Literature review

Exploring the benefits of biocontrol for sustainable agriculture

A literature review on biocontrol in light of the European Green Deal

Institute for European Environmental Policy

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Hulot, J.F. and Hiller, N. (2021) 'Exploring the benefits of biocontrol for sustainable agriculture – A literature review on biocontrol in light of the European Green Deal', Institute for European Environmental Policy.

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ACKNOWLEDGEMENTS

We gratefully acknowledge helpful reviews and comments from Jennifer Lewis (IBMA), Jo Sullivan (Conscience Consulting), and Tomas Garcia-Azcarate (Institute of Economy, Geography and Demography, Madrid).

This report was commissioned by IBMA, the International Biocontrol Manufacturers Association.

COVER PICTURE

The picture shows a hoverfly – a biocontrol agent which protects crops. Its larva eats aphids, and the adult pollinates.

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FOREWORD BY FAUSTINE BAS-DEFOSSEZ, EXTERNAL IMPACT DIRECTOR AT IEEP

The science is unequivocal on the need to move rapidly towards a sustainable food and farming system in order to stay within planetary boundaries. The European Green Deal, in particular its Farm to Fork and Biodiversity strategies, aims at setting the way towards that new system of food production and consumption. As a systemic and balanced alternative to chemical inputs in farming, biocontrol is certainly an enabler of that system change.

As an independent think tank striving for sustainability and science-based policymaking, we were very enthusiastic when IBMA approached us to conduct a literature review on the benefits of biocontrol for the environment and its wider economic, climate and governance impacts. We indeed believe that such evidence is needed for informed and sound decision-making on the European Green Deal objectives' implementation.

EXECUTIVE SUMMARY

Reducing harmful pressures on the environment is key to creating a sustainable and healthy food system. The political and technical conversation about agricultural production and plant protection methods, especially in the context of the European Green Deal and the Farm-to-Fork strategy, increasingly revolves around the effects of different inputs on biodiversity and health.

Biocontrol, at its core, aims at not causing harm to the environment, non-targeted species and human health. The four technical categories of biocontrol are macro-organisms (invertebrates), micro-organisms (viruses, bacteria and fungi), semio-chemicals (pheromones) and natural substances. Compared to the typically linear vision to plant protection with chemical products, biocontrol considers the structural approach of understanding the farm ecosystem of life cycles, insects' behaviour and the influence of agronomic practices on plant health. Biocontrol thereby becomes a key enabler of the European Green Deal in forming part of a system approach to sustainable agriculture. Based on a literature review, this paper explores the roles of biocontrol in a pathway towards sustainable agriculture, with both a focus on biodiversity and health and its potential wider impacts.

Drawing from the literature, biocontrol functions for plant protection and supports of biodiversity by significantly reducing the chemical pressure in the field. As a targeted measure, it has few adverse effects on non-targeted fauna and flora, thereby contributing to the maintenance and improvement of agricultural biodiversity. Soil quality and health equally benefit from decreasing harmful residues and contamination. The use of biocontrol can thereby contribute to a favourable status of microbial communities. Lower negative impacts on human health can equally be identified, where biological approaches can deliver for the safety of both consumers and farmworkers. The effectiveness of natural pest control enemies can be amplified by creating ecological focus areas. In addition, biocontrol performs best in a system of sustainable farming practices. Growing evidence for the efficacy of biocontrol products, in the EU and around the world, resulted both in a higher EU approval rate and an expected market growth for products of around 15% a year over the next five years.

The deployment of biocontrol, by incorporating farmers' experiences in the implementation process, paves the way for widespread adoption of Integrated Pest Management techniques, organic agriculture and agro-ecological farming. Based on the literature review, policy considerations include a need for a common EU definition for greater clarity in political discussions, an assessment of the legal framework, a push for greater field application and further research needs.

While more research of concrete interactions between all categories of biocontrol and biodiversity support is suggested, the literature highlights the positive impact of biocontrol in lowering chemical residues, its benefits in favourable environments and its targeted use. As a non-chemical input, biocontrol can offer a systemic and balanced solution for sustainable agriculture.

1. EXPLORING THE BENEFITS OF BIOCONTROL – INTRODUCTION

Biocontrol, or bioprotection, is the process of natural plant health protection based on the observations of plant ecology, predator-prey relationships amongst insects and other approaches of ecosystems functioning. The aim is to have minimal impact on human health and the environment.

As an integral part of the **European Green Deal**, the Farm to Fork strategy aims at creating a sustainable and healthy food system, where the use of products for plant protection plays a key role. By 2030, the strategy aims to reduce the use of chemical and hazardous pesticides by 50%, and 25% of land should be cultivated with organic production to lower environmental pressures (soil, water, health) on agricultural land and beyond.

In this context, biocontrol can be regarded as a **key enabler for achieving the objectives** of the European Green Deal, by contributing to the above-mentioned goals. It may also present a win-win-tool for the environment and the farmer, in reducing the use of inputs and create a more adapted method, which speaks to consumer concerns and demands. Still, upscaling biocontrol faces challenges, some of which are technical and socio-economic, while others relate to the legal status of biocontrol products.

In exploring alternatives to chemical plant protection methods, this paper gathers evidence on the role that biocontrol can play in sustainable agriculture, particularly in terms of benefits for biodiversity. The **literature review** draws on mainly peer-reviewed publications, as well as other scientific articles and books, and to a lesser degree grey literature for illustrative examples. The paper provides a comprehensive picture to policymakers, stakeholders and the public on the current status of biocontrol in the strategy towards sustainable agriculture.

To build a clear framework around the topic, the first section presents definitions around biocontrol. After outlining the current stances on efficacy levels and market position, the literature on benefits with regard to biodiversity, soil and health is examined. The fifth section then gives an overview of the wider impacts that biocontrol may have, including farm economics and climate considerations.

2. RELEVANT DEFINITIONS

The term biocontrol describes the protection of plant health through natural or nature identical means. While this definition is short and easy to use, ambiguities and room for confusion remain. When diving into the details and practical applications, the topic of biocontrol can become technical and complex, therefore a clear definition of its technologies and practices is of importance.

Biocontrol is frequently put in relation with agroecology, organic farming and integrated pest management. Although this connection provides a beneficial angle of analysis, biocontrol can be deployed in most farming systems and has a long history of use and development (see Annex I).

Biocontrol and bioprotection

The practice of **biocontrol** is described in the dictionary of agroecology and plant pathology as comprising the use of living organisms or natural substances to prevent or reduce damage and diseases caused by harmful organisms such as animal pests, weeds and pathogens (Busson, 2019, Prajapati et.al., 2020). The term **bioprotection** is used to label biocontrol and biocontrol technologies and to make the link with its natural dimension, meaning causing no damage to the environment - or a minimal, non-remanent effect - and no harm to humans and non-targeted animals, nor creating risks for human health (International Biocontrol Manufacturers Association, 2020).

