them to work sustainably while securing food production, preserving biodiversity and supporting farmers' incomes. The policy options proposed are based on an assessment of current and emerging crop protection practices and their impact on the common agricultural policy (CAP) objectives. This overview shows that several crop protection practices are under continuous development and have potential to improve future crop protection in Europe.

The likelihood that policy options can be implemented successfully depends upon the extent to which they are consistent with the interests of stakeholder groups. These include farmers, suppliers, supply chain partners, consumers and NGOs defending societal interests. Furthermore, it is important that crop protection policy options are embedded in a systems perspective. This should include related areas, such as phytosanitary policy, the entire crop production system, the supply chain, and international trade relationships – which need to be in harmony with the crop protection policy.

For each of these crop protection practices, different policy options are proposed, together with an impact assessment.

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