Cost of crop protection measures

STUDY

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Cost of crop protection measures

A follow-up to the study 'The future of crop protection in Europe' (2021)

Offering quantitative information on the options for alternative crop protection practices in the EU, this study aims to inform the European Parliament and, in particular, feed into the debate on decisions regarding the common agricultural policy within the European Parliament's Committee on Agriculture and Rural Development. Following on from an earlier study, which made an inventory of existing, new and emerging crop protection practices that could help reduce the use of conventional plant protection products, this fresh study attempts to estimate the costs of these practices as far as possible.

Some practices, such as mechanical weeding and precision agriculture, demand high investments but can be very effective in reducing plant protection product use. The same is true of biocontrol and plant breeding, which have a significantly lower cost per hectare for farmers. However, biocontrol focuses on specific pest species and cannot be easily applied to a broad spectrum of pests. Plant breeding takes time, but adoption and implementation of the new varieties are much easier for annual crops than permanent ones, which are renewed only once every 25 to 40 years. The options for induced resistance are not yet sufficiently robust and more research and development is required to make them more robust. That is also the case when it comes to applying ecological principles in order to increase biodiversity and 'green' plant protection products.

One specific area of interest is the training of farmers. Whereas some options do not involve much training, precision agriculture and the application of ecological principles to increase biodiversity can require considerable education and training.

AUTHORS

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Executive summary

Aim of the study

This study provides a quantitative assessment of the options for alternative crop protection practices in the European Union (EU) and aims to inform the European Parliament and, in particular, feed into the debate on decisions regarding the common agricultural policy (CAP) within the European Parliament's Committee on Agriculture and Rural Development.

Introduction

EU agriculture is still heavily reliant on the use of pesticides for crop protection. A transition is needed towards more sustainable farming systems to reduce this dependency. This could include the re-design of farming systems and the use of a range of new and emerging crop protection practices. This report considers mechanical techniques, plant breeding, biocontrol, induced resistance, application of ecological principles, precision agriculture (PA) and new plant protection products. These practices can all contribute to the development of sustainable farming systems, with the greatest impact being achieved when they are used together in the most suitable combinations. Continuous development of all crop protection practices is needed to disrupt the life cycle of pests, diseases and weeds more effectively, and to improve non-chemical control methods and application of chemical control using intelligent application technologies adapted to local circumstances. Meanwhile, knowledge of these practices and the skills of operators to apply them must also be improved.

Research question

The research question is to estimate the cost of the following activities:

- application of various measures employed on farms, divided across the various EU Member States, each with their typical farm sizes and types;
- training of farmers to implement the innovations proposed, with special attention to the conditions on small farms; and
- research and development required for the crop protection measures proposed: this research question focuses on the cost of EU research programmes such as Horizon Europe for the next five years with a specific focus on those measures that are not yet standard practice within the EU.

An additional research question addressed here is the following: to what extent do these costs affect crop margins in the different Member States, making these measures more or less financially feasible?

Methodology

The basis for this study are the measures or practices identified in the STOA study 'The future of crop protection in Europe' (2021). For each of the measures listed (mechanical techniques, plant breeding, biocontrol, induced resistance, application of ecological principles/diversified systems, PA, and plant protection products (PPPs)), a cost estimation was made for the three groups of research activities listed above, based on the following steps:

- an inventory of items per activity/practice and their associated cost (as far as possible);
- diversification of the cost of application and training for different farm sizes, with the help of experts, with a focus on different training models (such as coaching and courses);
- an inventory of farm sizes across the various Member States based on Eurostat data;
- a comparison of estimated cost per measure and the effect on crop returns (expressed in standard output (SO)), available in Eurostat.

Owing to the complexity of the measures proposed and the limited research budget, these calculations can offer no more than an order of magnitude.

Selection of relevant farm types

For this study, six farm types specialised in plant production throughout the EU were considered:

- arable farms with cereals, oilseed and protein crops,
- arable farms with other crops (also referred to as general field cropping),
- outdoor horticulture (field vegetables),
- vineyards,
- olive growing,
- fruit and/or citrus growing.

The farm types selected reflect the crops listed above. However, farms can still dedicate a small share of the land to other crops, e.g. farms specialised in cereal production but also growing potatoes in a crop rotation.

Clustering of Member States

The Member States of the EU27 were clustered according to the following four indicators:

- total area of each of the farm types distinguished;
- total number of farms involved in each of these farm types;
- total returns of each of these farm types, expressed in standard output;
- average crop protection cost of each of these farm types.

The data on these indicators made it possible to cluster the Member States of the EU27 in a number of groups that face comparable conditions, and are therefore likely to experience comparable impacts when adopting and implementing alternative crop protection strategies:[1]

- 'Cluster A': Greece, Spain, Italy, Portugal and Slovenia. All these Member States have general field cropping as their most important or second most important farm type (expressed in area), with olive or citrus growing as an important second or third farm type. These Member States have average or somewhat higher than average crop protection costs per hectare.
- 'Cluster B': Bulgaria, Estonia, Lithuania, Latvia, Hungary, Poland, Romania, Finland and Sweden. These Member States all have cereals, oilseed and protein crops as their primary farm type (expressed in area) and relatively low crop protection cost per ha (below average).
- 'Cluster C': Czechia, Denmark, Croatia, Austria and Slovakia. These Member States farm mainly cereals, oilseed and protein crops as the first or second farm type and have average crop protection cost per hectare.
- 'Cluster D': Belgium, Germany, Ireland, France, Luxembourg and the Netherlands. These Member States all have general field crops as the most important or second most important farm type and relatively high crop protection costs per hectare.

Farm size distribution

Farm size distribution was analysed for the four clusters identified. A large share of farms (39 to 79 %) in the four clusters had a size smaller than the threshold size of professional farms. Only 1 to 4 % of farms belong to the 'large farms' category. The remaining group (20 to 57 %) consists of family farms, a group with a wide variation in farm size and set-up.

[1] Cyprus and Malta, small Member States with very specific conditions, were not included in the clustering.

Results of cost estimation

Some practices, such as mechanical weeding and precision agriculture, demand high investments but can be very effective in reducing plant protection product use. The same is true of biocontrol and plant breeding, which have significantly lower cost per hectare for farmers. However, biocontrol focuses on specific pest species and cannot be easily applied to a broad spectrum of pests. Plant breeding takes time, but adoption and implementation of the new varieties are much easier for annual crops than permanent ones, which are only renewed once every 25 to 40 years. Options for induced resistance are not yet sufficiently robust. More research and development (R&D) is required to make these practices more robust and that is also the case for the application of ecological principles to increase biodiversity and 'green' plant protection products. All the concepts examined are promising, but require further research to ensure robust growing systems, i.e. optimal combinations of different options to promote control-effectiveness and cost-effectiveness. Cost-effectiveness is also linked to average revenues per hectare. On average revenues per hectare are highest in cluster D (north-western European countries) and lowest in cluster B (mostly eastern and northern European countries). As a result, farmers from cluster D can afford the higher cost of alternative crop protection, including training, than their counterparts in the other three clusters. On the other hand, the farmers in cluster D already have the highest average crop protection cost per hectare, partly explained by the relatively high revenue generated by the intensive crop types farmed, which stimulate relatively higher inputs.

Training of farmers

A specific item of interest is the training of farmers. Some of the crop protection options do not require much training, although effective dissemination of knowledge on how to use and operate these options needs attention, e.g. regarding when farmers should buy new, more tolerant or resistant varieties, mechanical weeders, bio-controllers or plant strengthening products. Precision agriculture and the application of ecological principles in order to increase biodiversity both require a lot of training.

It is not easy to incentivise hobby or subsistence farmers to undergo training as they do not have the time and/or budget to spend on such activities. Moreover, subsistence farmers may use a relatively low quantity of plant protection products per hectare or avoid using them altogether, mainly applying hand weeding. This assumption needs further research in order to ascertain whether subsistence farmers do require more assistance from trainers in order to transition to more innovative cropping systems. In contrast, large farms tend to have crop protection specialists, work with modern equipment, and regularly train staff from a farm budget for training. The focus of training activities should be on family farmers, who rely on regular meetings of cooperatives, meetings with advisors or extensionists, etc. to stay up to date on technological advances and innovations in the industry. For many of them, training will not be always easy on account of time and budget limitations. Support from the farm advisory systems (FAS), which were established in all Member States from 2017 onwards, can help for at least part of the cost of this training.

Discussion

The EU's agricultural sector is very diverse in crop specialisation, farm size distribution, labour availability and cost of operation. A future challenge could be to prepare recommendations for the clusters identified, and even within the clusters as to what combination of practices would be most effective for reducing plant protection product use and at the same time economically promising.

Major conclusions

- In all Member State clusters, there are significant numbers of hobby or subsistence farmers. However, they generate a relatively small share of revenues. Subsistence farmers are likely to perform more hand weeding and use relatively low quantities of plant protection products because of the associated cost. This assumption requires more research.

- The application cost of sustainable crop protection methods can be estimated most accurately for mechanical weeding methods.
- The application costs of technologies that require investments are scale-dependent and favour large farms. This is especially the case with precision agriculture.
- Training is necessary for techniques that require additional knowledge to ensure effective application. This is the case for techniques such as biocontrol and precision agriculture. Professional family farmers using considerable quantities of pesticides are an important group to consider. The FAS can assist in applying crop protection measures according to prescriptions.
- No indication can be made for the cost of research and development necessary to develop existing and emerging crop protection techniques. Techniques that are in their early stages of development, such as induced resistance, are likely to require substantial research and development investment.

Main policy options

- Focus public investment on large, responsive groups of farmers, such as family farmers, who use substantial quantities of pesticides, have a limited farm income but greatest potential to make their crop protection more sustainable.
- Develop tools to distinguish subsistence farmers who are largely or totally dependent on farming for their income, from hobby farmers.
- Consider the synergy between several alternative practices.

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1. Introduction

1.1. Context

This report provides quantitative information on the options for crop protection in the EU. It aims to inform the European Parliament and, in particular, feed into the debate on decisions regarding the common agricultural policy (CAP) within the European Parliament's Committee on Agriculture and Rural Development.

1.2. Summary of the previous report: Options for crop protection in the EU [2]

EU agriculture is still heavily reliant on the use of pesticides for crop protection. A transition is needed towards more sustainable farming systems to reduce this reliance. It is suggested that three stages of transition can be distinguished: efficiency, substitution and redesign (the ERS paradigm). Until now, the focus has been on two out of three stages in the transition to sustainability: efficiency and substitution. An increased focus on the redesign of farming systems is needed.

New and emerging crop protection practices covered in this report include mechanical techniques, plant breeding, biocontrol, induced resistance, applying ecological principles, precision agriculture, and new plant protection products (PPPs). These practices can all contribute to the development of sustainable farming systems, with the greatest impact being achieved when they are used together in the most suitable combinations.

Of the various new and emerging practices, **precision agriculture** (PA) is one of the most promising; with benefits on all productivity, sustainability, health and economic consequences. Its use in conventional farming is growing steadily, and further uptake is favoured by two trends in EU agriculture: decreasing numbers of people working on farms, and increases in the average size of farm holdings. Another factor working in its favour is that it may be easier for farmers (particularly large-scale) to incorporate precision agriculture into their existing practices, compared to other emerging techniques. Ease of uptake is likely to be particularly beneficial in the short-term[3].

An additional benefit of PA is that it has complementary beneficial effects on the other new and emerging practices, thus justifying the approach of combining it with various other practices.

A potential drawback is that farmers will need to learn new, and foreign (i.e. non-agricultural) skills in order to implement PA technologies. In addition, it will require further improvement in the interoperability of farming equipment.

New **plant breeding** techniques also show widespread benefits for crop protection on all indicators apart from biodiversity, where a neutral impact is indicated.

Biocontrol is one of only three new and emerging crop protection practices with the potential to make a positive contribution to biodiversity (the other two are 'applying ecological principles' and

[2] This text is part of the Executive summary in the report in which the options for crop protection have been collected, described and discussed (mainly the options themselves have been cited here, so not the full Executive summary has been included in this report, Riemens et al. (2021)).

[3] In fact, PA is more than a technique. It is a farm management concept where you apply technology and knowledge to manage crop plants and farm animals in the best way at the highest spatial and temporal resolution, within the economic, ecologic and social boundaries set, responding to the variation that is on the farm. In this way economic and social goals can be met. All techniques mentioned further on cannot be applied without a wide range of precision techniques (C. Kempenaar, WUR, pers. comm., 2021).

PA). 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. It shows a high potential for improving crop yields and generating positive impacts for public health and food safety. However, it may be more costly to adopt than conventional pesticides and there are currently a number of barriers limiting uptake worldwide.

Applying ecological principles has a strong benefit for biodiversity and also for crop yield per hectare, although the impact on farmer income is likely to be neutral in the short-term due to higher cost. Applying ecological principles increases plant diversity in and around crop fields through methods including crop rotation, green manure, under sowing, hedgerows, mulching and mixed cropping.

All diversification strategies benefit biodiversity, although combined diverse and conventional systems are likely to be the most resilient and bring the greatest environmental and economic benefits.

Induced resistance involves the use of biotic (living) or abiotic (non-living) agents to prime plant defence mechanisms. The practices include soil amendment, seed treatments, foliar spray elicitors and root drench elicitors. This is an emerging area of research and has not yet been adopted as a commercial crop protection practice, but could be beneficial in reducing the need for other crop protection treatments.

Improved **mechanical techniques** show small positive impacts on public health and food safety, but a negative impact on climate change. Effectiveness may increase when coupled with PA techniques, such as automated guidance based on global positioning systems (GPS).

New and emerging **plant protection products** show positive (or 'less-negative') benefits for environmental and safety factors in comparison to existing PPPs. This is because new pesticides are safer, due to strict regulation and controls in the way they are used, and they tend to be more specific in targeting pests. Also, they are applied more effectively, due to advances in application technology.

The **main challenge** is around how to integrate the new varieties, mechanisation, and biocontrol tools in new cropping systems that are enabled by precision agriculture technologies, such as autonomous robots, sensing devices and decision support tools. Breeding programs take at least 10 to 15 years, the development of a biocontrol agent takes 5 to 10 years, and designing diversified cropping systems, including addressing underlying research questions, all take a significant amount of time. Continuous development of all crop protection practices is needed to better disrupt the life cycle of pests, diseases and weeds, and to improve non-chemical control methods and application of chemical control using intelligent application technologies adapted to local circumstances, including the knowledge and skills of operators.

1.3. Research question

The research question is to estimate cost of the following activities:

1. the application of various measures employed on farms, divided across the different EU Member States (MS), each with their typical farm sizes and types;
2. training of farmers to implement the innovations proposed, with special interest for the conditions of small farms.
3. research and development (R&D) required for the crop protection measures proposed: This research question focuses on the cost of EU research programmes like Horizon Europe for the next five years with a specific focus on those measures that are not yet standard practice within the EU.

An additional research question addressed here is: To what extent do these cost affect crop margins in the different Member States, making these measures more or less financially feasible.