Depending on the types of living organisms or natural substances used, four categories of technological approaches to biological control are widely agreed:

- **Macro-organisms**: invertebrates, such as insects and nematodes used for biocontrol purpose - referred to as Invertebrate Biocontrol Agents
- **Micro-organisms**: viruses, bacteria and fungi
- **Semio-chemicals** or chemical mediators: pheromones
- **Natural substances** of mineral, plant or animal origin

In certain parts of the world, notably the USA, the term biocontrol is limited to macro-organisms, or Invertebrate Biocontrol Agents (BCAs). This report takes a wider approach which considers the four categories above. Among the EU Member States, France includes the four categories in the French Rural Code of

Law ("Code Rural et de la Pêche Maritime", article L 253-6).[1] **EU applicable law to biocontrol** is non-specific and partial, whereas biocontrol products must follow the EU pesticide regulation process (except for macro-organisms which may be regulated under differing national legislation of the 27 EU members) (see Annex II). However, no formal EU definition of biocontrol or bioprotection currently exists.

Agroecology

Agroecology brings together several concepts of sustainable agriculture, and therefore can be related to biocontrol. The term agroecology may have different significations depending on the context, where it may refer to a movement or a science in the domain of agriculture (see Table 1).

The Food and Agriculture Organisation (FAO) offers the following definition, which covers all the dimensions of sustainability: "*Agroecology is an integrated approach that simultaneously* ***applies ecological and social concepts and principles to the design and management of food and agricultural systems****. It seeks to optimise the interactions between plants, animals, humans and the environment, while taking into consideration the social aspects that need to be addressed for a sustainable and fair food system*" (Food and Agriculture Organisation, 2018).

Table 1 - Farming systems and available tools and techniques

	Agroecology	Organic	Conventional
Definition	FAO	EU regulation	X
Approach	Systemic	Systemic	Linear
Chemical synthetic pesticides	Minimal	Not allowed	Yes
Biocontrol	Yes	Yes	Yes

[1] This article also forms the legal base for the French national deployment strategy of biocontrol, published in November 2020.

Organic Farming

Organic farming is regulated at the EU level (European Commission, 2018), where plant protection products are subject to explicit authorization through restrictive positive lists that **exclude synthetic chemical pesticides**. In principle, preventative plant protection measures in the form of biocontrol, plant extracts and physical methods, form part of organic agriculture (Haller et.al., 2019). The EU organic farming regulation states that "*preventive measures, in particular the choice of appropriate species, varieties or heterogeneous material resistant to pests and diseases, appropriate crop rotations, mechanical and physical methods and protection of the natural enemies of pests*". All biocontrol technologies are allowed for organic production, with the unique exception of genetically modified micro-organisms if used for biocontrol action: the regulation *"excludes the use of GMOs, products produced from GMOs, and products produced by GMOs, other than veterinary medicinal products"* (European Commission, 2018).

Consequently, organic farmers extensively use biocontrol, yet not all farmers using biocontrol are certified organic. As an example, the use of invertebrates in organic fruit growing is described as indispensable (Herz and Matray, 2019). Both conventional and organic farmers can choose to practice biocontrol to protect their crops from pests.

Integrated Pest Management

Integrated Pest Management (IPM) refers to an ecosystem approach to crop production and protection that combines different **management strategies and practices** to grow healthy crops and minimize the use of pesticides.

The FAO describes IPM as "*the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms.*" (Food and Agriculture Organisation, 2021).

As biocontrol is a means to achieving pest control, it represents an important and preferred tool for crop protection in the IPM (Niggli et.al., 2020, Baker et.al. 2020). Synthetic chemical pesticides may be used in IPM as a last resort only if sustainable biological, physical and other non-chemical methods have not provided satisfactory pest control.

IPM is central to the **EU Directive for sustainable use of pesticides** (SUD). [2] Its enforcement is however described as weak. Chemical pesticides are still considered to be the option for easy application and inexpensive (Niggli et.al., 2020). In an analysis on the Bundesländer of Germany, the Julius Kühn-Institut further noted that application varies greatly, influenced also by the use of diverse products, and a proper assessment requires far greater data collection (Koch et.al., 2019). In a recent special report, the Court of Auditors confirmed this situation and called in its recommendations to make IPM a condition to receive CAP area payments (European Court of Auditors, 2020).

A clear **legal definition of biocontrol** and its relationship to IPM and organic agriculture, would remove potential misunderstandings. As stated above, an EU definition of biocontrol does not exist. Integrating a single EU wide accepted definition in upcoming regulations and guidance would be beneficial for a common understanding of the functions of biocontrol, and its value to the EU Green Deal.

Table 2: Defining biological control, IPM and organic farming

	Agroecology	Organic	IPM	Biocontrol
Scope	Organic and conventional agriculture	Organic agriculture only	Organic and conventional agriculture	Organic and conventional agriculture
Range of use	Agriculture	Agriculture	Agriculture and Forestry	Agriculture and Forestry
Precise EU definition	X	✓	✓	X

[2] Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides (see also Annex II).

EU regula-tion	No	Yes (Organic Farming Regulation)	No	Partly
Labelling of end products	X	✓	X	X
EU quantified objectives	No	25%	No	No
CAP financial support	Yes (eco-schemes, agro-environment)	✓	X	X

3. TECHNICAL ASPECTS, USE AND MARKET

In the first instance, biocontrol is expected to be highly effective for the intended purpose, namely controlling a particular pest on a particular crop. To be effective, attention should be paid to factors like temperature, soil water content, soil physical and chemical characteristics, as well as the method of application and the timing of application. Besides efficacy, this section considers the effective areas of application and market developments.

Efficacy

Biocontrol efficacy was often noted as unguaranteed compared to chemical inputs, because biocontrol is more context-specific, interacting with the natural eco-system. By paying additional attention to all elements of the farming system, efficacy can be optimised (see section 5).

Recent research in Australia on the potential of biocontrol against potato diseases indicated that initially, chemical treatment significantly reduced losses from diseases and associated viruses, especially when **combined with good agronomic practices** like crop rotation, lower nitrogen applications and constrained irrigation input (O'Brien and Milroy, 2017). However, the emergence of fungicide resistance in pathogen populations, deregistration of fungicides, and growing concerns about the health impacts of chemicals in food production prompted renewed interest in novel approaches through biocontrol.

