
Nature-Positive Approaches to Sustainability: Pollinators



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Contents

Executive Summary.....	1
1. Introduction.....	6
2. Broadening the Toolbox for Growers to Minimize or Prevent Adverse Effects on Pollinators	8
2.1 Screening for safe and effective active ingredients – building in safety for pollinators.....	8
2.2 Formulations to enhance safety to pollinators	10
2.3 Registration and approval of products.....	10
2.4 Product handling and application	11
2.5 Biological products.....	14
2.5.1 Enhancing plant defenses with biostimulants	15
2.5.2 Developing biopesticides and optimizing their use.....	16
3. Implement Integrated Crop Management & Integrated Pest Management.....	18
3.1 Data requirements for alternatives to pesticides and their use in IPM.....	22
3.2 Expanding pest management programs to further reduce risk from insecticides	23
4. Plant Breeding to Enhance Crop Resilience	25
4.1. Tolerance of pests and diseases	26
4.1.1 Safety to pollinators and other arthropods	28
4.1.2 Reduction of the volume of insecticide applied due to GM insect-resistant crops	29
4.2. Native resistance from crop diversity and crop wild relatives	30
4.3. Initiatives to improve crop resilience.....	30
4.3.1 Drought tolerance	31
4.3.2 Salt tolerance	31
4.4. Conclusion	31
5. Ecosystem & Landscape Scale Action	32
5.1. Improving pollination to improve crop yields	32
5.2. Increasing pollinator abundance and diversity	34
5.2.1 Promoting biodiversity in apple, potato, cabbage and leeks.....	35
5.2.2 Enhancing biodiversity of farmland through supporting habitats for pollinators	36
5.2.3 Multi-functional field margins	37
5.2.4 Ecological enhancement for pollinator diversity.....	38
5.3. Landscape connectivity	41
5.4 Ensuring healthy pollinators.....	42
6. Digital Farming & Precision Agriculture.....	43
6.1 Precision farming and drones to enhance the application of crop protection products	43
6.2 Precision placed field borders and pollinator habitats	44
6.3 Automation of insect sampling and identification	45

Executive Summary

Small- and large-scale farmers and others involved in the management of agricultural land have a unique potential to enhance biodiversity while feeding an increasing global population.

CropLife International brings together the leading research and development companies in the plant science sector to improve agriculture through engagement and partnerships. It is committed to sustainable agriculture and the responsible use of plant science technologies.

Member companies develop tools for farmers and growers that contribute to growing crops efficiently in a way that can positively contribute to biodiversity or reduce the potential adverse effects of agriculture on the environment, while optimizing yield and maintaining rural lives.

The focus of this report is on pollinators – which is a term that covers a wide range of insect species, including bees – as providers of ecosystem services. CropLife International activities regarding protecting pollinator health and supporting their populations do contribute towards achieving Target 7 and particularly Target 10 focussed on the sustainable use of biodiversity of the Post-2020 Global Biodiversity Framework, which will be finally concluded at COP 15. The activities of CropLife International and its members includes a wide range of activities that support pollinators, so this report has a broad scope through the product life-cycles of inputs such as pesticides and seeds, as well as the cropping cycles and agricultural landscapes. Examples of activities that support healthy pollinator populations and biodiversity in general on agricultural land are highlighted below.

Broadening the toolbox for growers to improve management of risks to pollinators

CropLife International supports a broad toolbox of sustainable agricultural practices for farmers from which they can select the best tool for their situation.

Advancement in pesticide development results in products with improved safety profiles for both human health and the environment. Dedicated technologies are used in the screening process for identifying new molecular leads for chemical pesticides. Candidate compounds are assessed at early stage of development including their potential impact on non-target organisms, and particularly bees as being critical pollinators. Formulation technology is available to reduce further any potential adverse effects. This includes technologies which maximize the efficiency of the pesticide, allowing the application of a reduced dose.