1.4. Methodology

The basis for this study are the measures identified in the STOA study 'The future of crop protection in Europe' (2021). For each of the measures listed (mechanical techniques, plant breeding, biocontrol, induced resistance, applying ecological principles/diversified systems, PA, and PPPs), a cost estimation was made for each of the three groups of research activities listed above based on the following steps:

1. An inventory of items per activity/practice and their associated cost (as far as possible);
2. Diversification of the cost of application and training for different farm sizes, with the help of experts, with a focus on different training models (like coaching and courses);
3. An inventory of farm sizes across the different Member States based on Eurostat data;
4. A comparison of estimated cost per measure and the effect on crop returns (expressed in Standard Output (SO)), available in Eurostat.

Due to the complexity of the measures proposed and the limited research budget, these calculations are not more detailed than giving an order of magnitude. For that reason, the inventory started with a selection of farm types in plant production and (clusters of) Member States included in this study, which has been described in Chapter 2. Valuable input was derived from an online workshop with Italian experts: Giovanni Dara Guccione, Dario Macaluso, Francesca Varia and Giancarlo Roccuzzo.

1.5. Reading guide

In the next chapter the selection of farm types and clusters of Member States is described (Chapter 2), followed by an assessment of the cost of alternative techniques including training and R&D (Chapter 3), with an overview in Chapter 4. Chapter 5 presents a discussion of the results in Chapters 2 to 4, and Chapter 6 provides conclusions and policy options. The glossary, bibliography and a number of appendices can be found at the end of the report.

2. Selection of farm types and clustering of Member States

In this chapter, the selection of relevant farm types is presented (2.1), along with indicators of importance for various farm types within each MS (2.2) and the clustering of Member States with a high degree of comparability (2.3).

2.1. Selection of relevant farm types

For an analysis of crop protection cost, it is important to focus on farm types with relatively high crop protection cost. For that reason, farms with a significant part in animal husbandry were left out of the analysis, including sheep, cattle, pig and poultry farms or mixed farms with a combination of these activities. The reason for this is that these farm types tend to have relatively large shares of their total cost and returns (expressed in SO, explained in Appendix 1) related to the husbandry and production of livestock and, as a consequence not related to crop cultivation or crop protection. Moreover, the crops that are grown on livestock farms usually have a relatively low input of crop protection: grassland, silage maize and other feed crops, mainly cereals[4].

Thus, for this study, the focus was on six farm types specialised in plant production[5] throughout the EU:

1. Arable farms with cereals, oilseed and protein crops (also referred to as COP-farms)
2. Arable farms with other crops (also referred to as general field cropping)
3. Outdoor horticulture (field vegetables)
4. Vineyards
5. Olive growing
6. Fruits and/or citrus growing.

More information on these farm types is given in textbox 2.1. This selection made it possible to study farm types with relatively higher cost of crop protection (either per ha or per Member State), for whom a change, specifically an increase, of crop protection cost due to the adoption and implementation of alternative crop protection strategies, could have a major impact on their financial viability.

[4] The differences in intensity of different crops/farm types can be derived from table 2.1 (in section 2.2), showing relatively high crop protection cost in outdoor horticulture, vineyards and fruits and citrus, compared to arable farming. For the Netherlands, the website Agrimatie (see e.g. this page) gives data on crop protection, e.g. active ingredient (a.i.) use in wheat compared to onion and potato, or with fruit farms or with a.i.-use on dairy farms.

[5] Greenhouse horticulture was not taken into account, representing a very specific farm type in mainly some Northwestern European MS but not commonly applied in large parts of the rest of the EU.

Textbox 2.1 Information on the crops grown at the different farm types:

1. Arable farms with cereals, oilseed and protein crops:
   a. cereals: e.g. wheat, barley, rye, maize
   b. oilseed crops: e.g. rapeseed, sunflower, soybean
   c. protein crops: e.g. peas, beans, clover, lucerne
2. Arable farms with other crops (also referred to as general field cropping): examples of such crops are potato, sugar beet, and onion
3. Outdoor horticulture (field vegetables): high quality vegetables e.g. cabbage, cauliflower, salad
4. Vineyards: for grape and wine production
5. Olive growing: for fresh olive and olive oil production
6. Fruits and/or citrus growing: besides citrus growing e.g. apple, pear, prune, cherry.

The farm types selected reflect the crops listed above. However, farms can still dedicate a small share of the land to other crops. E.g. farms specialised in cereal production but also grow potatoes in a crop rotation.

2.2. Indicators of importance for farm types

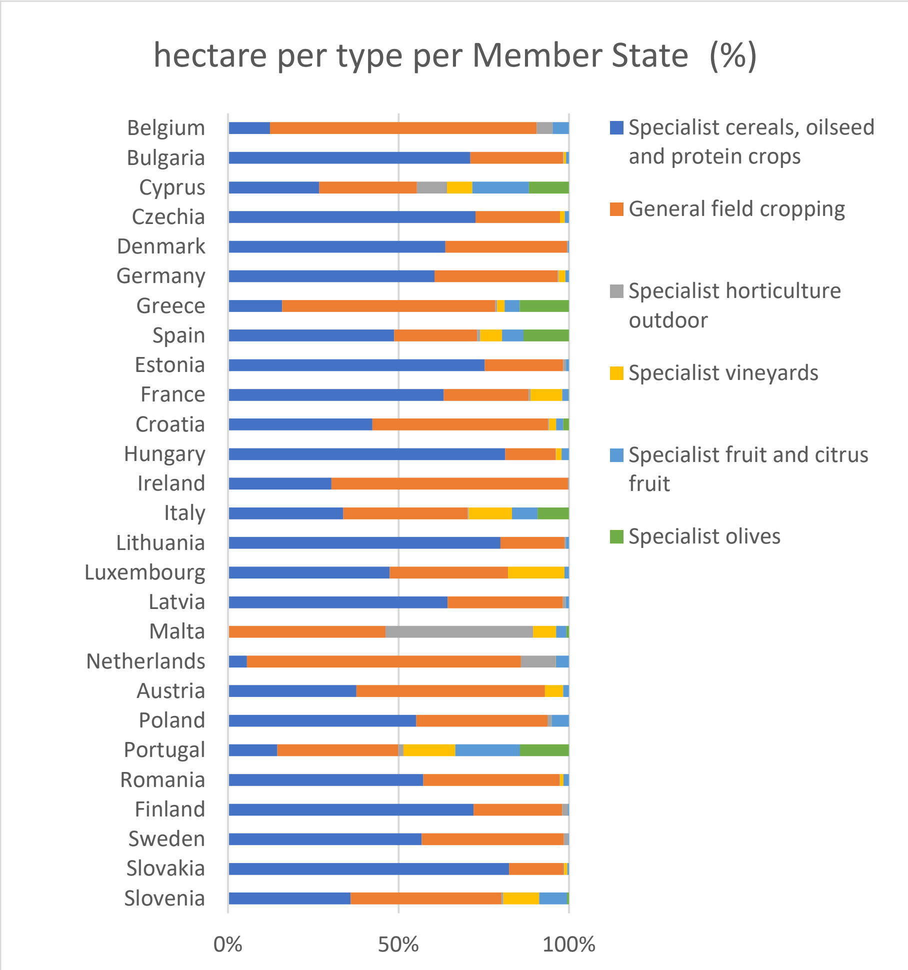
For each Member State, the relative importance of the different farm types in section 2.1 in terms of total area, total number of farms involved and total returns (expressed in SO) is presented in Figures 2.1 – 2.3 (Details are given in Appendix 2).

The first indicator of importance for specialised farm types in the different Member States is the size of cultivation area. In Figure 2.1, cultivation areas for the six key farm types are presented for each Member State as a share of the total crop area[6]. In most Member States, land use is clearly dominated by cereals, oilseed and protein crops and general field cropping (Figure 2.1). Aside from these crops, some Member States have relatively large areas (at least 10 % of total crop farming area) dedicated to:

- Fruits and/or citrus: Cyprus and Portugal
- Olives: Cyprus, Greece, Portugal and Spain
- Outdoor horticulture: Malta and The Netherlands
- Vineyards: France, Italy, Luxembourg, Malta, Portugal and Slovenia.

[6] Figures 2.1 – 2.3 present the farm types that make up at least 90% of total crop farming area in the different MS. In some MS, two farm types can already make up for 90% (or more) of total crop area; while in other MS, it takes three or four types to make up 90% of the area. See also Table A2.1 for absolute figures on area (Appendix 2).

Figure 2.1 – Proportion of area dedicated to specialised plant production by Member State in the EU 27



See textbox 2.1 for more information on the six farm types and footnote 6.

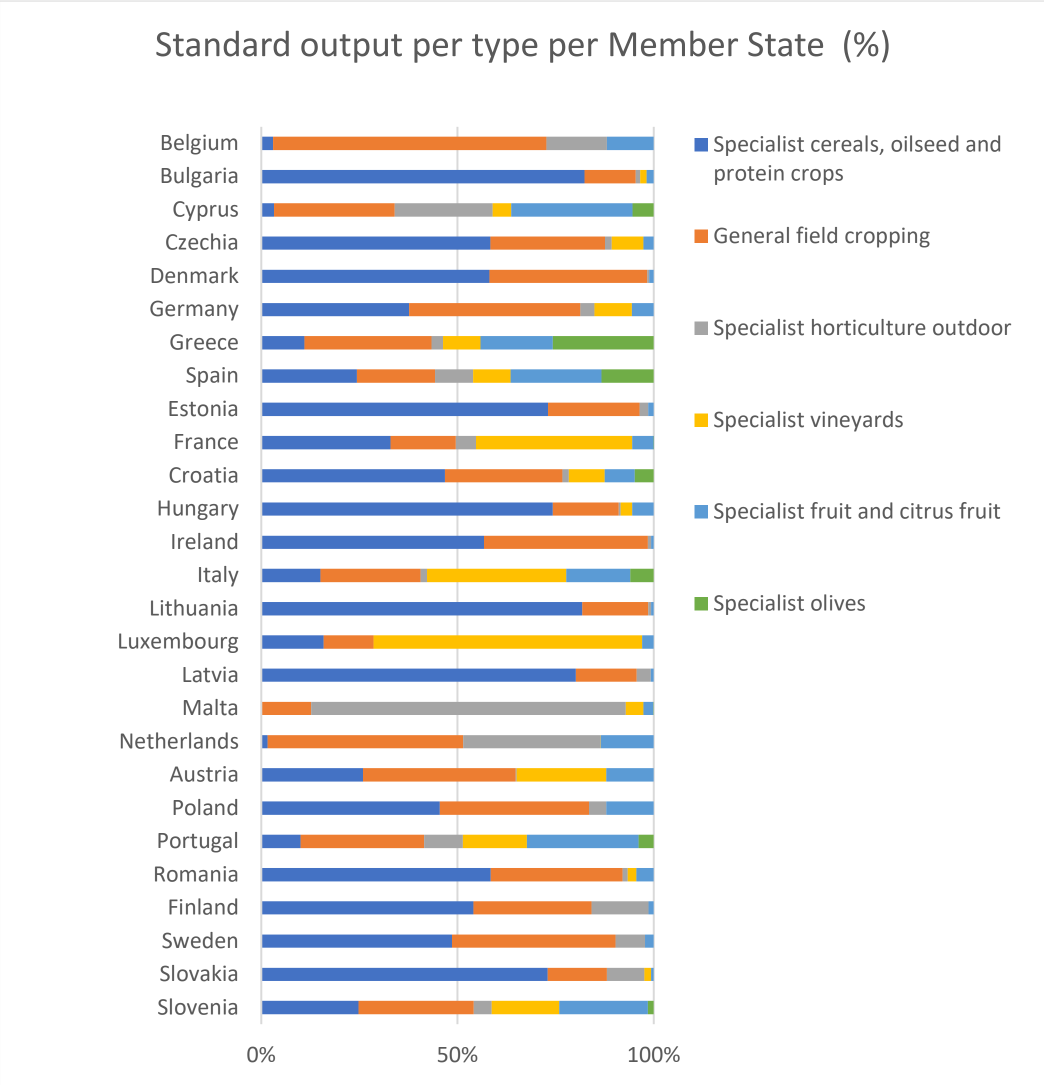
Data source: Eurostat, processed by Wageningen Economic Research.

The total area of these farm types is important when studying the adoption and implementation of alternative crop protection strategies. Such alternatives could have a greater impact on farm types that have a relatively large cultivation area and less of an impact on farms with a smaller cultivation area, assuming a more or less comparable level of pesticide input per ha.

However, this assumption does not hold true for all comparisons of farm types. More intensive crops like potato, vegetables and fruits are likely to show a higher level of pesticide input than less intensive crops such as cereals, rapeseed and protein crops (apart from organically grown crops). Intensive crops usually generate higher returns, which in turn explains for more risk-avoiding measures, including a higher level of crop protection input (Smit and Janssens, 1999; Theuws et al., 2002; Nicholas et al., 2011). For this reason, data on importance of crops in terms of SO is also provided (see Figure 2.2). SO represents standard values for gross revenues, i.e. not taking into account direct or indirect cost. Since more intensive crops tend to have higher SO-values per ha, farm types with relatively small areas can become more important when total SO-values per Member State are given. Nevertheless, the areas for cereals, oilseed and protein crops and general field cropping are so large in most Member States, that these crops dominate the EU-crop farming picture also in terms of SO. Figure 2.2 presents the SO of the six key farm types as a share of total SO for each Member State. The main findings are:

- Vineyards appear to be the most important farm type in SO-terms in France, Italy and Luxembourg.
- Outdoor horticulture is the most important farm type in Malta and the second most important farm type in Belgium and the Netherlands.
- Fruits and/or citrus is the main farm type in Cyprus and the second main farm type in Portugal and Spain.
- Olives is the second most important farm type in Greece and the fourth most important farm type in Spain.

Figure 2.2 – Proportion of standard output of specialised plant production farms in the EU27



7.

For each Member State the SO of the six farm types is presented as a share of the total SO in that Member State. See textbox 2.1 for more information on the six farm types in this figure and footnote 6.

Data source: Eurostat, processed by Wageningen Economic Research.