In that same research, the authors examined whether biocontrol would be capable of rivalling the equivalent level of control achieved with chemicals. While synthetic fungicide proved effective, research on biocontrol showed statistically significant suppression of the disease, with **levels of suppression** greater than 85%.

Baker et.al. (2020) describe the dynamic and resilient results that biocontrol can attain against exotic pests. The authors point to research that suggests invertebrate biocontrol agents are better equipped to adapt to local contexts, therefore are overall more effective natural enemies (Heimpel and Mills, 2017 – in Baker et al 2020). Where consistency of control is a concern, it could be solved by using mixtures, additives or digital monitoring, which provides a greater chance of successful implementation (see Box 1 in section 3).

Approaches combining biocontrol agents and agrochemicals achieve levels of disease suppression equal or superior to the use of biocontrol alone. In the above-mentioned study on potato plants, O'Brien and Milroy (2017) conclude that biocontrol is a safe, non-toxic, renewable alternative for controlling the studied potato pathogen, worth a focused effort to develop practical biological control systems to bring adequate protection consistently across production systems and geographic locations within the intended range of use (O'Brien and Milroy, 2017).

Areas of application

The above examples indicate that biocontrol can obtain sufficient efficacy levels for a satisfactory level of crop protection. Such levels are met in **horticulture**, especially under glass in a protected environment, where biocontrol has become a mainstream and popular choice of pest control in Europe.

EU research has shown that such efficacy levels could also be reached in **orchards and vineyards**. The Horizon2020 project POnTE delivered interesting findings for fighting *Xylella fastidiosa* ravaging olive trees in Southern Italy with the help of a biocontrol inundation strategy reducing pathogen incidence below 10% (Liccardo et.al, 2020). The FP7 project BCA GRAPE showed the potential effect of particular *Ampelomyces* fungi strains, where efficacy levels meant a significant reduction of the powdery mildew disease, both in incidence and severity (BCA-grape, 2007).

Looking outside the EU, to tropical fruit in **Pakistan's papaya orchards**, for instance, biocontrol has recorded good efficacy levels. Where conventional chemical pesticides turned ineffective to treat severe infestation by the papaya mealybug due to resistance, natural predators proved to be successful (Shaikh, S. 2017). Similarly, for bananas, the EU research project MUSA aims to develop locally adapted IPM strategies based on beneficial microorganisms to control several common pests and diseases (MUSA, 2020).

Regarding cereals and arable crops in general, biocontrol does not stand out as the preferred option by farmers today. However, promising results of its efficacy suggests a greater use in the near future:

- On **wheat**, empirical evidence from field trials in northeast England shows that biocontrol technologies are a realistic option for controlling wheat pests and diseases (Crop Health North, 2019). Spring wheat and winter wheat yields obtained at three different plots locations are within the same range, without significant deviation between chemical insecticides and fungicides and biological treatments (see Chart 1). Varied management regimes bring some variability in qualitative terms only, on higher protein content in the case of biological treatment.

- On **maize**, the larvae of the European corn borer (*Ostrinia nubilalis*) can reduce yield by 20-30%, while insecticide resistance is building.

Trichogramma is a very small wasp that parasites and kills eggs of the corn borer larvae. They are released on maize vegetation from the air, with helicopters or drones, on a quarter of the French maize area. Enhanced efficacy is ensured when combined with a light chemical treatment as regular field application has shown (Carpentier, 2014).

Chart 1: Results of biocontrol in field trials with cereals

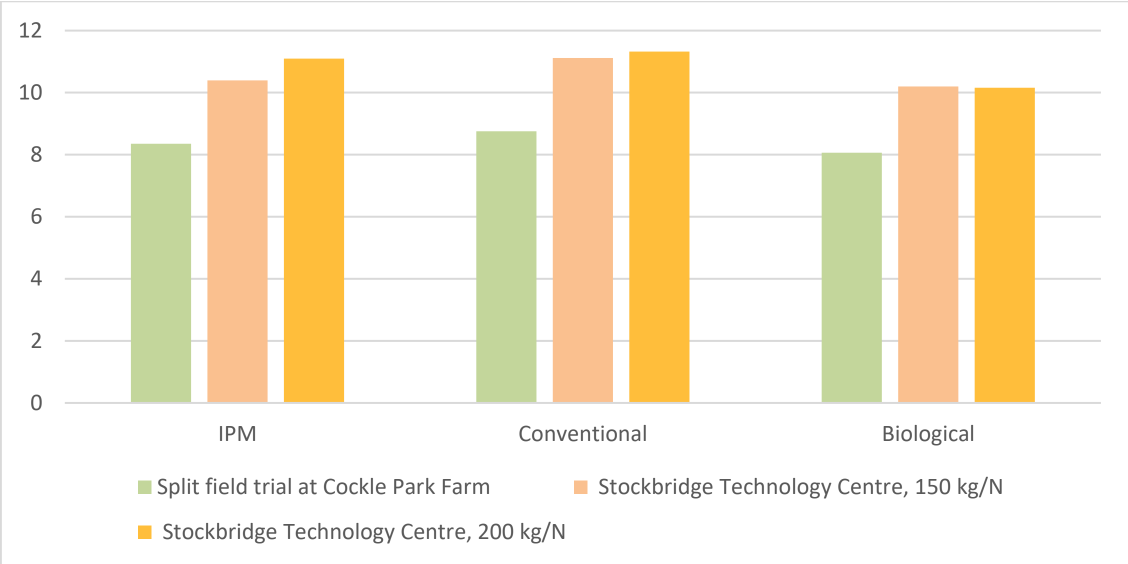

Chart 1: Winter wheat yields under selected management/crop protection regime were recorded at three fields trails locations in 2019 (Project Crop Health North, UK). No significant deviation was observed. Source: https://www.crophealthnorth.co.uk/project-results/

Market observations

The growing demonstration of biocontrol **efficacy has boosted the biocontrol market**. Over the last ten years, the range of products and agents available to EU farmers for biocontrol use has expanded significantly. The large number of EU funded research projects has paved the way for developing and expanding the variety of biocontrol products on the market (Annex III for detailed analysis of biocontrol projects financed under FP6, FP7 or Horizon2020).

In the last 10 years, the number of **non-chemical, low-risk and basic substances approved in the EU** under R. 1107/2009 **has doubled** (2009-2019) (European Commission 2020b).

Outside the scope of the EU pesticide regulation, macro-organisms used for the biological control of plant pests have followed a similar trend. These are subject to national legislation in the majority of EU Member States and the request to develop a harmonised approach for their assessment and position on the market is currently considered by the EU.[3] In parallel, the most hazardous active substances are being removed from the list of authorised PPP in the EU, to reduce risks to the environment and health (European Commission, 2020d).[4] Against this background, biocontrol opens pathways for sustainable solutions to plant health problems.