Research is also undertaken by the companies to determine potential pesticide exposure pathways for non-target organisms because that knowledge may determine how a product can be used safely. The final product selected for use by farmers thereafter is thoroughly evaluated by robust, independent regulatory systems.

Companies and regulatory authorities also undertake periodic reviews of products to ensure new information is taken into account for product approvals. This can result in voluntary withdrawals or restrictions of use, or revocations of products for specific uses by the regulatory authorities.

Post-registration monitoring for potential adverse effects allows monitoring of specific risks that become apparent under large scale use including, for example, effects on pollinators. Labels and approvals can be amended to deal with effects if they arise.

Product labels and product application training fosters proper use of the product. The FAO recently included a CropLife International proposal for a pollinator precautionary pictogram in the second revision of the guidelines on good labelling practice for pesticides. CropLife International typically trains around 500,000 individuals each year, up to 8 percent of whom are trainers, and member companies train many more.

Likewise, in the search for new pesticides, CropLife International members are actively involved in research into and commercialisation of biological-based products. These include biostimulants and

bio-fertilisers as well as biopesticides. These typically have a low potential for adverse effects on pollinators which is also confirmed during the development phase. Biostimulants can strengthen the crop plant's natural defences against pests and diseases, reducing the need for pesticides.

Expand the implementation of Integrated Crop Management and Integrated Pest Management

Integrated Crop Management (ICM) is a system of crop production which conserves and enhances natural resources while producing food on an economically viable and sustainable foundation. It is based on a good understanding of the interactions between biology, the environment, and land management systems. Integrated Pest Management (IPM) is an integral component of ICM. The FAO defines IPM as 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 making it more targeted and complemented by different pest control options such as biological, cultural, or microbiological control.

CropLife International and its member companies and associations support sustainable agriculture to produce sufficient, affordable food and fibre in an environmentally and socially sensitive manner. CropLife International member companies develop and promote products, services, as well as ICM and IPM, and integrate them in best practices in cooperation with many scientists and extension agents. However, implementation of these practices lies with farmers so they must be able to see the benefits and be equipped with necessary information and training programs to ensure uptake of these practices.

Natural enemies of pests can reduce the chance of pests establishing and proliferating in crops and causing economic damage. A diverse range and abundance of natural enemies is needed to ensure there are sufficient of the relevant species to suppress a particular pest when it arrives. This can be delivered by providing a range of habitats and adhering to IPM principles.

Although the benefits of ICM and IPM are clear, robust benefit data are valuable to engage growers and encourage them to implement best practices to support pollinators and biodiversity in general. Member companies are actively producing such data and information and use these to support the use of best practices by their farmer customers.

Plant breeding to enhance crop resilience

CropLife International member companies invest in innovative, leading-edge research and development to develop beneficial crop varieties. These activities include conventional and enhanced breeding techniques as well as using novel techniques.

The commercial development of transgenic crops with specific toxicity for certain insect pests is relevant for pollinators. These crops express compounds with specific toxicity for certain plant insect pests. The compounds are mostly proteins, known as *Cry* proteins, and often crystal proteins of *Bacillus thuringiensis*. Bt spores are also used as an insecticide in organic agriculture, but the effect of a single spray rapidly declines in the field. Transgenic crops offer a more effective way to deploy the active ingredient. Regulatory authorities and assessors, such as EFSA in the EU and the EPA in the US, require testing of the Bt protein for target non-target effects. To achieve approval for commercial use, the trait must not be toxic to pollinators.

Replacing synthetic chemical insecticides by Bt crops for pest control supports the conservation of natural enemies and can contribute to more effective biological control of both target and non-target pests as part of an IPM strategy. With Bt varieties of cotton, brinjal, and corn (for corn rootworm control) the fields receive less insecticide spray, so there is less potential for harm to pollinators. The estimated reduction of insecticide use in the year 2018 compared to what might be expected if the crop had been planted to conventional seed is -82% season in maize and -55% in cotton. Data for soybean from 2013 to 2018 show a total -8.2% reduction during the six years.