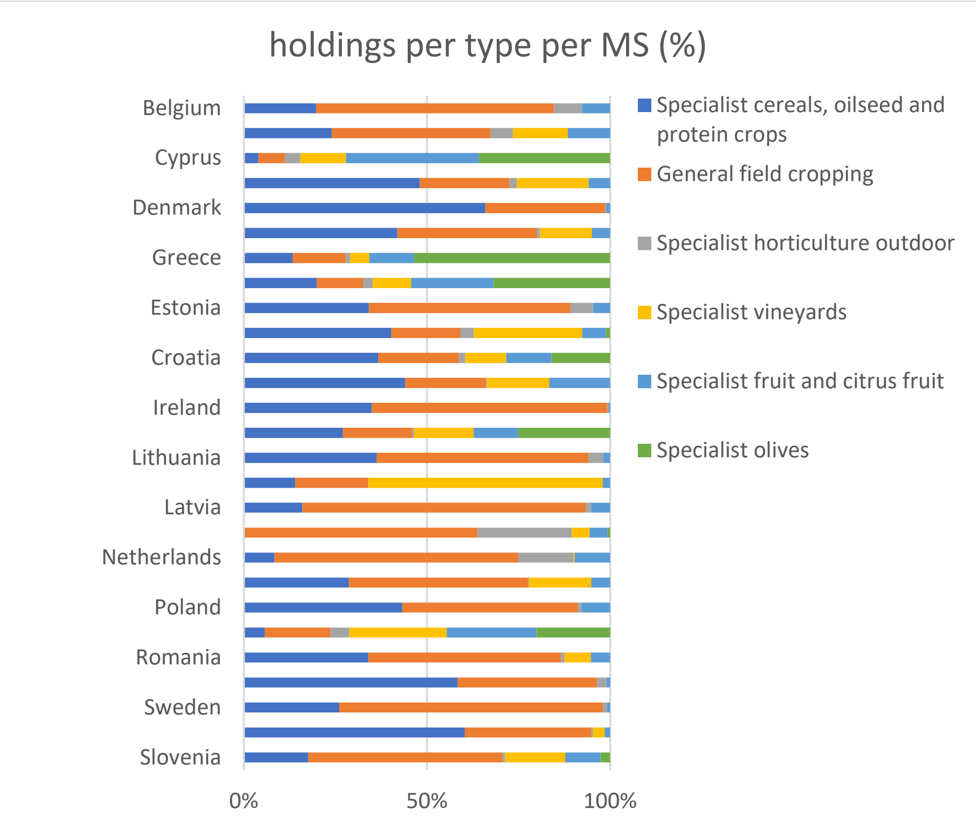
The data in Figure 2.2 show that besides the 'large' crops (cereals, oilseed and protein crops and general field cropping), the other four farm types selected are also important to consider as they represent relatively profitable income sources in the respective Member State, even though their share in the total area is smaller than their share in SO.

A third indicator is the number of holdings (i.e. farms) within their respective Member State and farm types. For example, when a large number of farmers have to be trained for the adoption and implementation of new crop protection strategies, it can have a significant impact in terms of logistics, training capacity and cost. Thus, the importance of different farm types in terms of number of farms is given (Figure 2.3):

- Similar to the conclusions drawn from size of cultivation area and SO, cereals, oilseed and protein crops, and general field cropping dominate the farm numbers in the EU.
- In general, the other four farm types are more production intensive with smaller size in area per farm, which gives a different picture than the importance based on area for some Member States:
  - Greece, Portugal and Spain have relatively high numbers of olive growers. In Greece and Spain, the olive growers represent even the largest group of farmers compared to the other five farm types.
  - Vineyards make up the highest number of farms in Portugal, and the second highest number of farms in France. In Bulgaria, Cyprus, Germany, Hungary and Slovenia, vineyards constitute the third largest group of farms.
  - In a number of Member States, there are large numbers of fruit and/or citrus growers, mainly in Portugal and Spain (second largest group) and the Netherlands (third largest group).

The conclusion from this analysis is that using the number of farms as an indicator for importance of farm types provides additional information compared to that for area and SO, and should therefore be taken into account.

Figure 2.3 – Number of specialised plant production farms as a proportion of total number of holdings (i.e. crop farms) per Member State in the EU 27



See textbox 2.1 for more information on the six farm types in this figure and footnote 6.

Data source: Eurostat, processed by Wageningen Economic Research.

A fourth indicator is the cost of crop protection per ha, i.e. the cost of the pesticides applied. This data is available in the public dataset of FADN and presented in table 2.1. From this dataset, the average crop protection cost per farm type were derived and the weighed (over cultivation area) average over the six farm types per Member State calculated. This weighed average was compared with the overall average value in the EU27, with qualitative scores for evaluation. From table 2.1, it follows that:

Table 2.1 – Average crop protection cost per hectare and deviation from the EU average per Member State

Member State	Average crop protection cost per ha per farm type (specialist crop farmers) a)							
	Arable farms with COP b)	Arable farms with other field crops c)	Outdoor horticulture	Vine-yards	Fruits and Citrus	Olives	Weighted average	Deviation from average d)
Belgium	-	231	1.023		1.476		351	+++
Bulgaria	67	63	554	238	155		71	--
Cyprus	10	71	459	194	302	-	134	0
Czechia	127	150	607	377	254		136	0
Denmark	103	140	606		343		120	0
Germany	129	169	640	438	706		160	0
Greece	79	122	1.215	265	381	71	152	0
Spain	37	119	1.164	97	225	94	103	0
Estonia	47	21	102		3		43	---
France	155	223	481	405	438	-	202	++
Croatia	75	147	333	487	504	78	114	0
Hungary	75	76	286	306	341		88	-
Ireland	171	-					171	+
Italy	93	113	931	340	393	66	166	+
Lithuania	69	57	100		14		68	--
Luxembour	-	-		932			932	+++
Latvia	78	41	-		-		75	--
Malta		131	371	-	-		333	+++
Netherland	-	431	1.927		1.357		730	+++
Austria	68	105	-	193	518		106	0
Poland	75	77	172		230		86	0
Portugal	91	148	468	204	313	39	179	+
Romania	54	54	298	341	246		59	---
Finland	40	36	391		-		44	---
Sweden	79	86	1.620		-		84	--
Slovakia	111	133	-	-	-		114	0
Slovenia	78	143	-	275	327	-	153	0
Total	88	137	808	283	308	83	128	0

This table presents the average cost of chemical crop protection (PPPs) per ha per farm type per Member State over the years 2015-2019. b) COP: Cereals, oilseed and protein crops. c) Other arable crops than cereals, oilseed and protein crops, e.g. potato, sugar beet and onion. d) +++" means that the national average is more than two times as high as the overall average; "++" means >1.5; "+" means >1.25; "---" means <0.5; "--" means <0.66, and "-" means <0.8 times the total average;0 means between 0,8 and 1,25 times the total average.

Source: FADN public database, processed by Wageningen Economic Research. Empty cells mean that that farm type is not present in that Member State. Cells with a '-' indicate that the number of sample farms is too small to present reliable data.

1. Member States that are known to have intensive cropping plans tend to have high average crop protection cost per ha. This is especially true for the Netherlands, Belgium, Luxembourg and Malta. The Netherlands and Belgium do not have cereals, oilseed and protein crops as the major farm type (expressed in area) but rather general field cropping, including intensive crops like seed, ware and starch potatoes, as well as sugar beet, onion and vegetables, besides flower bulb growing.
2. France, Ireland and Portugal also have relatively high cost per ha, followed by Germany, Greece, Italy and Slovenia.
3. In contrast, many East- and North-European Member States have low cost per ha, due to relatively larger areas demanded by cereals, oilseed and protein crops: Bulgaria, Estonia, Hungary, Lithuania, Latvia, Poland, Romania, Finland and Sweden.

From the four indicators assessed in this study, i.e. importance of farm types expressed in size of cultivation area, SO, number of farms and the average crop protection cost per ha, the different Member States were clustered. This allows for the creation of comparable groups of Member States for which the options for alternative crop protection strategies could be assessed further.

2.3. Clustering of Member States

The data presented in section 2.2 makes it possible to cluster the Member States of the EU27 in a number of groups that face comparable conditions and are therefore likely to experience comparable impacts when adopting and implementing alternative crop protection strategies: [7]

1. 'Cluster A': Portugal, Italy, Greece, Slovenia and Spain. These Member States all have general field cropping as their most important or second most important farm type (expressed in area), with olive or citrus growing as an important second or third farm type. These Member States have average or somewhat higher crop protection cost per ha compared to average.
2. 'Cluster B': Bulgaria, Estonia, Hungary, Lithuania, Latvia, Poland, Romania and Finland and Sweden. These Member States all have cereals, oilseed and protein crops as their primary farm type (expressed in area) and relatively low crop protection cost per ha (below average).
3. 'Cluster C': Czechia, Denmark, Croatia, Austria and Slovakia. These Member States mostly farm cereals, oilseed and protein crops as the first or second farm type and have average crop protection cost per ha.
4. 'Cluster D': Belgium, Germany, France, Ireland, Luxembourg and the Netherlands. These Member States all have general field crops as the most important or second important farm type and relatively high crop protection cost per ha (+++ or ++) .

2.4. Farm size distribution

For a partial analysis of training cost, Member State clusters were examined in more detail, with a particular focus on numbers of hobby and subsistence, small and large farms. Figures 2.4 – 2.7 present the farm size distribution in the four clusters. Three categories were discerned:

[7] A number of small MS with very specific conditions like Cyprus and Malta have not been included in the clustering.

1. hobby or subsistence farms[8];
2. professional family farms;
3. large farms.

Each Member State has its specific threshold under which farms are categorised as hobby or subsistence farms. The threshold values are available on the FADN-website[9]. Farms with a size larger than this threshold are either categorised as '(professional) family farms' or 'large farms'. The two latter categories were discerned, because the availability of labour and the opportunities for training are different between these farm types.

The difference between family and large farms is somewhat arbitrary. It depends primarily on the farm type and Member State[10]. An absolute SO-threshold was defined relative to the threshold values for hobby farms to distinguish family and large farms:

1. When the threshold SO value for hobby farms is 25,000 euro, then the threshold SO value between family and large farms was set to 500,000 euro;
2. When the threshold SO value for hobby farms is 8,000 or 15,000 euro, then the threshold SO value between family and large farms was set to 250,000 euro;
3. When the threshold SO value for hobby farms is 4,000 euro, then the threshold SO value between family and large farms was set to 100,000 euro.

The data from this section is used to give an indication of training cost as presented in section 3.8. The data is given for two to four of the major farm types in this study (arable, horticulture, vineyard, olive, citrus farms; see textbox 2.1) for each Member State[11] .

Figures 2.4 – 2.7 show that a large share of farms in the four clusters have a size smaller than the threshold size for family farms, and only 1-4% of the farms belong to the category of 'large farms'. In cluster A, 58% of the plant production farms belong to the category 'hobby and subsistence farms' (Figure 2.4). However, they account for only 16% of land use and produce 8% of total revenue (expressed in SO). In contrast, 'large farms' in cluster A account for 18% of land use but produce 25% of total revenue. This also means that the average revenue per ha are higher on large farms than on hobby and subsistence farms. The remaining 41% of farms are family farms, constituting 66% of total crop farming area and 67% of total revenue (Figure. 2.4).

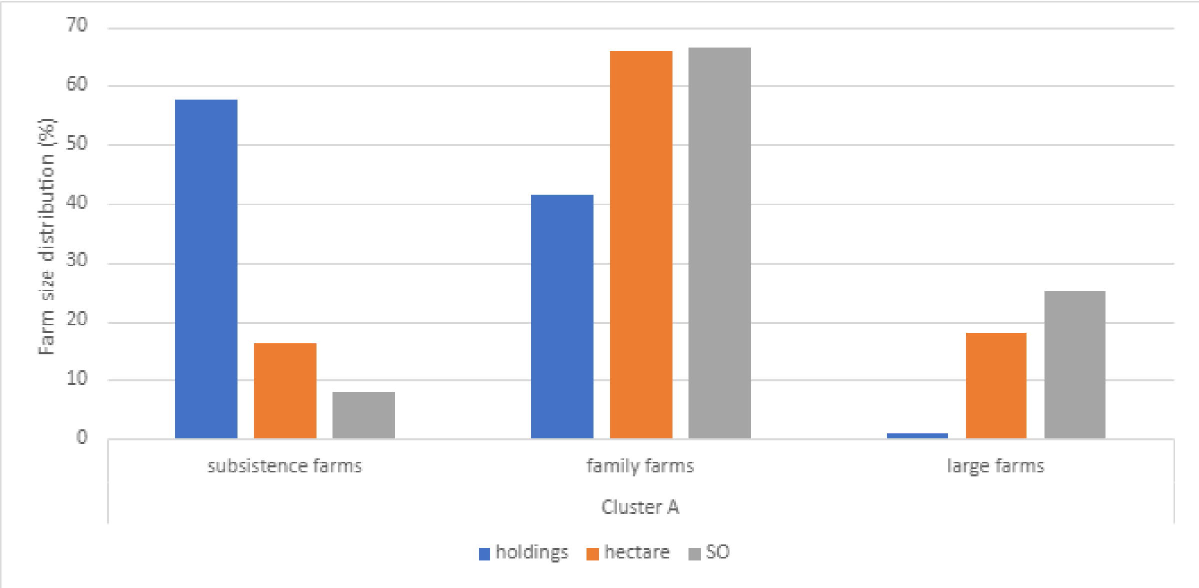
[8] Very small farmers (with a farm size larger than a threshold value, expressed in SO, can be either hobby or subsistence farms. A farmer with a hobby-farm has sufficient income from outside the farm and runs the farm for pleasure, without the need to supplement his income. Subsistence farmers may also have (some) income from outside the farm, but the food and/or the returns from the farm are essential for feeding and maintaining the farm family.

[9] The group 'family farmers' has a large variation in farm size and set-up. There is variation between the clusters, but also within clusters and within MS. There is e.g. difference in farms with an unfavourable structure, and soil type and not having a successor and farms with very favourable structure and soil characteristics and with a successor..

[10] The threshold between both types would ideally be defined in terms of SO per unpaid AWU (annual work unit; the unpaid AWU represent the farmer and the family members that work on the farm including part-timers), but this indicator is not included in the Eurostat database.

[11] The figures represent a coverage of at least 90% of the total population of farms per MS. In the first cluster, three or four farm types are required to reach 90%, in the other three clusters only one or two.

Figure 2.4 – Farm size distribution (in %) in cluster A

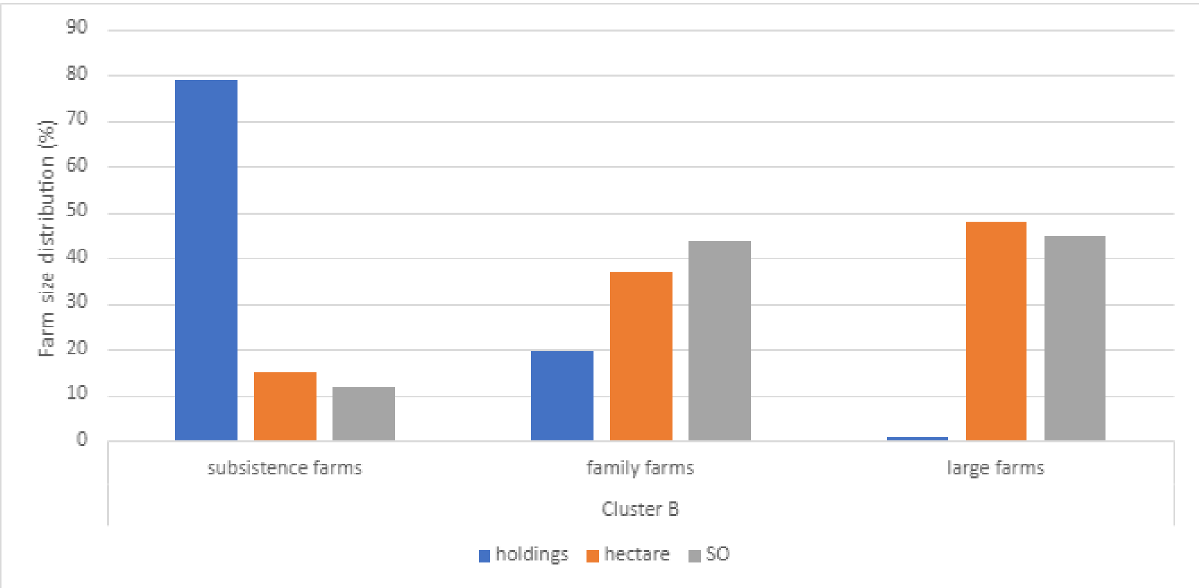


Farm size is expressed in three ways: 1) number of holdings; 2) area in hectare; 3) revenue in SO.