The **biological control market is growing** and is expected to expand further, by around 15% a year for the next five years (Mordor Intelligence, 2021). In the EU, a trend can be observed - approximately half of all applications for approval for new active substances are for biological plant protection products (Koch et.al., 2019). Literature from 2006 states that, at the time, biological control was still at the beginning, and only a few products were available on the European Market (Alabouvette et.al., 2006). Since then, the demand for food produced without the use of chemicals has grown.

Among the technological categories of biocontrol, micro-organisms are the most dynamic segment. Microbials occupy already about two-thirds of the market, and the majority of research projects (see below the section on research) focus on micro-organisms. With upcoming innovations arriving at maturity this segment is expected to grow at a faster rate.

The **biggest markets are the USA, Brazil and the EU**, where biocontrol uptake is growing under the influence of several converging factors. In the USA, actions towards regenerative agriculture play a role in extending non-chemical plant protection (Forum for the Future, 2020). Registrations have recently expanded in Latin America Specific products, such as Trichoderma (fungi), find their largest distributors in Asia, followed by Europe (Woo et.al., 2014).

Regarding mass production, Junaid et.al. (2013) and Groot et.al. (2020) suggest that mass production can be supported by looking into extending the shelf-life of biocontrol products, while also better understanding their wider application (Junaid et.al., 2013, Groot et.al., 2020, Prajapati et.al., 2020). In a report on Germany, it was pointed out that, at the moment, there are too few incentives for minimising the use of chemical plant protection products (Niggli et.al. 2020).

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[3] 18 MS have national legislation in place, with some differences in their approach, according to a survey conducted by the Portuguese Presidency of the EU in the trimester of 2021 (background note for the Council debate of 4 March 2021: https://data.consilium.europa.eu/doc/document/ST-6645-2021-INIT/en/pdf)

[4] The number of emergency authorisations delivered by the MS has sharply increased, to address dangers to plant health which could otherwise not be contained.

Challenges and opportunities for biocontrol products

A major obstacle in the development of economically competitive biocontrol has been the requirement in the major markets to register microbial control agents following rules originally intended for chemical pesticides (Eilenberg and Hokkanen, 2006). This lack of systemic approach at the EU level is reported by scientists, practitioners and the industry, covering, among others, the approach to data requirements for registration and the inclusion of microbiological science in evaluations and legislation (Köhl et, al., 2019, Sundh and Eilenberg, 2020). Funding research for finding innovative sustainable solutions may end without a product or new approach if the legislative process for approval and use of the new biological solutions generates bottlenecks and backlogs.

Organic production is growing due to consumer demand and policy support. The **EU Farm to Fork strategy** sets a 25% objective for organically farmed land by 2030. It also aims at reducing risk and use of pesticides by 50% (European Commission, 2020c). Regulations on pesticide use are becoming more stringent, and both the farming community and consumers are concerned by the toxicity of chemical pesticides. Rising costs of pesticides and increased efficacy of biocontrol also create incentives for farmers to shift from chemicals to biological control solutions.

4. BENEFITS FOR BIODIVERSITY, SOIL AND HUMAN HEALTH

4.1 Biodiversity

Biocontrol has recognised potential to support the protection and enhancement of biodiversity, particularly in the framework of IPM and in combination with organic production (Herz, 2020, Niggli et.al. 2020, Prajapati, 2020). Reducing the overall use of chemical pesticides has widely acknowledged benefits for biodiversity.

Biodiversity can be enhanced by **lowering pressures** resulting from chemical inputs, respecting non-targeted insects and other organisms, and leaving no toxic residues in the environment (Herz, 2020, Baker et.al. 2020, Niggli et.al. 2020). According to a study from Germany, alternative approaches, such as biocontrol, are specifically desirable for fruit, vines and potatoes, where widely used fungicides and individual broad-acting insecticides harm the environment and biodiversity (Haller et.al. 2019).

Creating spaces for biodiversity to flourish in agriculture, such as flower strips, can improve the effectiveness of natural enemies (Lambion and van Rijn, 2021). Similarly, a mapping of evidence from the EU by Holland et.al. (2017) found that semi-natural habitats have an overall positive effect on deployment of biocontrol, meaning the effect was greater in the right conditions (Holland et.al., 2017). To accurately understand the relationship between plant protection products (chemical and natural) and biodiversity, the need for long-term studies has been noted (Niggli et.al.2020).

This fits into the perspective of biocontrol positively interacting in a system of sustainable farming practices, as the state of biodiversity comes together from implemented **crop measures** (tillage, crop protection, fertilisers etc.), abiotic factors (climate change, the composition of the soil, etc.), and biotic factors (semi-natural habitats, refuges etc.) (Niggli et.al., 2020). To support farmers in the adoption of biocontrol, Box 1 demonstrates the relevance of technical advisory services in an example of rice production in Spain.

In this way, organic farming is often cited in supporting biodiversity, also as it refrains from the large-scale use of pesticides (Baker et.al. 2020). The European Commission considers this link by stating that “land farmed organically has about 30% more biodiversity than land farmed conventionally.” (European Commission, 2021e). While biocontrol is not limited to organic farming, its functions are often presented in the framework of IPM and organic farming in the literature.

Box 1 - Biocontrol for rice production - La Albufera de Valencia

Biocontrol in the form of pheromones is successfully used against the rice stem borer in 16,000 ha of rice production in Albufera, Spain. Historically, the rice stem borer was controlled by organophosphate insecticides in this region. Through experimentation, demonstration of best practice, training and farmer financial incentives through regional CAP funding, the entire cultivation area converted to biocontrol. The switch decreased both the environmental impact and chemical exposure for farmworkers, as well as creating favourable conditions for biodiversity to flourish in the region.

Efficacy: The method requires the use of dispensers placed across the fields by the regional technical services. Monitoring stations support the effectiveness of application, and field surveys measure the damages. A comparison is drawn – in early 1990s rice stem borer levels were at 60-70 Months/Traps/Day (MTD); which has fallen to less than two today.

Long-term application: Field studies have shown how the effectiveness of using biocontrol in this area increased over the period of application. It requires time to observe the impact of the biocontrol product, make adjustments and refine the methodology to optimise efficacy.

Biodiversity: With its freshwater lagoon and the habitat of migratory birds, the region has a significant environmental value, and the biocontrol method is said to have decreased pollution significantly and at the same time increased the region's biodiversity over time. Other insects, controlling secondary pests, also flourish under the conditions that the biocontrol methods provide.