Data source: Eurostat, processed by Wageningen Economic Research.

In cluster B, 79% of the plant production farms belong to the category of 'hobby and subsistence farms (Figure 2.5). They account for 15% of crop farm land use and produce 12% of total revenue (expressed in SO). In contrast, the 'large farms' in this cluster account for 48% of land use but produce 45% of total revenue. The remaining 20% of the farms are family farms, constituting 37% of total crop farming and 43% of total revenue (Figure. 2.5).

Figure 2.5 – Farm size distribution (%) in cluster B



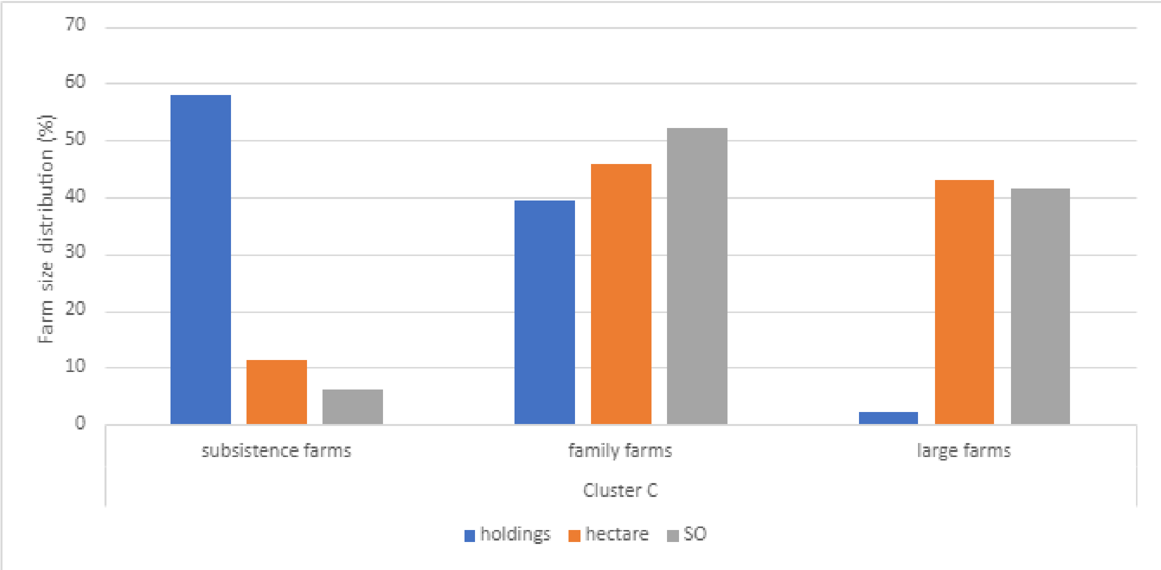
Farm size is expressed in three ways: 1) number of holdings; 2) area in hectare; 3) revenues in SO.

Data source: Eurostat, processed by Wageningen Economic Research.

In cluster C, 58% of the plant production farms belongs to the category of 'hobby and subsistence farms' (Figure 2.6). However, they account for only 11% of land use and produce 6% of total revenue (expressed in SO). In contrast, the 'large farms' in this cluster account for 43% of land use but produce

41% of total revenue. The remaining 40% of the farms are family farms, constituting 46% of total crop farming area and 52% of total revenue (Figure. 2.6).

Figure 2.6 – Farm size distribution (%) in cluster C

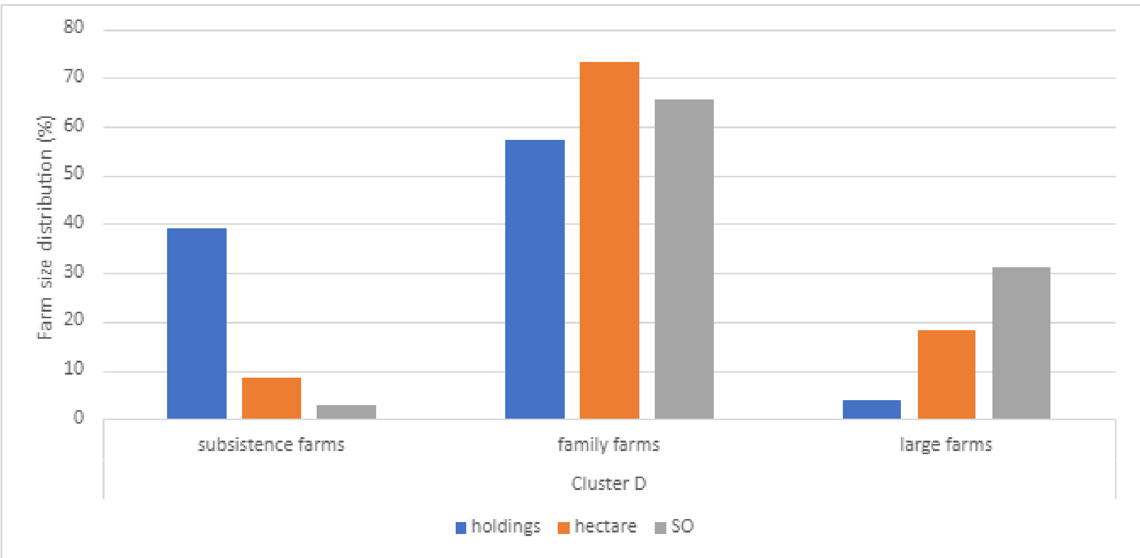


Farm size is expressed in three ways: 1) number of holdings; 2) area in hectare; 3) revenues in SO.

Data source: Eurostat, processed by Wageningen Economic Research.

In cluster D, 39% of the plant production farms belongs to the category 'hobby and subsistence farms' (Figure 2.7). They account for only 8% of land use and produce 3% of total revenue (expressed in SO). In contrast, the 'large farms' account for 18% of land use but produce 31% of total revenue. This also means that the average revenue per ha is higher on the large farms than on the small farms. The remaining 57% of the farms are family farms, constituting 73% of total crop farming area and 66% of total revenue (Figure 2.7).

Figure 2.7 – Farm size distribution (in %) in cluster D



Farm size is expressed in three ways: 1) number of holdings; 2) area in hectare; 3) revenues in SO.

Data source: Eurostat, processed by Wageningen Economic Research.

The conclusions from the analysis on farm size are as follows:

1. In all clusters of Member States, there are significant numbers of hobby or subsistence farmers. However, they account for a relatively small proportion of total revenue. Subsistence farmers are more likely to perform more hand weeding and use relatively low amounts of PPPs due to the cost associated. However, this assumption requires more research.
2. The number of large farms in all the clusters is relatively small (1-4%), but the importance differs between clusters. These farms use relatively more land and account for a high share of total revenue. In some clusters, their revenue per ha is also relatively high. The crop protection measures that these farms take, would therefore have a large impact. Their share in land use is relatively high and in the clusters A and D they also have relatively high revenue per ha. This indicates that relatively intensive crops are grown and is likely to be associated with more intensive methods of crop protection.

3. Results

In this chapter, the results of carefully considered and peer reviewed estimations of the cost of several techniques to reduce the reliance on PPP's are presented. Most of the options require either an investment, cost more in application or both.

3.1. Mechanical techniques

Mechanical techniques refer to replacing (part of the) chemical crop protection by the use of technological equipment. This is an option to control weeds (not for pest or disease control). Weeding by hand is also an option instead of spraying herbicides but is a time-consuming activity. On family and large farms this would require a lot of time, labour and cost. Therefore, mechanical techniques have been developed to save time and labour cost. In summary, mechanical techniques can be a useful option to replace both hand weeding and spraying herbicides, specifically when there is no crop on the field or when the rows of a crop have sufficient distance to make weeding between the crop rows ('inter-row weeding') with machinery feasible.

Mechanical weeding techniques have been developed in three main applications: full field weeders, inter-row weeders and intra-row weeders (removal of weeds in the row, between the crop plants). Full field weeding can be carried out before the crops are sown or planted and for some crops also in the pre-crop emergence phase, depending on sowing depth. Once crops have been sown or planted options to weed between the rows (inter-row) and even between plants within the rows (intra-row) are available. Full field weeding takes more time but does not make use of PPPs, net resulting in either decreased or increased weed control cost, depending on the conditions and on the specific techniques applied. Inter-row weeding is not always possible, specifically not when the row width is too narrow. Wider row spacing is an option but may result in significant yield reduction due to a lower number of plants per ha. Inter-row weeding has a small effect on weeds between plants and these need to be removed by hand or will affect crop yield. In the organic arable farming sector, hand weeding takes between 10 and 200 hours per ha, depending on the crop (KWIN AGV, 2018). In high margin crops like onion more effort is spent on weed control than in low margin crops like cereals (KWIN AGV, 2018).

Another option is intra-row weeding, which is extremely precise work in order to avoid damage or removal of crop plants. Therefore a RTK-GPS system is required besides the investment in the weeder itself. A RTK-GPS system cost roughly €15.000 (Inagro, 2017). The Investment in a standard GPS-equipment takes €4,000 but this will be a less accurate version. Some precise applications even require GPS-equipment on both the tractor and the weeding device. However, such an investment gives a difference between 2 cm and 5 cm accuracy and allows for a higher driving speed, which increases the capacity (in area treated per hour).

The cost of mechanical weeding greatly depends on the cost of labour in the different Member States, since mechanical weeding cost more time per ha than spraying. Therefore, the viability of such techniques depends on the availability and cost of labour. In some western European Member States the rise of increasingly large machinery is a result of the lack of available workers. As a consequence, in such Member States the attractiveness of mechanical weeding will not be high. An alternative is to hire contract workers for the job, but that is also costly (G. Roccuzzo, pers. comm., May 20 2021).

3.2. Plant breeding

Plant breeding is a method to improve resistance or tolerance of crops against diseases and pests, decreasing the need to apply PPPs against that specific disease or pest[12]. The cost of plant breeding consists of R&D during a significant number of years, mostly by private companies. The cost associated is difficult to estimate. In most cases, it is not clear how much reduction in PPP-use can be achieved when a new variety is introduced. That differs per Member State, per crop, and even per variety. A field demonstration showed that in starch potato cultivation, a fungicide reduction of roughly 50% can be achieved when blight resistant potato varieties are grown (Nieuwe Oogst, 2020)[13]. This would save roughly €190 per ha in fungicide use (KWIN-AGV, 2018). The cost of a blight resistant cultivar is not significantly higher than a non (or less) resistant cultivar; the additional cost is estimated at €25 per ha (Averis, pers. comm., May 18, 2021). However, using the blight resistant potato varieties comes with strict regulations. AVEBE, the Dutch starch potato processor, decides when the farmer who grows this variety, needs to spray the fields. The background of this regulation is the necessity to prevent the fungi to break the resistance. To maintain such a strict regime might be a challenge for both farmers and processors.

Breeding is not a quick solution for food tree crops like olives, grapes and citrus fruits. The so—called breeding cycle in such permanent crops takes many years and makes improvements in varietal resistance more difficult. Growers of such crops replace the existing orchard only once in 25 – 40 years[14]. Therefore, it takes decennia before varietal improvements become effective on a large scale in the field. Moreover, in practice farmers take their local conditions and the market potential into account when choosing the best variety for their farm. In other words, when they select a new variety, they also take other characteristics of the varieties available into account than resistance or tolerance levels. Future margin is one of the major selection criteria.

3.3. Biocontrol

'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' (cited from Riemens et al., 2021). An example of biocontrol is the use of natural enemies to control pest insects that threaten a crop.

Biocontrol methods are generally more expensive than chemical crop protection, mainly because of the need for multiple applications and additional tasks like crop monitoring. Direct cost of several biocontrol options range from €175 to €350 per ha (in case of Trianum, an organic fungicide for controlling soil diseases). The sterile insect technique for controlling onion fly cost €400 per ha and application of nematodes cost roughly €600 per ha (F. Druyf, Koppert, pers. comm., May 18, 2021).

Biocontrol options can be an effective measure but the whole farm needs to be adapted to enhance natural enemies. This includes reduction of chemical inputs, using cover crops and ensuring hiding/nesting places for insects. This implies a combination of this technique with ecological

[12] Since numerous diseases and pests occur in nature, each threatening one or more crop species, a fully tolerant or resistant crop or crop variety against all relevant diseases and pests has never been developed so far. Besides, resistance and tolerance in crops can be broken by mutations and genetic adaptation of disease or pest organisms involved. Moreover, new diseases and pests can be introduced and spread, making new types of resistance or tolerance necessary. Concluding, plant breeding for resistance or tolerance is an ongoing story.

[13] Late blight is the severest disease in potato, which can fully destroy the crop, in the worst case leaving no harvestable tubers at all. A relatively large part of the fungicide applications in potato cultivation is applied against this disease. A sustainable late blight resistance would be a good step towards a decreased reliance of potato cultivation on PPPs.

[14] To illustrate, in potato new varieties are presented every other year. These new varieties normally have a somewhat increased resistance and/or yield levels. In contrast, in olive the rootstocks that are used nowadays, were already introduced in the 1990's.

principles to increase biodiversity (G.D. Guccione, pers. comm., May 20 2021). Adoption of such a system also requires training of advisors and farmers.

3.4. Induced resistance

'Induced resistance involves the use of biotic (living) or abiotic (non-living) agents to prime plant defence mechanisms. The practices include soil amendment, seed treatments, foliar spray elicitors and root drench elicitors. This is an emerging area of research and has not yet been adopted as a commercial crop protection practice, but could be beneficial for reducing the need for other crop protection treatments' (cited from Riemens et al., 2021). Bio-stimulants can be regarded as a form of biocontrol, but in contrast to the options in 3.3 (Bio-control), bio-stimulants are not registered as PPPs. A lot of R&D and also promotion of such substances has been carried out in the last decade, but there is still a lot of uncertainty about their effectiveness, especially under field conditions (BO Akkerbouw, 2020). Different interested farmers do experiments with bio-stimulants, which is an option as long as the cost per ha is limited. In theory, there is a lot of potential, but farmers need to be sure that the crop protection measures that they take, will work out effectively. They will not take the risk that their crops will suffer severe yield loss due to diseases, weeds and pests. The crop protection solutions that they decide for, need to be robust. In contrast, bio-stimulants seem to work under extreme conditions, e.g. in unbalanced crop systems. But in more balanced systems in which the famers have all aspects of the farm under control, the effect tends to be limited. The cost varies widely for different applications. Even for the same application the cost differences between regions can be 40% (G. Roccuzzo, pers. comm., May 20 2021).

3.5. Applying ecological principles/diversified systems

'Applying ecological principles increases plant diversity in and around crop fields through methods including crop rotation, green manure, under-sowing, hedgerows, mulching and mixed cropping' (Riemens et al., 2021). In this section, three options are presented and discussed.

3.5.1. Wider crop rotations

The cost of widening crop rotations differ for each farm. It depends on the current crop rotation. For an intensive farm with several high margin crops like potato and onion this measure might have a large impact. For a more extensive farm with mainly cereals the impact will be lower. An example for Dutch conditions is given in table 3.1.