Source: provided by IBMA - https://ec.europa.eu/info/sites/default/files/research_and_innovation/contact/documents/report-aellri-webinar-3-4_24july2020_en.pdf

Biocontrol has evolved into being a **targeted measure, with little adverse effects on non-targeted fauna and flora**. In the past, biocontrol in its form of using invertebrates against pests was not always free from unintended effects. While this was the case in the '70s at the early stages of classical biocontrol development, it is no longer a valid argument. As reported by Hajek and Eilenberg (2018), "*for classical biological control decimates populations of nontargets, a closer look at the data has shown that there is little proof, at least for insect introductions.*

One recent review reported that out of over 2,000 exotic insect natural enemies released for classical biological control against insects, only eight have caused confirmed population-level declines in nontarget species, while an additional four examples are suspect. Whether the number is eight or twelve, this is still an extremely low percentage of the total." (Hajek and Eilenberg, 2018). Since then, the number of classical biological control introductions has declined and continues to decline from 1990 to the advantage of micro-organisms and other biocontrol technologies (see Annex I). New biocontrol approaches are seen as being more effective and targeted, while also being, energy-saving and soil-friendly (Haller et.al. 2019).

While the need for more research of direct interactions between all categories of biocontrol and biodiversity support is suggested, the literature highlights the positive impact of biocontrol in lowering chemical residues, its benefits in favourable environments and its targeted use.

4.2 Soil quality and health

The positive interplay between biodiversity and soil health is an area where biocontrol can play a key role. The living organisms in the soil create a vital living ecosystem, which can, among other functions, filter potential pollutants and sustain healthy plant growth. The reviewed studies indicated benefits of biocontrol both in decreasing chemicals reaching the soil and creating favourable states for soil microbes.

The interaction of invertebrates etc. and biological fertilisers with microbial communities, Bajsa et.al. (2020) indicates that their introduction may have 'an impact on different groups of soil microbes and at different distances from the root' (Bajsa et.al., 2020). Still, the authors state that the overall use of agricultural practices to combat plant pathogens, such as crop rotation, play a vital role in shaping resident **soil microbial communities**, where more studies exist. Furthermore, in a list of sustainable effects of biocontrol agents particularly, Prajapati et.al. (2020) indicate the encouragement of soil microflora, as well as the 'volatilisation and sequestration of certain inorganic nutrients' (Prajapati et.al., 2020). More biodiversity means more active soil life, which procures a stronger biological base of the ecosystem.

In many cases, the literature examines widely studied and used components for biocontrol, such as the fungi Trichoderma spp., which have been acknowledged for their positive **plant protection properties**, also against soil-borne diseases, and enhanced resistance against abiotic stresses (lack of nutrient, drought, etc.) (Woo and Pepe 2018, Woo et.al., 2014, Prajapati et.al., 2020, Junaid et.al., 2013).

These studies also explore components of biostimulants, in terms of nutrient and vegetative growth-enhancing ability, for the plant or the soil rhizosphere.

For biocontrol and soil conservation, Holland et.al. (2017) noted a shortage of **research into the interaction between different ecosystem services**, as well as the absence of harmonized data collection across the EU (Holland et.al. 2017). The study further notes that both biocontrol and soil conservation studies were poorly distributed across European countries, with a concentration in Western European countries. Likewise, more can be drawn from research inputs that indicate the advantages of microbial plant inputs for balanced soils and the options for soil carbon sequestration (Moyer et.al., 2020).

When it comes to the pesticide levels in EU soil, biocontrol may be a crucial contributor to decrease levels of chemical contamination. Soil is subject to contamination from the overuse of chemical products, resulting in a harmful mixture of pesticide residues (Geissen et.al. 2021).

Biocontrol use introduces an alternative method that fits into holistic system practices in agriculture and **reduces the risks of contamination**, specifically in a framework of agroecological methods or organic farming. A recent chemical analysis of EU soil revealed that the total content of pesticides in conventional soils was between 70% and 90% higher than in organic soils, a conclusion drawn from three projects addressing soil quality: RECARE (2018), iSQAPER (2021) and DIVERFARMING (Geissen et.al. 2021). The study revealed the need to develop more knowledge on the effects of pesticide cocktails in soils to protect soil's biodiversity.

Under the above-described conditions, biocontrol has an advantage in its overall and long-lasting effects, which itself has a positive knock-on effect on biodiversity and crop resilience. Biocontrol opens a virtuous circle generating more biodiversity and more resilient agricultural ecosystems. This points to the need to regard and analyse biocontrol within in a systemic approach, whereas biocontrol works in a holistic manner interacting between plants, agents and other agricultural methods used (see section 5.3).

4.3 Human health

In contrast to the studied effects of chemical agricultural impacts, the use of biocontrol lowers negative impacts on human health. From **farmers and field workers** to residues in food products, chemical pesticides pose a multitude of health issues. Over the past years, the human health consciousness dimension in the different stages of agricultural production has increased significantly.

Biological approaches can deliver on the safety of both **consumers and workers** (Junaid et.al., 2013, Baker et.al. 2020).

An evident benefit of biological control on human health is at the primary production stage as farmers and field workers do not handle toxic products at the moment of use and application on plants. Biological control does not generate toxic residues capable of entering the **food production process** at later stages. Even if combined with some applications of chemical pesticides, biocontrol delivers benefits for general health by drastically reducing the exposure of the population to toxic substances contained in chemical synthetic pesticides.

Research on lab animals and farm workers has shown that chronic exposure to high doses of pesticides is associated with neurodegenerative diseases such as Parkinson's disease and cognitive deficits. Numerous studies, such as one conducted in the USA and Canada by Latifovic et.al. (2020) have identified pesticide use, notably organophosphates pesticides, involved in an increased risk of Hodgkin lymphoma, a form of cancer more frequent among farmers and farm workers (Latifovic et.al. 2020).

The risks from chemical pesticides for the general population have been studied in detail since the publication of Rachel Carson book 'The Silent Spring' in 1962. For example, the long-term consequences on the developing brain of pesticide exposure during pregnancy and the early years of life have been studied in the United States through three U.S. studies that have followed children since the late 1990s to investigate the impact of chemicals in the environment on their brains. The studies are finding troubling effects, such as IQ deficits and ADHD-like behavioural problems. Some evidence also suggests pesticides may interfere with the normal sexual development of the brain (Mascarelli, 2013).

5. WIDER IMPACTS ON FARM ECONOMICS, CLIMATE AND GOVERNANCE

5.1 Farm economics

The FAO estimates that between 20-40% of global crop production are lost to pests annually. Each year, plant diseases cost the global economy around $220 billion, and invasive insects cost around US$70 billion (Food and Agriculture Organisation, 2019). Controlling pest and diseases on crops is a necessity in economic terms and for food security. While chemical pesticides can reduce crop losses, they come at the cost of considerable damage to the environment and human health. As a non-chemical input, bioprotection can offer a systemic and balanced solution for sustainable agriculture.