In the example of table 3.1, widening the crop rotation by implementing another crop (x, with a margin comparable with cereals) or increasing the area of cereals directly cost in this case €20,250 due to a lower total farm margin. However, widening the crop rotation could increase the yields of the individual crops in the long term. There is no data on how much yield increase could be expected; however one should not expect more than 5%. An increase of crop yields by 5% would in the example case increase the total farm margin by €4,500. The net cost would in that case be €15,570 in total or €262.50 per ha. In this calculation, a decreased use of PPPs has been taken into account, which also could be a result of a wider crop rotation.

Table 3.1 – Example of margin loss due to widening a crop rotation on a 60-ha arable farm in the Netherlands a)

Scenario	Crop margin (euro/ha)	Total margin (euro)
Cropping plan in scenario A		
30 ha cereals	750	22,500
15 ha seed potato	3,500	52,500
15 ha sugar beet	2,500	37,500
Total farm		**112,500**
Cropping plan in scenario B		
30 ha cereals	750	22,500
10 ha seed potato	3,500	35,000
10 ha sugar beets	2,500	25,000
10 ha crop x ('cereal-like)	750	7,500
Total farm		**90,000**

a) This table shows two scenarios, an intensive cropping plan with high shares of seed potato and sugar beet and a scenario in which part of the cultivation area of these crops is replaced by a less intensive (more cereal like) crop.

Source: KWIN-AGV 2018, processed by Wageningen Economic Research.

3.5.2. No tillage

Crop yield in a no tillage wheat system is found to be equal to that of conventional systems. Operation cost are lower (Sánchez-Girón et al. 2007). On average, the expected cost over several crops in a crop rotation is roughly €50 per ha per year, taking into account the slightly reduced operation cost and reduced crop yields (De Wolf et al. 2019).

3.5.3. Increasing biodiversity

In a study by Wageningen Economic Research the cost for increasing biodiversity in arable farming was estimated between €180 and €320 per ha. The calculations were carried out for an average farmer to reach the same 'level of biodiversity' as the top-30% best performing farms in biodiversity in the Netherlands (Beldman et al., 2019).

During the financial crisis in 2008, Italian farmers tried to reduce cost by using ecological methods. Experts indicate that ecological methods are the preferred option in Italy. The cost of this measure in for instance a vineyard is the cost of cover crops and of mechanical weeding. Normally, cost of crop protection in a vineyard consists of the cost of tillage and herbicides (F. Varia, pers. comm., May 20 2021). The same applies for olive and citrus orchards.

3.6. Precision agriculture

3.6.1. Description of precision agriculture

In this section a literal description of precision agriculture (definition and opportunities) is given according to Van Woensel et al., (2016), which is worked out for this specific study:

'Precision agriculture (PA) or precision farming, is a modern farming management concept using digital techniques to monitor and optimise agricultural production processes. Rather than applying the same amount of fertilisers (or crop protection products) over an entire agricultural field, or feeding a large animal population with equal amounts of feed, PA will measure variations in conditions within a field and adapt its fertilising or harvesting strategy accordingly. Likewise, it will assess the needs and conditions of individual animals in larger herds and optimise feeding on a per-animal basis.

PA methods promise to increase the quantity and quality of agricultural output while using less input (water, energy, fertilisers, pesticides, etc.). The aim is to save cost, reduce environmental impact and produce more and better food. The methods of PA rely mainly upon a combination of new sensor technologies, satellite navigation and positioning technology, and the Internet of Things. PA has been making its way into farms across Europe and is increasingly assisting farmers in their work.'

In the context of this study, PA can help reduce the amount of pesticides applied in different farm types. However, application of PA requires high investments in PA-technology and training of farmers and farm personnel. Such investments and training programs are easier to pay and carry out on large than on small farms. In intensive farming, with higher crop margins, PA is also easier made profitable than on farms with lower crop margins.

A side-effect of PA is that it makes farming technically easier. That can be helpful for Member States in which there is a shortage of (young) farmers and farm personnel. Farmers get the opportunity to cultivate larger farms per person, which makes investments in modern PA equipment even more worthwhile than when only input reduction and yield increase are considered. For Member States with a significantly high share of people working in agriculture, relatively simple and cheap systems are much more attractive. In these Member States the focus is not on decreasing labour cost but on cost reduction of inputs, like fertilisers, pesticides, energy and water. This approach leads to a more viable and sustainable agriculture, reducing the risk of bankruptcy and the loss of connected jobs on farms and in the companies in the chain.

3.6.2. Cost of precision agriculture

The cost of PA depends on the state of the farmer's current machinery. Up-to-date equipment already allows for minor forms of precision agriculture. State of the art tractors are generally equipped with GPS-systems and can, with minor investments, be updated with the more precise RTK GPS. In Italy, 90% of tractors sold are equipped with a form of GPS (G.D. Guccione, pers. comm., May 20 2021; see also section 3.1).

Existing practices

Decision support systems (DSS) on e.g. disease control mainly facilitate optimal timing of fungicide and insecticide use in field crops. Such computer-assisted options are available for roughly €600 per year (Dacom, n.y.). Also for herbicide use, such a DSS is available (AgroVision, n.y.) However, the adoption process has been slow so far. The perceived risk, certainly for disease control, in relying on a computer model and the (lack of) accuracy of local data are presented as explaining factors for slow adoption. The economic benefit of a DSS must result from reduction in PPP-use. The cost of the DSS is already compensated by a relatively small reduction in PPP-use. The more pressing issue is the timing and spraying capacity. A DSS indicates the best timeframe to perform plant protection measures. However, on larger farms this timeframe is often too short to spray all the fields in time. As a consequence, larger farms tend to spray early or weekly to prevent disease outbreaks.

Combining a DSS with variable rate technology (see below), farmers can save roughly 30% on pesticide input on average (over crops).

Controlled traffic farming

When controlled traffic lanes are applied, the soil between the lanes tends to stay in a better shape than under full field traffic. This leads to more robust crops and a decreased need to control weeds, pests and diseases. The investment cost for such techniques for arable farms is on average €900/ha (DAW, n.y.). The cost mainly concerns the adaptation needed on the equipment to adjust to a larger track width. Several international sources state a potential yield increase of 10%. When the crop yield is €2,000 per ha, such a yield increase would result in an increased revenue of € 200 per ha. In that case, the investment would pay back in five years. However, controlled traffic farming means a significant change in a farming practice. The adoption of such a system does not only imply adaptation to equipment but also that some tasks will take longer due to a reduced working capacity.

Variable rate technology

Most new spraying systems already facilitate variable rate technology. In order to make use of this technology, task maps or real time sensors are required to feed information to the system. Task maps can be made with free software using satellite images. There are agricultural services who provide task maps for €30 per piece (NPPL, 2019).

Table 3.2 shows the agronomic results on pesticide (active ingredient) and (N-)fertiliser use that followed from applying smart technologies. Under Dutch conditions, a reduction of 20-25% in pesticide use and of 22-30% in nitrogen fertiliser use appeared feasible. A comparison between PA in potato growing in the Netherlands and in olive growing in Greece showed that PA increases sustainability in olive and both profitability and sustainability in potato (Van Evert, 2017).

Table 3.2 – Reduction in pesticide and nitrogen use through applying smart technologies on two demonstration locations in the Netherlands (average data of 2017-2020)

A Abbenes a)

Type of pesticide or fertiliser	Input reduction (%)	Reference
Haulm destruction herbicide (kg a.i./ha)	53	0.8
Weed control herbicide (kg a.i./ha)	17	3.6
Disease control fungicide (kg a.i./ha)	15	4.7
Total herbicide and fungicide use (kg a.i./ha)	20	9.0
Total N-fertiliser use (kg N/ha)	30	252

B Reusel a)

Type of pesticide or fertiliser	Input reduction (%)	Reference
Haulm destruction herbicide (kg a.i./ha)	43	0.6
Weed control herbicide (kg a.i./ha)	17	1.6
Disease control fungicide (kg a.i./ha)	23	4.7
Total herbicide and fungicide use (kg a.i./ha)	25	6.8
Total N-fertiliser use (kg N/ha)	22	275

a) A.i. = active ingredient of pesticides; N = nitrogen; the reference is SOP (standard operation procedure, i.e. the application as carried out by conventional farmers) in the region in 2017.
Source: C. Kempenaar (2021, in preparation).

Emerging practices like precision spraying require an investment of roughly €10,000.

Practices under development like sensor-based methods for detection, identification and quantification of diseases and weeds plus high-resolution spraying (with an exact dosage for each nozzle on the spraying equipment) currently cost roughly €100,000 (NPPL, 2020). Also several robot platforms with precision spraying are in development. Cost of these systems are not yet known. Incidentally, robot applications are already offered by contract workers as a service (e.g. weed control for 200 euro per ha by a robot). However, this technique is not yet wide-spread for practical use (see also section 3.1 on mechanical weed control).

3.7. PPPs

3.7.1. Spraying nozzles

When PPPs are applied, the challenge is to reduce negative environmental effects as much as possible. One of the ways to reach that is to minimise drift of pesticides applied, meaning that as little as possible pesticide spray is carried away from the field by the wind and disturbs the environment. Spraying nozzles with drift reduction specification are estimated to cost roughly €100 a year per farm. New spraying systems with drift reduction technology allow for a reduction in PPP-use and could cost roughly €1,000 less per year than older systems (Buurma et al. 2012). Replacement of older by new spraying equipment is recommended to improve spraying performance and protect the environment.

3.7.2. 'Green' PPPs

Examples of green PPPs are micro-organisms like Bacillus amyloliquefaciens (strain MBI 600), Pseudomonas chlororaphis (stem MA342) and spinosad viruses like the Cydia pomonella granulose virus, plant extracts like green mint oil, laminarin, nonane acid and Carvon, plant hormones like Gibberelline acid and other natural substances like sulphur, iron(III)phosphate, Kompaan, Oil-H and Contans. The cost of a number of these PPPs is given in table 3.3.

Table 3.3 – Cost of green PPPs – examples a)

Green PPP	Active ingredient	PPP-category	Cost (euro/kg or l)
Serenade	Bacillus subtilis stem QST 713	Fungicide	13.50
Contans	Coniothyrium minitana	Fungicide	37.00
Xen Tari	Bacillus thuringsiensis	Insecticide	79.00

a) Examples of green PPPs available in the Netherlands.

Data source: Delphy (2021).

3.8. Training in new crop protection methods

Several new or adapted crop protection methods will require specific training. The cost of training programs can be significant and especially high for smaller farms with relative low crop margins. For that reason, the farm size distribution in the EU27 was studied in more detail (see also Chapter 2).

Some alternatives may require little or no training of farmers, specifically plant breeding and mechanical weeding. The representatives of breeding and seed companies will give advice to farmers how to optimally use new varieties. The same applies for the advisors of machinery companies. In contrast, the cost of training may be relatively high for PA, since this option requires a broad knowledge of machinery and IT besides agronomy and soil science. Alternatives like biocontrol, induced resistance, and green pesticides require a short training in the field, e.g. a demonstration. The application of ecological principles also requires knowledge of the theory behind these principles and repeated field sessions for demonstration and advice.

Training of farmers is part of keeping the business running ('permanent education'; Kortstee et al., 2011). However, this is easier to adopt by larger farms with specialists for certain tasks like crop protection than by family farms. Larger farms usually have budget allocated to training of personnel and urgent tasks during trainings can be more easily delegated to other personnel on the farm. Besides, training budgets are not always available at farms, specifically not on smaller family farms and on hobby and subsistence farms. There are especially many of such farmers in the clusters A and B (as presented in Chapter 2). For cluster A, more detailed figures are given in Appendix 3 (Figures A3.1 – A3.3). It appears that especially in the olive sector, the share of hobby and subsistence farms is very high[15].

The Farm Advisory System (FAS) of the EU may contribute to the solution of budget problems that hobby and subsistence and small family farmers are faced with when an obligation for (additional) training would result from legislation[16]. As presented in textbox 3.1, FAS can provide information on different aspects of farming that are linked to crop protection and the need to reduce reliance on PPP-use, like cross-compliance, water protection, handling PPPs; integrated pest management, risk management and appropriate preventive actions to address plant diseases and minimum requirements for plant production products. Also innovation could be part of this, e.g. when farmers invest in PA-technology or mechanical weeders.

As presented in section 2.4, a large number of farms in the four clusters have a size below the threshold of professional farms. This share ranges between almost 30% in cluster D to more than 50% in cluster A. This large group of farms is run by hobby or subsistence farmers, meaning that they probably work most of the labour time outside their farms. Their focus is not on the farm itself, although the food that they produce there can play an important role in food supply of the family. Most likely, these farms are not well equipped with machinery and equipment. Quite a number of them may do the land work even mainly manually. In general, this group of farmers is not easy to incentivise by advice and extension services (Theuws et al., 2002). However, part of them may spend only small budgets on PPPs.

The group of professional farmers is easier to approach. They rely on information meetings, meetings by advisors and extensionists[17], cooperative meetings, etc. to stay up-to-date on technological advancements and innovations in the industry. The majority of them consists of family farmers, of whom most will apply a 'low cost strategy'. On average, their income is not high and they cannot afford to do significant payments for training purposes. It is important to reach this group with training, since their total PPP-use as a category will be quite considerable. At the same time, alternative crop protection practices may cost more, as shown in the previous sections, which makes them less prepared to adopt these practices. Besides, being unfamiliar with these alternatives and how to apply them makes farmers reluctant to

[15] For subsistence farmers and also for relatively small family farms with low perspectives, coaching could be more suitable than training. Support of such farmers to choose a strategy not only to survive as a farmer but also to improve the perspectives of the farm in general, facing the developments in society, market and production chains could be more helpful and, indirectly, also support improved crop protection strategies (Beldman et al., 2013). FAS can also play a role in facilitating coaching (see textbox 3.1).

[16] The word 'additional' is used here, since in many MS basic training is already required for farmers and contract workers, specifically for application of PPPs and certification schemes including crop protection and food safety. The trainings referred to in this study is additional to that basic training.

[17] Extensionists are independent advisors, whereas advisors are often linked to companies that sell products to farmers.

adopt these measures and invest in equipment, etc. FAS may bring a solution to these problems, at least partly, since farmers have to contribute to the payments of the cost of the advice that they receive. The system reaches already 1.3 million farmers in a year, with the help of 12 400 advisors (Angileri, 2020).

Textbox 3.1 Aims of the farm advisory system

All countries in the European Union have a farm advisory system (FAS). The FAS helps farmers to better understand and meet the EU-rules for environment, public and animal health, animal welfare and the good agricultural and environmental condition (GAEC).

The FAS provides information about:

- obligations at farm level resulting from the statutory management requirements and the standards for good agricultural and environmental land conditions ("cross-compliance");
- agricultural practices beneficial for the climate and the environment and maintenance of the agricultural area ("greening");
- measures at farm level provided for in rural development programmes for farm modernisation, competitiveness building, sectorial integration, innovation and market orientation as well as for the promotion of entrepreneurship;
- requirements for water protection, efficient and sustainable water use;
- use of plant protection products;
- integrated pest management.