As regards the cost of biocontrol, its influence on farm income, and wider economic impact, the literature is limited. One study on economics around dairy agriculture in New Zealand is pertinent. The biocontrol programme based on releasing a flea beetle (Longitarsus jacobaeae) was successful in fighting the ragwort, which decreases the feeding value of pasture as its alkaloid content is poisonous to cattle and it displaces desirable plant species. A study conducted an **ex-post economic analysis**, where a benefit/cost ratio of 14.1 to 1 was found when biocontrol and no-biocontrol scenarios are compared. The approach calculated net present values and the cost/benefit ratio produces robust results with a sensitivity test (Fowler et.al., 2016).

Economic studies on plant protection largely focus on IPM. A study on vegetable production in Bangladesh found that IPM has reduced the number of pesticide applications and pesticide costs and thus potentially increased farm returns (Rahmana et. al. 2018). These **increased returns** may help reduce poverty and malnutrition in rural areas of Bangladesh, and also imply environmental and health benefits. Rahmana et. al (2018) conclude that "*IPM research and training provides sizable benefits to the society as a whole*" and call for increased funding from the country and donors (ibid.). There are several other studies with similar conclusions which underpin support to IPM development programmes in African and Asian countries, notably by USAID (Newton, 2019).

5.2 Climate change mitigation and adaption

The climate impacts of biocontrol can be examined in relation to GHG emissions and the carbon footprint of the employed technologies. At the **production stage**, chemical pesticides contribute to GHG emissions emitted by and energy used by the chemical industry, which account for 5-6 % of emissions worldwide (Ritchie, 2020). At the level of **on-farm use**, emission reductions may occur as biocontrol may require less energy and fossil fuels to be deployed (e.g., traps, or insect releases), instead of delivering chemical pesticides using specific machinery and tractors. There is however little evidence in the literature. Depending on the production process, biocontrol may have a decisive impact on climate mitigation.

In order to create conclusive evidence on biocontrol's properties as a climate-friendly alternative to chemical pesticides, the global picture may play a greater role than measuring carbon footprints. As pointed out in the introduction, biocontrol should be seen first and foremost as an enabler for sustainable farming systems. The difference of concepts and approaches to pest control makes direct comparisons a hazardous exercise.

5.3 Governance – for a systemic approach

Controlling plant pests and diseases is a necessity for good plant health and food security. The use of chemical pesticides and the employment of biological control present two **different approaches to achieving plant protection** – namely a linear and a structural vision.

At farm level, the chemical pesticide solution is typically a linear process thinking, regarding a certain number of variables and parameters, and dominated by one single indicator, such as crop value per hectare. Reaching the objective of crop protection may thereby ignore negative consequences on the environment, farm workers health and biodiversity, as they relate to parameters outside the main linear pathway.

On the other hand, the use of biocontrol requires farmers to consider the entire farm system to **understand the dynamics of life in the ecosystem in a holistic way**. Only with an all-encompassing view and in-depth understanding of life cycles, insects' behaviour, and the influence of agronomic practices on plant health can the farmer find a pest-control solution based on natural mechanisms. This method also obliges its user to accept a degree of variability in results, as one accepts variability in nature. Experimentation and continuous corrections are common pathways to arriving at personalized biocontrol action.

At the level of a government, regional or national, promoting biocontrol paves the way for widespread adoption of IPM techniques, organic agriculture and agro-ecological farming. The positive impacts on biodiversity, human health and farm economy will boost rural areas and the bioeconomy sector. At the European level, biocontrol would play a key role in meeting Green Deal objectives of pesticide reduction, organic farming increase and zero pollution objectives.

6. CONCLUSION: RESEARCH NEEDS AND POLICY RECOMMENDATIONS

Biocontrol presents a plant protection method with multiple implications for sustainable agriculture. Rather than taking a linear approach to pest control, biocontrol techniques form part of a systemic approach of interactions on agricultural land, integrating understanding and observations of fragile ecosystems. In line with the European Green Deal and in particular Farm-to-Fork objectives, this literature review provides evidence-based information to decision-makers on the ways in which biocontrol can enable systemic change towards sustainable agriculture.

Deploying biocontrol functions for plant protection and **supports biodiversity** by significantly reducing the chemical pressure on the field. Soil quality and health similarly benefit from this approach, where chemical inputs currently contribute to contamination and harmful residues in the ground. The use of biocontrol can thereby contribute to a favourable status of microbial communities. With little adverse effect on non-targeted flora and fauna, biocontrol supports to the maintenance and improvement of biodiversity in agriculture. The **effectiveness of the natural enemies** can be amplified by creating ecological focus areas, for instance with flower strips. The application works best and is most effective in a system of sustainable farming practices. Reduced chemical input can equally **benefit human health,** where biological approaches can deliver on the safety of both consumers and farm workers.

While the need for more research of direct interactions between all categories of biocontrol and biodiversity support is suggested, the literature highlights the positive impact of biocontrol in lowering chemical residues, its benefits in favourable environments and its targeted use.

The potential of biocontrol described in this paper can be further harnessed and explored, both from policy and research sides. Stemming from the literature review, **five recommendations** are outlined below.

Definition

While definitions of biocontrol and various methods exist in the literature, there is a need for an EU definition of biocontrol, and the technologies used, in political and legal discourse. In the context of the European Green Deal, an EU definition would bring greater clarity to the political discussion on pest control for sustainable agriculture. Particularly for the Farm-to-Fork strategy and the

Common Agricultural Policy (CAP), a commonly used definition would create a better understanding of the technical aspects of biocontrol.

Legal framework

The current EU legal framework addressing pest control methods can be regarded as incomplete and maladapted to biocontrol (see more details in Annex II). The framework was designed to approve or reject products which are potentially toxic to living organisms, and to fix safe residue levels in food products. A long process of scrutiny is justified on the grounds of safety and efficiency. With biocontrol, the aspect of toxicity to other living organisms is not applicable in the same way as for chemical products. The same goes for their residues, as biocontrol products are biodegradable. Therefore, a differentiated evaluation process of biocontrol products should be considered at EU level.

Alignment opportunities

The promotion of biocontrol as a mainstream enabler of sustainable agriculture would allow for better alignment of the CAP with the SDGs and the Farm-to-Fork strategy. An increase uptake of biocontrol use, as part of IPM, would open pathways for achieving the 2030 targets of 25% organic farming on EU agricultural land and the 50% chemical pesticide reduction within the available timeframe. As outlined in the review, biocontrol methods require observation and adaptation, whereby efficacy develops over the timeframe of application. The authors of this paper see potential in agriculture living labs and demonstration farms networks, on the model of the EIP-Agri, to circulate scientific evidence, practical knowledge and exchange of experience that is required.