The FAS may also provide information on:

- the promotion of farm conversion and diversification of their economic activity;
- risk management and appropriate preventive actions to address natural disasters, catastrophic events and animal and plant diseases;
- minimum requirements for agri-environment-climate payments beyond mandatory standards and minimum requirements for fertilisers and plant production products, also regarding organic farming;
- information related to climate change mitigation and adaptation, biodiversity and protection of water.

The EU countries ensure a clear separation between advice to farmers and checking the right allocation of income support.

(cited from EU-website)

Another source of support are the operational groups, also coordinated, supported and partly financed by the EU in the context of EIP-Agri (European Innovation Platform). The EIP also supports the collection of research results on different subjects that are also of importance for improving crop protection practices as described in this study. Moreover, missing information can become part of a Horizon Europe project.

Training costs tend to vary largely among Member States due to large differences in price and wage levels. For Dutch farmers, a training for e.g. PA could cost e.g. €285 for a starter's course of three times half a day (Terranext, 2021), just to get insight in this way of working. Learning how to collect data and to process and translate them into task maps requires a more extensive training, with repeated updates. One could think in the order of 3 days a year or €600 per year. For the other practices, smaller training budgets will be required per year, part of which may be supported by FAS-resources or other EU-initiatives.

3.9. Research and development

In the transition from PPP-reliant cropping systems to more diversified systems, research and development play an important supporting role, both in fundamental aspects of the alternative options discussed in this study and in ways to implement the alternatives in practice, in different crop rotations and under different climatic and socio-economic conditions. As indicated in the previous section, Horizon Europe plays an important role to supply missing scientific and practical knowledge[18] and make the alternative options work well. The Horizon Europe framework programme has a proposed budget of 100 billion euro from 2021 to 2027 and is the largest collaborative multinational research and innovation investment in Europe. Part of this budget is allocated for agricultural research and research on crop protection is a part of that. Some of the R&D-gaps have been identified in the following sub-sections.

3.9.1. Mechanical techniques

More research needs to be carried out to improve the effectiveness and accuracy of mechanical weeding, specifically in intra-row applications. The cost of such improvements is hard to estimate. Development of robotic systems would help to reduce the amount of labour required to carry out mechanical (and hand) weeding, which is especially of interest for Member States where farmers and farm personnel are scarce.

3.9.2. Plant breeding

R&D in developing varieties with higher and broader resistance and tolerance levels is an ongoing task and business. Cost estimations are hard to make. Breeding companies are in the lead in this option.

3.9.3. Biocontrol

Currently, biopesticides comprise only 5% of the global crop protection market, with a value of about $3 billion worldwide (Marron, 2014; Olson, 2015). One of the leading companies providing biocontrol options is Koppert biological systems in the Netherlands. It has an estimated annual revenue of €220 million (AD, 01-04-2019). Croplife Europe committed to invest €4 billion into biopesticide innovation by 2030 (Croplife, n.y.).

3.9.4. Induced resistance

The global bio-stimulant market is valued at $2,638 million in 2020 and is projected to reach $5,040 million by 2026. Europe is the largest and fastest growing segment of the market studied and is growing at an annual growth rate of 12.3% in 2020 (Report linker, 2021). However, more independent research is required to assess the effectiveness of bio-stimulants and comparable alternatives for PPPs.

[18] Practical knowledge is partly developed in operational groups (in EIP-context), mixed groups of farmers, advisors and researchers.

3.9.5. Applying ecological principles/diversified systems

There is a lot of interest in this subject, but a lot of research is still required to develop such systems for the different farm types that are inventorised in this study. Such research also needs to give information on cost and benefits of such systems, about which little data is available.

3.9.6. Precision agriculture

For PA, important challenges are to make the high-technological systems more user-friendly and to increase crop yields in a wider range of crops with less input. Cost-effective integration of sensor data with DSSs and modern implements is key as well as development of a more mature data-position of the farmer, i.e. that the farmer stays owner of the data that are collected.

3.9.7. Green PPPs

More knowledge needs to be collected on green pesticides, for which additional research is required. This is in the first place a responsibility of the pesticide companies, but the business model of green PPPs tends not to be attractive. Public support as well as independent research are essential to make this development succeed.

3.9.8. Subsistence farmers

An interesting and important question is whether subsistence farmers perform much hand weeding and use relatively low amounts of PPPs due to the cost associated. If this is true, then it means that in the process of decreasing the use of PPPs, this group of farmers needs relatively little attention in knowledge dissemination, extension and advisory activities. However, subsistence farmers may also work with outdated spraying equipment and PPPs, contributing to environmental and food problems more than strictly necessary in the light of all the innovations from the last decades. The impact of the conclusions will be high, since the number of subsistence farmers in some of the clusters is high, although their share of the total cultivated crop area, is relatively low.

4. Overview

Table 4.1 gives the full overview of the alternative protection practises in this study. Data on cost per ha or per year and total investments has been collected as far as this data is available. To complete this table for the other options, more research is required.

Table 4.1 – Breakdown of alternative crop protection practices as listed in Riemens et al. (2021) and a cost and investment estimation, as far as data is available a)

Mechanical techniques	Cost or investment
Existing practices	Depends on hand weeding (€50 to €1,500 per ha)
Full field weeders	No GPS required
o Cultivator	Crop specific
o Harrow	
o Comb cut	
o Rod weeder	
o Broad cast knife	
o Hoe	
Inter-row weeders	GPS cost €4,000 (G. Roccuzzo, pers. comm., May 20 2021).
o Inter-row cultivators	Crop specific
o Brush weeders	
o Rotary cultivators	
o Rolling cultivators	
o Basket weeders	
o Rolling harrows	
Intra-row weeders	RTK GPS cost €15.000 (Inagro, 2017).
o Torsion weeders	Crop specific
o Finger weeders	
o Flame weeders	
o Air pressure weeders	
High-power electric discharges (Zasso)	No data
Electricity to boil weeds inside out from the root upwards (Rootwave)	No data
Emerging practices	
o Inter-row weeders using guidance systems	No data
o Intra-row weeders using cameras and computer vision and real time	€120/ha (KWIN AGV, 2018)
o Weed seed harvesters, preventing weed seed return	No data
Practices under development	
o Autonomous robotic weeders with non-chemical	No data
o Robovator (Denmark)	
o Robocrop InRow weeder	
o Steketee IC weeder	
o Agrorobotti (AgroIntelli)	

Plant breeding	Cost or investment
Existing practices	positive €150/ha (Nieuwe Oogst, 2020; Averis, pers. comm., May 18, 2021)
Traditional breeding	No data
o Selection breeding	
o Crossbreeding	
o Hybrid breeding	
Mutagenesis	
Marker-assisted selection	
Cisgenesis	
Intragenesis	
Emerging practices and practices under development	
Genomic selection	No data
Genome editing techniques	
o Sequence-Specific Nuclease (SSN)	
CRISPR-Cas	
TALENs	
ZFNs	
Reverse breeding	
Induced early flowering	

Biocontrol	Cost or investment
Existing practices	
Insect control	€80/ha in Italy. Government plan (G. Roccuzzo, pers. comm., May 20 2021).
Release of antagonists (insects, mites, nematodes, fungi, virus)	€80-€500/ha (G. Roccuzzo, pers. comm., May 20 2021).
Pest behaviour manipulation	€350/ha (pheromone release codling moth) (Avagrar,
Sterile insect technique	€400/ha (onion fly) (F. Druyf, Koppert, pers. comm., May
Nematode control	
Inoculation of soil with antagonists (bacteria, fungi, nematodes)	€600/ha (F. Druyf, Koppert, Pers. comm., May 18 2021).
Disease control	
Spraying with antagonists (fungi, bacteria)	No data
Inoculation of soil with antagonists against soil fungi	€175-350/ha (in case of species Trianum P) (F. Druyf,
Weed control	
Antagonists (fungi) for control of *Cirsium* spp. (New Zealand)	No data
Emerging practices	
Weed control	
Antagonists (insects, bacteria) for control of *Cirsium* spp.	No data
Rust for control of all weeds	
Seed-eating beetles for control of all weeds	

Induced Resistance	**Cost or investment**
Emerging practices and practices under development	
Soil amendments	No data
Seed treatments	No data
Elicitors as foliar sprays	No data
Elicitors as root drench	Mycorrhiza €200 /ha (F. Druyf, Koppert, pers. comm.,

Applying ecological principles to increase biodiversity	**Cost or investment**
General increase in biodiversity	€180-€320/ ha (Beldman et al., 2019)
Existing practices	
Temporal diversity	
o Widening of the crop rotation	€10,000/year (KWIN AGV, 2018)
o Use of green manures	€100-€250/ha (KWIN AGV, 2018)
o Under-sowing of clover	€70/ha (seed cost)
Rod weeder	No data
o Minimal tillage (no tillage)	€50/ha (De Wolf et al. 2019)
Use of service crops (e.g. Tagetes)	No data
Living mulches and roller crimper	No data
Emerging practices	
Spatial diversity	No data
o Use of flower strips	
o Use of hedgerows, beetle banks and riparian buffers	
o Wildlife friendly mowing (from the inside to the outside)	
o Mulching	
Genetic diversity	
o Variety mixtures	
o Mixed cropping of legumes and cereals	
o Mixed farming	
o Agroforestry	
o Novelty crops	
o Agri-environmental schemes	
Cut and carry fertiliser instead of manure	
Practices under development	
Agroforestry	No data
Pixel cropping	

PA	Cost or investment
Existing practices	
Controlled traffic farming	€900/ha (+10% yield) (DAW. n.y.).
Decision support systems	€600/year (Dacom, n.y.)
Variable rate technology	No data
Task maps	Free/ €30 per map (NPPL, 2019)
Emerging practices	
Precision spraying	€10,000 (NPPL, 2020).
Pulse width	€35,000 (NPPL, 2020).
Practices under development	
Sensor-based methods for detection, identification and quantification of diseases	€100,000 (NPPL, 2020).
Remote sensing for weed control	No data

PPPs	Cost and investment
Existing practices	
Alternate mode of action	No data
Spray nozzles	€100/year (Agrarisch Waterbeheer, 2017)
Dose reduction (LDS; low dosage system)	No data
Precision spraying	positive €1,000/year (Buurma et al., 2012)
Emerging practices and practices under development	
Micronutrient formulations	Depends on number of applications

a) To complete this table for the options without cost quantification, more research is required.

This table shows the cost of alternative crop protection practices or the investments that have to be made. In some cases the net cost-benefit analysis is positive, meaning that the benefits are estimated to be higher than the cost. In those cases, the cost are expressed as 'positive'.

The cost of these practices was compared with the average revenues per ha (table 4.2). On average revenues per ha are highest in cluster D and lowest in cluster B. As a consequence, farmers in cluster D can afford higher cost for alternative crop protection including training than their counterparts in the other three clusters. On the other hand, the farmers in cluster D have already the highest average crop protection cost per ha, partly explained by the relatively high revenue of intensive crops, which stimulate relatively higher inputs.

Table 4.2 – Average revenues in SO per ha in the four clusters of Member States

Cluster of Member States	SO (euro/ha)
A	1,477
B	674
C	1,106
D	2,163

Source: Eurostat, data processed by Wageningen Economic Research.

Table 4.3 gives a summary of the data on cost per ha for the different groups of practices discussed in this study, expressed as a range between minimum and maximum cost. It also gives an inventory of factors that determine the height of this cost, making it impossible to give just one figure per practice. These factors are the following:

1. Crops are an important determining factor. The cost for permanent crops like olive, grape and citrus fruits differ from the cost for arable crops. But even within these groups the cost differ largely.
2. Labour cost is a determining factor when hand labour is required or when hand labour needs to be minimised.
3. The availability of some products for alternative practices will determine the price. When there is a high demand for e.g. a resistant variety, this may increase its price. This will then be a constraining factor for planting this variety.
4. Some alternative methods require extra knowledge. For instance, growing a more resistant variety will not increase economic benefits when the farmer does not take the higher resistance level into account. When the crop is sprayed as a non-resistant variety then there is no benefit of using this resistant variety. Knowledge about the consequences of growing this variety is required.
5. Some pests can be more easily controlled than others and this has consequences for the cost.
6. Some practices do not have a proven efficacy. When the efficacy is proven, it will become clear to what level the cultivation cost per ha can increase to attain a net positive economic effect.
7. Farm systems determine the efficacy of some practices, for instance biocontrol options work better when a farm uses low amounts of plant protection products. It is therefore important that the crop protection options will not be assessed in isolation.
8. Finally, farm size determines cost to a large extent, as returns to scale play a role in practices with relatively high investments like precision agriculture.

Table 4.3 – Summary of cost per ha for the groups of practices in this study and determining factors for the level of this cost

Alternative practice	Minimum cost per ha (euro)	Maximum cost per ha (euro)	Determining factor
Mechanical techniques	0	1,500	Crop, labour cost
Plant breeding	150 positive	No data	Crop, availability, knowledge
Biocontrol	100	600+	Crop, farm system, pest species
Induced resistance	No data	No data	Effectivity, farm system
Applying ecological principles to increase biodiversity	0	265	Crop, farm system, geography
Precision agriculture	0	10,000+ a)	Crop, farm system, farm size, knowledge
Plant protection products	0	No data	Crop, pest species, farm system

a) This figure refers to investments.

This table shows the range of cost estimated for the different groups of alternative practices. The range is from '€150 positive per ha' (meaning that the benefit is higher than the cost) to € 1,500 per ha.

Source: Table 4.1 and the underlying references as listed in that table.

5. Discussion

This study shows that quite a number of alternative practices are either not robust enough to build crop management on or too costly to adopt and implement. This is in agreement with the former study on these practices (Riemens et al., 2021).

The external environmental cost and benefits are not considered in this study. When environmental cost and benefits are also taken into account, the cost - benefit analysis will give different results[19]. It will help policy makers, farmers, and related industrial partners to decide which investments will be profitable in the long term. Environmental cost may put a burden on society as a whole and will increasingly be re-directed to the farmers.

When the EU or individual Member States would consider financial support to stimulate the adoption and implementation of options which require investments, e.g. in mechanical weeding or precision agriculture, then it is wise to keep in mind that farm equipment is depreciated in roughly 15 years. Replacing equipment with the latest technology is not economically and environmentally viable when the existing equipment is only 10 years old. There are some options to update machinery, for instance with GPS-systems. However not all machinery is suitable to be updated. The same principle applies to permanent crops like olive, citrus and grape. A 10-year-old vineyard will not be uprooted to replace with more resistant and/or higher quality varieties. In short, some measures take a considerable time, especially for permanent crops.

A general observation regarding all measures refers to the socio-economic conditions. The adoption of measures vary between regions and crops. For instance, the richer vineyard growers use more precision agriculture techniques compared to the citrus growers. In general, commodity crops allow lower investments than specialty crops. Moreover, adoption of new techniques depends on the availability of budget for investments. Another factor is the risk attitude of farmers and growers. Application of new technologies creates uncertainty about the efficacy. Therefore, it is important that farmers will not only be trained in short courses, but also have access to examples in which the new technologies will be demonstrated in practice, such as demonstration fields and experimental farms. This is e.g. carried out at the Farm of the Future in the Netherlands.

The number of farms continuously declines and the average farm size increases. Farms without future perspective will stop in the short or medium term. Many farmers that have taken the decision to stop will not be receptive or motivated to change their crop management. Therefore, the public and private efforts to adopt and apply existing and emerging techniques making crop protection more sustainable have to be focussed on farms with future perspectives. In contrast, farms without future perspectives, and without ability and motivation to make crop protection more sustainable should be supported practically and financially to terminate farming in due time.

For small farms and subsistence farms it is important to make a distinction between hobby farms which have limited importance for income generation, and subsistence farms which are the only or major source of income for the farm family. The latter group requires specific attention from policy makers with respect to their income position.

Making one cost estimation for the cost of for instance mechanical weeding that cover both potato and citrus fruits, makes a very rough estimate. For the existing practices some cost can be estimated. However, emerging practices and practices under development are generally not commercially available yet. The cost of these practices are difficult to estimate and it is even more difficult to inventorise benefits compared to current practices.

[19] 'Environmental cost' refer to e.g. cost of purifying water resources from pesticide residues as a part of preparing drinking water from those resources (Galgani et al., 2021).

The EU's agricultural sector is very diverse, when specialisation in certain crops, farm size distribution and labour availability and labour cost level are taken into account. A challenge is to prepare policy options for the clusters but even within the clusters on which combination of practices would be most effective for reduction in PPP-use and are at the same time economically promising.

6. Conclusions and policy options

6.1. Conclusions

This study is a follow-up to the inventory carried out by Riemens et al. (2021). The main conclusions are:

1. Member States that are known to have intensive cropping plans tend to have high average crop protection cost per ha. This is especially true for the Netherlands, Belgium, Luxembourg and Malta.
2. France, Ireland and Portugal also have relatively high protection cost per ha, followed by Germany, Greece, Italy and Slovenia.
3. In all clusters of Member States, there are significant numbers of hobby or subsistence farmers. However, they generate a relatively small share of revenues. Subsistence farmers are likely to perform more hand weeding and use relatively low amounts of PPPs due to the cost associated. This assumption requires more research.
4. The number of large farms is in all the clusters small (1-4%), but these farms have a relatively high share in crop land and generate a high share of total revenue. In some clusters, the revenues per ha of the large farms are also relatively high. The crop protection measures that these farms take, have therefore a relatively high impact. Their share in land use is relatively high and in clusters A (mostly southern European countries) and D (north-western European countries) they also have relatively high revenues per ha; high revenues per ha indicate that relatively intensive crops are grown including a more intensive way of crop protection.
5. Cost for application of sustainable crop protection methods can be estimated most accurately for mechanical weeding methods.
6. Cost for application of technologies that require investments, are scale dependent, and favour large farms. This is especially the case with PA.
7. Training is necessary for techniques that require additional knowledge about efficacious application. This is the case for techniques such as biocontrol and PA. Professional family farmers with a considerable pesticide use is an important group to address for training. The FAS can assist to apply crop protection according to the prescriptions and decrease the cost of training for this purpose.
8. No indication can be made for the cost of R&D necessary to develop the existing and emerging crop protection techniques. Techniques which are in early stages of development, without evidence about their contribution to sustainability such as induced resistance are largely dependent of substantial R&D investments.
9. On average revenues per ha are highest in cluster D (north-western European countries) and lowest in cluster B (mostly northern and eastern European countries). As a consequence, farmers in cluster D can afford higher cost for alternative crop protection including training than their colleagues in the other three clusters. In contrast, the farmers in cluster D have already the highest average crop protection cost per ha, partly explained by the relatively high revenue of intensive crops, which stimulate relatively higher inputs.

6.2. Policy options

1. Focus public investments on large groups of farmers such as family farmers, who have substantial pesticide use, limited farm income but future perspective to make their crop protection sustainable.

2. Develop tools to distinguish subsistence farmers who are largely or totally dependent on farming for their income, from hobby farmers. Pay targeted attention to this specific group of small farmers, especially in Eastern and Southern parts of the EU.
3. Consider the synergy between several alternative practices;
    a. PA and mechanical weeding have a synergy. The availability of the basic PA-equipment on machinery will open application options for advanced mechanical weeding. These machinery and devices have large investment cost and are therefore more applicable in a situation with larger farms en higher margin crops. As a consequence, such investments cannot be advised to small farmers with relatively low revenues.
    b. Biocontrol, induced resistance and applying ecological principles to increase biodiversity have synergy as well. These three crop protection options strengthen each other by providing a system with fewer chemical inputs.
    c. Plant breeding and alternative plant protection products are applicable in both annual and permanent crops. However in permanent crops, it will take more time before effects on crop protection and sustainability can be measured at farm level.

Glossary

- CAP: common agricultural policy
- Cluster A: Greece, Spain, Italy, Portugal, and Slovenia;
- Cluster B: Bulgaria, Estonia, Hungary, Lithuania, Latvia, Poland, Romania, Finland and Sweden;
- Cluster C: Czechia, Denmark, Croatia, Austria and Slovakia;
- Cluster D: Belgium, Germany, Ireland, France, Luxembourg and the Netherlands.
- EIP (in full: EIP Agri): 'The agricultural European Innovation Partnership (EIP-AGRI) works to foster competitive and sustainable farming and forestry that 'achieves more and better from less'. It contributes to ensuring a steady supply of food, feed and biomaterials, developing its work in harmony with the essential natural resources on which farming depends' (cited from their website). This partnership supports e.g. operational groups, in which farmers and other stakeholders in food production and consumption can work together for innovation.
- EU: European Union
- farm type or type of farming: characterisation of a farm according to the products (crops, animal husbandry) that are produced. This study is limited to farms that are specialised in plant production, leaving out farms with major animal husbandry production
- FAS: farm advisory system
- fungicide: PPP to control fungal diseases
- herbicide: PPP to control weeds
- Member State (MS): Member of the EU27
- PA: precision agriculture
- PPP: plant protection product
- pesticide: chemical compound to control weeds, pests or diseases
- research and development (R&D): activities to attain scientific knowledge and make that knowledge work in practice in the form of new tools, equipment, procedures, etc.
- standard output (SO): see Appendix 1.

References

AD. Het geheim van een succesvol familiebedrijf (The secret to a successful family business; in Dutch), 2019. Source: https://www.ad.nl/economie/het-geheim-van-een-succesvol-familiebedrijf~ac18ef6f/.

Agrarisch Waterbeheer. Driftreducerende spuittechnieken. Toolbox emissiebeperking (Drift reducing spraying techniques. Toolbox emission limitation; in Dutch), 2017 Source: https://agrarischwaterbeheer.nl/system/files/documenten/pagina/4._driftreducerende_spuittechnieken.pdf

Agrovision. CropVision. Oogsten met zekerheid (CropVision. Harvesting with certainty (General information in English; price DSS in Dutch). Source: https://www.agrovision.com/nl/producten/teelt/teeltregistratie

Angileri, V. The implementation by Member States: FAS notifications. Presentation at FAS webinar, 21 October 2020.

Avagrar. Isomate CLR MAX IT. Source: https://avagrar.de/detail/index/sArticle/1177

Beldman, A.C.G., D. Lakner and A.B. Smit. Changing conditions require a higher level of entrepreneurship by farmers: use of an interactive strategic management tool. In: A. Kuipers, A. Rozstalnyy and G. Keane (eds.), Cattle husbandry in Eastern Europe and China; Structure, development paths and optimisation, Wageningen Academic Publishers, 2013, EAAP publication No. 135, pp. 125-131.

Beldman, A., N. Polman, H. Kager, G. Doornewaard, A. Greijdanus, H. Prins, M. Dijkshoorn and J. Koppenjan. Meerkosten biodiversiteitsmaatregelen voor melkvee- en akkerbouwbedrijven (Additional cost of biodiversity measures for dairy and arable farms; in Dutch, with English summary). Wageningen: Wageningen Economic Research, 2019. Report; no. 2019-105. https://doi.org/10.18174/501680.

BO Akkerbouw. Biostimulanten in de akkerbouw (Bio-stimulants in arable farming; in Dutch), 2020 Source: https://edepot.wur.nl/518547, 2020.

Bremmer, J., M. Riemens and M. Reinders. The future of crop protection. Study. Panel for the Future of Science and Technology; EPRS | European Parliamentary Research Service; Scientific Foresight Unit (STOA). PE 656.330 – February 2021. https://doi.org/10.2861/086545

Buurma, J., B. Smit, P. Leendertse, L. Vlaar, and T. van der Linden. Gewasbescherming en de balans van milieu en economie: Berekeningen bij de 2e Nota Duurzame gewasbescherming (Crop protection and the balance between environment and economy: Calculations accompanying the 2nd Memorandum on Sustainable Crop Protection; in Dutch), 2012.

Croplife. Innovation & Investment: More targeted ways to protect crops with less impact on nature. Source: https://croplifeeurope.eu/commitments/2030-commitments/innovation-investment/

Dacom. Spot op adviezen over het gebruik van gewasbeschermingsmiddelen (Spotlight on advices on the use of pesticides; in Dutch). Source : https://www.dacom.nl/producten/ziektemanagement.

DAW. Vaste rijpaden op perceel (Controlled traffic lanes in the field; in Dutch). Source: https://agrarischwaterbeheer.nl/system/files/documenten/boek/vaste_rijpaden_op_perceel.pdf

Delphy. Handleiding gewasbescherming akkerbouw en veehouderij 2021 (Manual crop protection arable and dairy farming 2021; in Dutch).

De Wolf, P., A. Dawson, and K. Klompe. Kosten en baten van bodemmaatregelen: Grondbewerking, organische stofaanvoer en Tagetes patula als aaltjesvanggewas (Cost and benefits of soil measures: Tillage, organic matter supply and Tagetes patula as nematode catcher crop; in Dutch). Wageningen Plant Research, Business unit Open Teelten, Report No. WPR-819, 2019.

EC (European Commission), Directive 2001/18/EC of the European Parliament and of the Council of 12 March 2001 on the deliberate release into the environment of genetically modified organisms and repealing Council Directive 90/220/EEC - Commission Declaration. Official Journal L 106, 17/04/2001 P. 0001 - 0039

EC (European Commission), Directorate-General for Agriculture and Rural Development, Directorate C. Strategy, simplification and policy analysis. C.3. Farm economics, 2020. Committee for the Farm Accountancy Data Network; Typology Handbook. Brussels, RI/CC 1500 rev. 5. https://circabc.europa.eu/ui/group/880bbb5b-abc9-4c4c-9259-5c58867c27f5/library/afb82ffd-ed89-4a86-a9c6-e3d28397fa17/details

Galgani, P., G. Woltjer, R. de Adelhart Toorop and A. de Groot Ruiz. Valuation framework for true price assessment of agri-food products. Bionext, True Price and Wageningen University and Research, 2021 https://trueprice.org/wp-content/uploads/2021/05/2021-05-11-Valuation-framework-for-true-price-agri-food-final-version.pdf

Inagro. Alternatief GPS systeem beloftevol voor eenvoudige toepassingen (Alternative GPS system promising for simple applications; in Dutch), 2017. Source: https://www.inagro.be/Artikel/guid/3702#:~:text=Afhankelijk%20van%20de%20uitvoering%20en,doorgaans%20maar%2020%20cm%20nauwkeurig.

Kortstee, H., N. Hamers - van den Berkmortel, K. de Grip, H. Hermans, B. Smit, R. Stokkers and M. de Vlas. Een leven lang leren; Voortdurende ontwikkeling van ondernemerscompetenties in kenniscoalities (Permanent education; Ongoing development of entrepreneurial competences in knowledge coalitions; in Dutch, with English summary), Den Haag, Report Wageningen Economic Research 2011-069, 2011. Source: https://edepot.wur.nl/197173.

KWIN-AGV. Kwantitatieve informatie akkerbouw en vollegrondsgroenteteelt (Quantitative Information on arable and field vegetable farming; in Dutch). M. van der Voord (ed.). PPO Publicationnumber 776, Wageningen University and Research, Business Unit Field Crops, 2018.

Marrone, P. G. The market and potential for biopesticides. In Biopesticides: state of the art and future opportunities (pp. 245-258). American Chemical Society, 2014.

Nicholas, P., S. Moakes, Z. Stojanowa, H. Harizanova, R. van der Meer, B. Smit and J. Bremmer. Identifying producers willingness to adopt low pesticide input systems under different scenarios of relative profitability. WP7.3 of: Theoretical Developments and Empirical Measurement of the External Cost of Pesticides. Collaborative Project Seventh Framework Programme, Theme 2 Food, Agriculture and Fisheries, and Biotechnology, 2011. Source www.eng.auth.gr/mattas/teampest/deliv2.htm

Nieuwe Oogst. Duurzamer telen begint bij rassenkeuze zetmeelaardappelen, 2020. Source: https://www.nieuweoogst.nl/nieuws/2020/09/14/duurzamer-telen-begint-bij-rassenkeuze-zetmeelaardappelen.

NPPL. 'Ik heb werkbare taakkaarten om variabel te poten' ('I have workable task maps for variable planting'; in Dutch), 2019 Source: https://www.proeftuinprecisielandbouw.nl/ik-heb-werkbare-taakkaarten-om-variabel-te-poten/#:~:text=Omdat%20het%20TT%2B%2Dconcept,afhankelijk%20van%20het%20gekozen%20pakket

NPPL. Precisiespuiten: nauwkeurigheid heeft een prijskaartje (precision spraying: accuracy has a price label; in Dutch), 2020. Source: https://www.proeftuinprecisielandbouw.nl/precisiespuiten-nauwkeurigheid-heeft-een-prijskaartje,

Olson, S. An analysis of the biopesticide market now and where it is going. Outlooks on pest management, 2015, 26(5), 203-206

Reportlinker. Biostimulant market - Growth, trends, COVID-19 Impact, and forecasts (2021 - 2026), 2021. Source: www.reportlinker.com/p06062823/Biostimulant-Market-Growth-Trends-COVID-19-Impact-and-Forecasts.html?utm_source=GNW

Riemens, M., B. Allema, J. Bremmer, D. van Apeldoorn, Y. Bai, C. Kempenaar, M. Reinders and M. Wenneker. The future of crop protection in Europe; Appendix 1: Overview of current and emerging crop protection practices. Study. Panel for the Future of Science and Technology. EPRS | European Parliamentary Research Service. Scientific Foresight Unit (STOA). PE 656.330 – February 2021.

Sánchez-Girón, V., A. Serrano, M. Suárez, J.L.. Hernanz, and L. Navarrete. Economics of reduced tillage for cereal and legume production on rainfed farm enterprises of different sizes in semiarid conditions. Soil and Tillage Research, 2007, 95(1-2), 149-160.

Smit, A.B. and S.R.M. Janssens. Bij het afscheid van een teeltkundige (3). Effecten van prijsdaling op inputniveaus in de Nederlandse akkerbouw (Dedicated to the farewell of an agronomist (3). Effects of a price decrease on input levels in Dutch arable farming; in Dutch). Spil 161 – 162, 26 – 29, 1999.

Terranext. Starterscursus precisielandbouw (Beginners course precision agriculture; in Dutch), 2021. Source: https://www.terranext.nl/opleidingsaanbod/agrarisch/starterscursus-precisielandbouw.