Furthermore, the CAP national strategic plans should play a key role in the adoption and increased uptake of biocontrol. The existing Farm Advisory Services have to be reinforced to support the adoption of biocontrol from a technical angle. Moreover, they should integrate an EU-wide eco-scheme regime to grant supplementary support to farmers engaged in bioprotection and phasing-out pesticides, moving away from a focus on yield maximisation and towards the overall health of the system.[5]

To limit the risk aversion of some farmers to adopt new techniques and in addition to advisory services, access to a specific agricultural insurance scheme limited to farmers engaging into sustainable agriculture and biocontrol could be explored for the first years of the transition. Such a scheme could be financed at national

[5] This constitutes a WTO-compatible incentive payment as it is not crop-specific and it is paid for environmental protection purposes

level through the State Aids regime, or co-financed through the second CAP pillar. Alternatively, the scheme could be financed through operational funds of the producers' organisations in the fruit and vegetables sector, or in any other sector. The national Strategic Plan opens the door to new instruments as allowed by the new CAP regulation, post 2022. In any case, any such instrument should be conditional on a contractual engagement, commitment from the farmer and time bound.

Research needs

In the past years, research on biocontrol, including that funded by the EU has increased considerably (see Annex III). Based on the literature review, the authors suggest extending research topics and investment beyond technical issues and integrate wider issues such as the relation between biocontrol and climate change mitigation. Additional research can also be directed to the concrete interaction between biocontrol measures and potential benefits for soil, and the capacity to eliminate chemical pesticide residues over time.

Field application

Biocontrol as an enabler in IPM requires a push to move from projects to wider field application. Research projects on ecological approaches and organic farming help build understanding how different plant protection methods may support sustainable agriculture. A move to greater field application should be properly accompanied by the policy instruments available in the CAP, such as ecoschemes, conditionality of direct payments and agro-environmental measures. Larger scale and accelerated application will show the potential that biocontrol demonstrates for controlling plant pests and diseases, in support of EU Green Deal targets.

ANNEX I EVOLUTION OF BIOCONTROL

Biocontrol existed well before synthetic chemical pesticides started to be used. Over time, biocontrol and its use have evolved through three distinctive phases:

The classic biological control is **invertebrates**, acting through the acclimation of a pest's natural enemy, taken from its original habitat and introduced for permanent establishment and long-term control of the pest. For example, a female beetle imported from Australia saved Californian citrus trees from a male pest, the cottony cushion scale, at the end of the 19th century (Hajek and Eilenberg, 2018).

Next followed augmentation strategies with large-scale releases of not only macro-organism biocontrol agents (BCAs), but also **micro-organisms** for the short-term control of pests; through "inundation biocontrol" when control is achieved by the released organisms themselves; or "inoculative biocontrol", when the released organisms are expected to multiply for control. For example, the processionary moth (Thaumetopoea. Pityocampa) caused defoliation of pines in Southern Europe and is now controlled with a bacterium that produces proteinaceous insecticidal toxins, Bacillus thuringiensis. Most forest areas are now treated with microbial insecticides, of which B. thuringiensis is the major one (Sanchis, 2016).

A more recent biocontrol innovation relies on the resident population to control pests, instead of releasing natural enemies into the environment. This form of conservation biocontrol acts by protecting and enhancing this population through a **systemic approach** maintaining biodiversity and habitats and inducing change in farming practices. For example, **intercropping** of cotton and wheat in China proved efficient to protect cotton crops from aphids: wheat serves as a reserve of predators to the aphids (Hajek and Eilenberg, 2018). Another example is **strip cultivation** where polyculture shows superiority in pest protection compared with monoculture (Marion de Boo, 2018). In a sugar beet monoculture, aphids that carry the yellowing virus cause spoiled harvests on a large scale, a situation that led France to reauthorize neonicotinoids despite their known toxicity to pollinators. If strip cultivation were to be adopted by sugar beet farmers, conservation biocontrol would be facilitated, aphids would not spread as fast, and pollinators would be preserved.

ANNEX II – EU LEGISLATIVE AND POLICY FRAMEWORK

The applicable legislation for biocontrol in the EU pertains to the legislative framework to protect health and environment, more precisely the pesticides Regulations and Directives. There is however no specific regulation on biocontrol or bioprotection, and only certain technologies are under the scope of pesticide regulation, while other technologies are subject to national regulations.

Table 3 - Key EU legislation on PPP

- Regulation (EC) No 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC
- Directive 2009/128/EC of the European Parliament and of the Council of
  21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides
- Directive 2009/127/EC of the European Parliament and of the Council of
  21 October 2009 amending Directive 2006/42/EC with regard to machinery for pesticide application
- Regulation (EC) No 396/2005 of the European Parliament and of the Council of 23 February 2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin

Pesticides are part of the biocides, namely any substance that can destroy living organisms. Strict rules and procedures apply to the biocides in the EU in order to minimize the risk they pose to humans, animals and the environment (European Commission, 2021c).

The category of biocides used to prevent, destroy, or control a harmful organisms ('pest') or diseases affecting plants form the **Plant Protection Products** (PPP), commonly referred to as “pesticides” (Woo and Pepe, 2018). These include the PPP as well to options to protect plants or plant products during production, storage and transport. The qualification of herbicides, fungicides, insecticides, acaricides, nematicides, molluscicides, rodenticides, growth regulators, repellents, etc. depends on their main action, or more precisely of the action of their main active substance. This regulatory approach however was designed with the chemical type of pesticides in mind, it does not fit very well with biopesticides and does not specifically cover all categories of biocontrol technologies. Natural substances and semio-chemicals are within the scope of the PPP regulations but with special guidance documents that aim to adapt the regulation to the technology.

At the moment, only the active PPP substances are regulated at EU level, in the form of a positive list. The residual quantity of pesticides that may be contained in food or feed (at a tolerable level for avoiding risks on consumers health) is also regulated at EU level, with detailed Maximum residual levels (MRL) fixed for the whole EU. All the information is available through the Pesticides database maintained by the European Commission (European Commission, 2021d).

By contrast, the corresponding commercial products are not listed in EU regulation, they are instead subject of national law. This system allows each EU Member State to authorize the commercialization of products adapted to the characteristic of their agriculture (for instance, it would for now be irrelevant to list products against the olive fly in Finland) but different availability between two neighbouring MS poses distortion problems between farmers. A consequence of this multiple-layers legislative approach (submission by companies, EFSA assessment, EU listing, national authorisation) is that it takes a long time between discovery and field application, typically 5 to 8 years. This is far too long to match the pressing needs for changing farm systems in the course of the next decade if we want to meet the objectives of the Green Deal. Biocontrol stands at a particular disadvantage in this construction of EU legislation. This situation calls for at least a review of the PPP legislation and ideally in developing a bespoke regime for bioprotection, with faster evaluations, approval and registration processes.

Since 2012, the EU took further steps to reduce risks and impacts of pesticide use on human health and the environment, with the EU Directive for the sustainable use of pesticides that puts on MS the responsibility on MS, through national action plans, to promote integrated pest management (IPM), organic farming and non- chemical alternatives to pesticides. Its enforcement, as seen above, is however weak and criticised by the Court of Auditors.

In 2019, the European Commission fixed the long-term objectives of climate neutrality and biodiversity restoration by 2050, advocating for a new growth strategy in the "Green Deal", itself derived into several strategies, notably for the food chain, Farm-to-Fork, and biodiversity (European Commission, 2020a, European Commission, 2020c). They put forward quantified objective such as halving the use of chemical pesticides and announcing clear policy support to biocontrol.

The directive on sustainable use of pesticides will be opened for revision and the placing on the market rules facilitated (European Commission, 2020c). The European workplan included a review of the microbial data requirements within Annex II of 1107/2009 and a review of the SUD during 2021.

Furthermore, the Action Plan for Organic Farming foresees 21 actions to help reaching the 25% target of land managed under organic rules. Among other actions, mobilising research will be key for achieving this objective and funds are ear-marked to that effect: *"European Commission intends to dedicate at least 30% of the next calls related to Intervention Area 3 "Agriculture, forestry and rural areas" of Cluster 6 of Horizon Europe to topics specific to or relevant for the organic sector*." Such earmarking is a notable exception to the usual principle of globalization of research budget. This envelope will help continuing financing R&I projects for developing biocontrol and increase their impact. One of them could be finding alternative to copper, a contentious input used in organic production, as mentioned at action 20 which also intend to "*foster where appropriate the use of alternative plant protection products, such as those containing biological active substances.*" (European Commission, 2021b).

While the objectives of the Green Deal support the mainstreaming of biocontrol for plant protection in the EU, their realization is hampered by the legislative construction of the EU law on the matter. The multi-layer approach takes too long while climate and biodiversity urgencies would need accelerated processes. Biocontrol stands at a particular disadvantage in this construction. It calls for at least a review of the PPP legislation with biocontrol in mind – beyond the microbials data requirements and SUD currently under review - and ideally in developing a bespoke regime for bioprotection, with faster evaluations, approval and registration processes.

ANNEX III – EU FUNDED RESEARCH PROJECTS

The EU funds research on biocontrol through its Research and Innovation (R&I) programmes. The fact that research on Biocontrol or Biocontrol agents is funded by the EU indicates *per se* a recognition of the potential utility of biocontrol. The type of research which receives financial support from the EU gives a supplementary indication on the EU technical and political choices for biocontrol as well as those knowledge gaps that were identified as deserving public money to be addressed.

The EU database Cordis references all EU-funded R&I projects, a search with the keyword "biocontrol" brought 129 returns, once the category "projects" is selected (CORDIS, 2021). Projects that are older than 20 years were set aside from the scope as more recent R&I projects were considered more pertinent. In practice from the selection of 129 projects, 55 projects relate to the Framework research Programs (FP) FP1 to FP5, covering the period from 1984 to 2002. The other 74 R&I projects belong to the FP6, FP7 and Horizon 2020 programmes, with the following timeline breakdown:

- 10 projects for FP6 (2002-2006)
- 20 for FP7 (2007-2013)
- 44 for Horizon 2020 (2014-2020).

The increasing number of projects financed by the EU over time shows a growing interest in biocontrol both from the research community and from the European policymakers. Not only the number of financed projects doubles at each period but also the size of each individual project grows. Hence, the volume of finance available for biocontrol research has considerably increased over the past twenty years, an indisputable proof of growing attention and focus on biocontrol issues.

From the Horizon 2020 projects, a majority (23) of projects aim at the mobility of researchers and their training, as well as exchanging knowledge and gaining new knowledge. As this part of the R&I program is operated in a "bottom-up" fashion, it shows the dynamism of the young researchers on the question of biocontrol.

Another group of projects (9) is geared to the market. They aim at raising technology readiness levels (TRLs) and developing near-to-the-market prototypes of biological agents. Frequently such projects are object of public-private partnership with SMEs (involving the SME instrument) or industries (involving the Bio-Based Industries Joint Undertaking), again in a "bottom-up" way. It shows an appetite for biocontrol and biocontrol products from the market as a whole.

Finally, 12 projects are not following the “bottom up” approach. They are collaborative research projects, assembling under the umbrella of a specially created consortium for each submission research agencies, universities and other R&I bodies working together through the EU and sometimes involving third countries partners. They were selected amongst the numerous respondents to calls launched in application of the R&I Work Programme published every two years by the European Commission to operate the pillar of Horizon2020 devoted to “Societal Challenges” (SC), namely pillar 2. All 12 projects fall in the SC2, the societal challenge of ‘Food security, sustainable agriculture and forestry, marine and maritime and inland water research and the bioeconomy’. They aim at delivering a scientific response to plant protection or food conservation with the help of biocontrol. The projects frequently lead researchers to define methods or guidelines for further work and they sometimes include elements for scaling up and get closer to the market.

Two recurrent motivations are quoted to justify the financial support from the EU budget. Firstly, it is the fact that the pesticides regulatory framework of the EU has progressively eliminated the most toxic active substances from the authorization lists. Where chemical solutions are no longer usable, research should help finding new solutions which will be less harmful to the environment and health. Biocontrol is a key element in the design of such sustainable solutions, together with changed farming practices and new plant varieties. Secondly, emerging diseases like Xylella fastidiosa affecting olive and almond trees or hard to combat diseases like mildew need efficient and future-proof solutions which biocontrol seem to be at an advantage to deliver. Still, sizeable efforts are needed to fill knowledge gaps and identified pathways for generalized on-farm use.

A striking characteristic of the type of research is the predominance of micro-organisms research among the projects (32, which is 70 % of here analysed projects). The other biocontrol sectors are less present with only four projects looking at macro-organisms, two on semio-chemicals and four on natural substances or equivalent (plus two projects which are not sector-specific).

Another characteristic is the exclusive focus on technical issues for all the projects funded by the EU budget. Given the alignment of EU budgetary rules on the do not harm and sustainability principles, it shows that the benefits of biocontrol are considered systematically positive, especially on environment, while the economic and social impacts are simply not studied.

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