Theuws, L.W., J.S. Buurma, A.B. Smit, C.J.M. Vernooy, S.C. van Woerden, E.H. Poot and A.J.J. van Roestel. Ondernemerstypen en kennisverspreiding rond geïntegreerde teelt (Types of entrepreneurship and knowledge dissemination in the context of integrated crop cultivation; in Dutch). Den Haag, Wageningen Economic Research (LEI), 2002, report 7.02.06. https://edepot.wur.nl/20009

Van Evert, F.K., D. Gaitán-Cremaschi, S. Fountas and C. Kempenaar. Can Precision Agriculture Increase the Profitability and Sustainability of the Production of Potatoes and Olives? Sustainability 2017, 9, 22 pp.

Van Woensel, L. Chr. Kurrer and J. Tarlton. Precision agriculture and the future of farming in Europe. Scientific Foresight Study. Brussels, Scientific Foresight Unit, EPRS, PE 581.892, 2016. 10.2861/020809

Appendices

Appendix 1 – Definition of standard output (SO)

Standard output (SO) is the standard value of gross production. It is used for classifying farms according to the EU farm typology (in which the type of farming is defined by main production activities) and for determining the economic size of farms. Total SO of a holding is the sum of the individual production units of a specific holding multiplied by their respective SOC (Standard Output Coefficients). The standard output (SO) of each crop and livestock characteristic is the regional average monetary value of the agricultural output at farm gate price over the reference period; in other words, it can be obtained by multiplying the quantity of each production obtainable from a certain crop of livestock by its unit price. Standard output coefficient (SOC) is the average monetary value of gross production of each agricultural variable, corresponding to the average situation in a given region, per unit of production. The SOC of a crop or livestock variable is the monetary value of the agricultural gross production at the farm gate price calculated as follows:

- including sales, farm use, farm consumption and changes in stocks;
- including both the value of the main and any secondary products;
- excluding direct payments (coupled, decoupled or other payments), value added tax and taxes on products, compensations in case of bad weather or animal disease;
- the SOC should correspond to the output expected in normal conditions: e.g., if in a year the whole country is concerned by an epizooty, this abnormal year may be excluded from the calculation for the products concerned.

The SOC is a unit value. It is calculated at farm gate price, in euro per hectare of crop or euro per head of livestock (exceptions apply for mushrooms in euro per 100 m^2, poultry in euro per 100 heads and bees in euro per hive). VAT, taxes and subsidies are not included in the farm gate price. The SOC of a variable corresponds to the weighted average situation on the agricultural holdings situated in a given geographical unit (referred to here as region) (definitions given by the EC are cited here (2020)).

SOC-values per crop per Member State can be found here.

Appendix 2 – Area, number and standard output of farm types, per Member State

Table A2.1 – Cultivation area of specialised plant production farms in the EU27 (x 1,000 ha)

Member state	Specialist cereals, oilseed and protein crops	General field cropping	Specialist horticulture outdoor	Specialist vineyards	Specialist fruit and citrus fruit	Specialist olives
Austria	394	579	0	56	17	0
Belgium	44	281	17	0	17	0
Bulgaria	2 883	1 101	7	29	33	0
Croatia	346	422	2	17	17	14
Cyprus	15	16	5	4	9	6
Czechia	871	296	1	17	15	0
Denmark	684	384	2	0	4	0
Estonia	305	93	3	0	4	0
Finland	884	319	21	0	3	0
France	7 580	2 986	68	1 116	228	7
Germany	3 605	2 151	20	114	64	0
Greece	536	2 119	18	74	148	491
Hungary	2 506	458	2	49	68	0
Ireland	258	590	1	0	1	0
Italy	2 228	2 400	22	831	498	606
Latvia	621	327	8	0	9	0
Lithuania	1 189	280	8	0	12	0
Luxembourg	4	3	0	1	0	0
Malta	0	3	3	0	0	0
Netherlands	30	431	54	0	21	0
Poland	3 853	2 689	88	0	353	0
Portugal	152	373	15	160	199	151
Romania	4 723	3,291	12	84	130	0
Slovakia	640	123	2	8	3	0
Slovenia	35	44	1	10	8	1
Spain	6 803	3,401	136	880	885	1 862
Sweden	657	483	14	0	3	0
United Kingdom	2 948	3 705	15	1	47	0

Table A2.2 – Number of specialised plant production farms in the EU27

Member State	Specialist cereals, oilseed and protein crops	General field cropping	Specialist horticulture outdoor	Specialist vineyards	Specialist fruit and citrus fruit	Specialist olives
Austria	13 490	23 080	70	8 040	2 450	0
Belgium	2 210	7 270	850	0	870	0
Bulgaria	19 380	35 050	4 950	12 080	9 370	0
Croatia	20 890	12 540	990	6 370	7 010	9,100
Cyprus	820	1 490	870	2 550	7 460	7 380
Czechia	5 340	2 720	220	2 180	650	0
Denmark	11 030	5 510	10	0	200	0
Estonia	2,350	3,790	430	0	320	0
Finland	19 670	12,800	880	0	340	0
France	88 220	41 130	8 080	64 880	14 050	2 580
Germany	42 030	38 020	860	14 210	5 030	0
Greece	65 980	70 900	6 360	25 880	60 160	264 430
Hungary	82 590	41 460	450	32 080	31 180	0
Ireland	4 630	8 530	60	0	50	0
Italy	185 430	129 780	3 560	111 100	83 130	172 360
Latvia	6,120	29,730	560	0	2 000	0
Lithuania	23 640	37 750	2 640	0	1 210	0
Luxembourg	70	100	0	320	10	0
Malta	0	3 300	1 330	250	251	40
Netherlands	1 350	10 800	2 440	50	1 580	0
Poland	333 060	369 880	7 790	0	60 250	0
Portugal	6 470	20 220	5 900	30 020	27 610	22,780
Romania	408 450	633 390	11 100	86 140	63 540	0
Slovakia	5 680	3 250	40	310	140	0
Slovenia	3 720	11 260	150	3 470	2 050	560
Spain	131 780	84 330	17 290	69 590	149 440	211,090
Sweden	7 400	20 430	340	0	240	0
United Kingdom	20 050	30 100	190	90	1 660	0

Table A2.3 – Standard output of specialised plant production farms in the EU27 (in million euro)

Member State	Specialist cereals, oilseed and protein crops	General field cropping	Specialist horticulture outdoor	Specialist vineyards	Specialist fruit and citrus fruit	Specialist olives
Austria	371	556	4	327	173	0
Belgium	65	1 517	335	0	260	0
Bulgaria	1 746	275	25	35	38	0
Croatia	329	210	11	64	54	34
Cyprus	5	48	39	7	48	8
Czechia	765	382	23	106	34	0
Denmark	758	524	7	0	16	0
Estonia	122	39	4	0	2	0
Finland	415	231	112	0	10	0
France	8 468	4 300	1 306	10 256	1 398	8
Germany	4 330	5 029	412	1,096	641	0
Greece	414	1,219	111	358	695	967
Hungary	1 832	415	11	72	136	0
Ireland	237	174	3	0	3	0
Italy	2 684	4 557	292	6 326	2 922	1 061
Latvia	308	60	14	0	3	0
Lithuania	664	136	6	0	6	0
Luxembourg	4	3	0	17	1	0
Malta	0	4	23	1	1	0
Netherlands	44	1 356	953	2	368	0
Poland	2 954	2 464	287	0	786	0
Portugal	136	430	134	223	389	52
Romania	2 618	1 505	57	97	200	0
Slovakia	500	104	65	11	5	0
Slovenia	40	48	7	28	37	3
Spain	3 398	2 767	1 349	1 328	3 228	1 853
Sweden	444	380	69	0	21	0
United Kingdom	3 256	2 491	293	5	310	0

Appendix 3 – Farm size distribution in three subclusters in cluster A

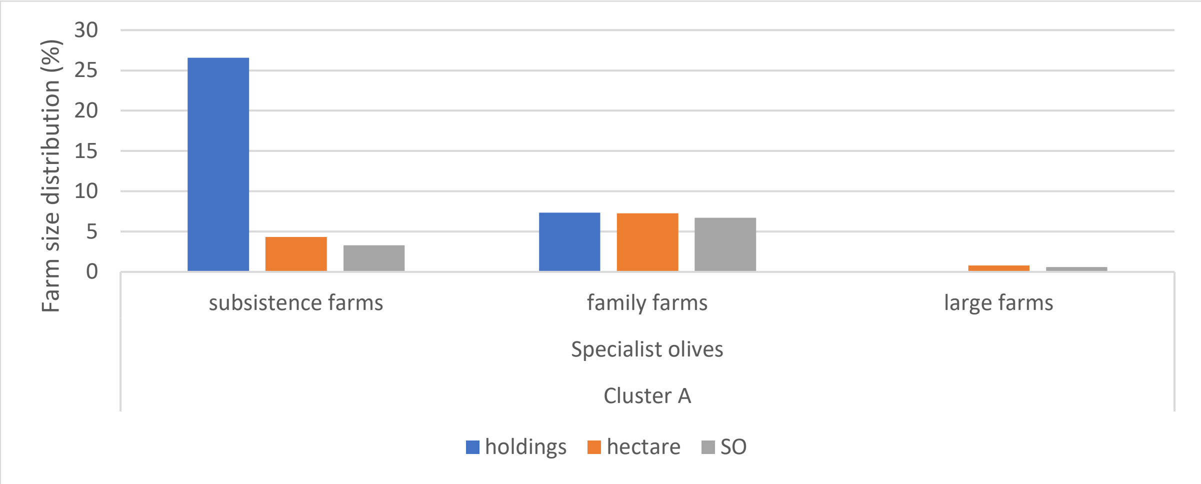


Figure A3.1 – Farm size distribution (in %) in cluster A, farm type 'specialist olive farms'.

Farm size is expressed in three ways: 1) number of holdings; 2) cultivation area in hectare; 3) revenues in SO. Source: Eurostat, processed by Wageningen Economic Research.

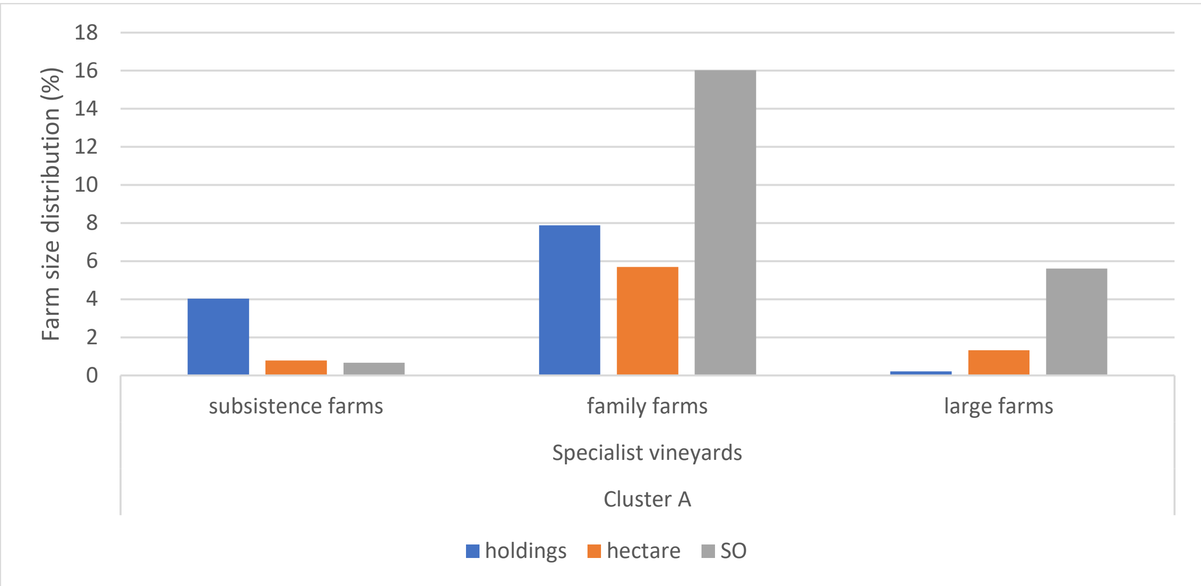


Figure A3.2 – Farm size distribution (in %) in cluster A', farm type 'specialist vineyard farms'.

Farm size is expressed in three ways: 1) number of holdings; 2) cultivation area in hectare; 3) revenues in SO. Source: Eurostat, processed by Wageningen Economic Research.

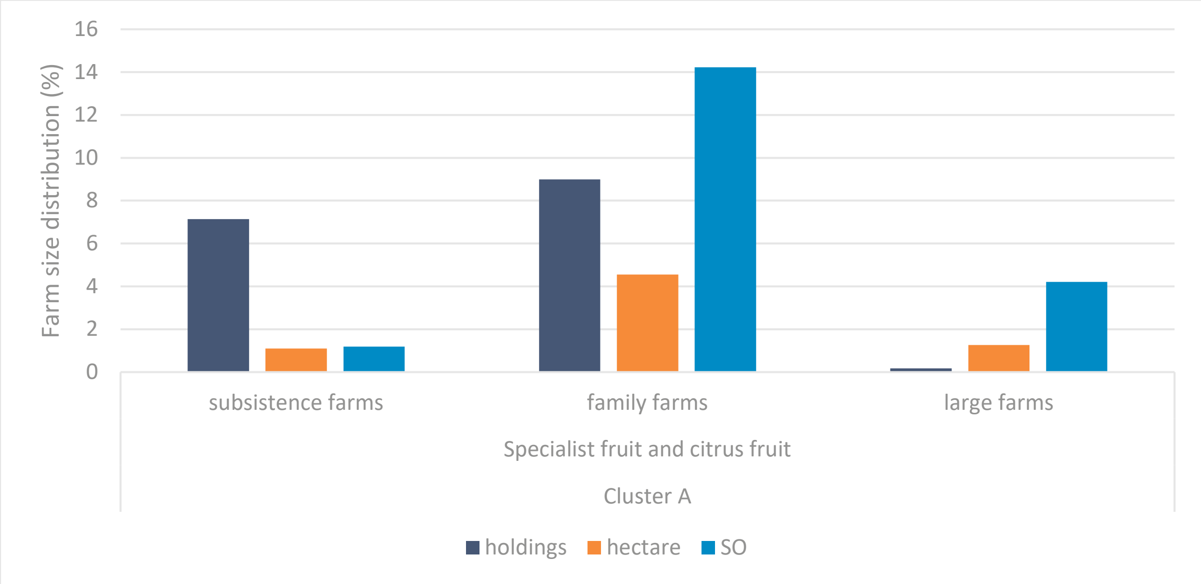


Figure A3.3 – Farm size distribution (in %) in cluster A, farm type 'specialist fruit and citrus farms'.

Farm size is expressed in three ways: 1) number of holdings; 2) cultivation area in hectare; 3) revenues in SO.
Source: Eurostat, processed by Wageningen Economic Research.

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Existing, new and emerging crop protection practices, including mechanical techniques, precision agriculture, biocontrol, plant breeding, induced crop resistance, application of ecological principles to increase biodiversity and use of 'green' plant protection products, could help to reduce the use of conventional plant protection products and were described in an earlier STOA study. This new study provides cost estimates for various alternative crop protection practice options in the EU.

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