Conventional breeding and gene editing is being used to make crops more resilient to attacks by pests and diseases in a range of horticultural and arable crops as well as crops grown mainly by smallholder farmers. Wild crop relatives are important sources of genetic diversity which can be searched for desirable traits. Drought Tolerance Maize for Africa (DTMA) has enhanced ability to withstand periods of acute soil drying, and Water Efficient Maize for Africa (WEMA) is adapted to growing under conditions with a low supply of water. Rice hybrids that are less susceptible to diseases and abiotic stresses and tolerate a higher salt content in water than conventional varieties are available in countries in Southeast Asia and Africa as well as India.

Ecosystem and landscape scale action

CropLife International and its members demonstrate to farmers and other stakeholders that there are practices that are readily available to improve agricultural and broader ecosystems and the landscape. They cooperate with the public sector, non-governmental organizations and other stakeholders to identify and promote best practices, to inspire farmers and propose best practices to policy makers.

Insect pollinators play a fundamental role in the production of many fruits, vegetables, and field crops and numerous studies have valued insect pollination as an ecosystem service for agricultural food production at both global and national scales. Agricultural production systems have been identified where insect pollinators contribute to improved yields, the stability of yields between seasons and the quality of the crop. Examples from projects carried out by members of CropLife International include:

- Pears in Belgium: assessments of the quality of the pears indicated that insect-mediated pollination had a significant positive impact, with a tendency for higher quality pears in the close vicinity of bee nesting boxes.
- Pomegranates and onions in India: improved pollination services for pollination-dependent crops resulted in increased yields of both crops.
- Rambutan and longan in Thailand: a beehive rental programme with training on the responsible use of pesticides to selected farmers increased average yields by 19.5% and 27.1% for rambutan and longan, respectively, compared to farmers who did not rent hives.
- Kiwi fruit in China: the introduction of bees to kiwi orchard raised yields and produced better quality fruits.

Generally, increasing the heterogeneity of any landscape increases pollinator richness. Most wild bees nest in the ground, in plant stems or in cavities of various kinds. Ensuring that a range of nesting sites, either natural or artificial, are available will encourage wild bees to move into an area and remain there. Diverse plant communities can provide ideal foraging resources for pollinators. In agricultural land this can be achieved, for example, by intercropping, leaving ground cover and the use of wildflower strips or field margins that increase the availability of nectar and pollen resources. The report describes enhancement methods which have been researched and promoted by member companies of CropLife International and some of the partnerships and collaborations that have helped to achieve these. Some of the projects include very detailed entomological work to identify the impact of these techniques, including the effects on populations of pollinators, parasitoids, and other beneficials as well as pest species and non-target species.

The key to achieving biodiversity goals is to increase the participation of farmers particularly by encouraging their awareness of the impact of their activities so that they follow a more environmentally conscious management of their farms and field margins. Wildflower strips and other interventions at field level can make valuable local contributions to biodiversity and connecting these at farm level has a greater impact, but connectivity at a landscape or regional level is necessary for the greatest potential to enhance biodiversity. Critical to creating such a network is fostering communication between the farmers and involving municipalities and regional or national governments in the activities. One such approach is the farmer cluster, a community of farmers,

located in the same region, who share knowledge and support and motivate each other to improve biodiversity and the ecological health of their farms.

Managed honeybees are considered as livestock but also play an important role as pollinators. Although the number of honeybee colonies has increased across the globe in the past 60 years, bee health issues remain a challenge. One of the main causes is a mite, *Varroa destructor*. A bee colony in a mite-infested beehive typically collapses within three years if there is no human intervention. Besides the threat posed by the *Varroa* mite itself, they carry diseases, particularly viruses, which spread among bees during their social interaction in the hive to weaken the colony. By combining the few effective control measures with good beekeeping management practices (integrated apiculture), it is possible to reduce the harm caused by *Varroa* and to control the impact of this parasite. However, developing technologies such as RNA-based products offer potential for improved solutions to the problem.

Digital farming and precision agriculture

At a practical farm level, three primary technologies are proposed to define precision agriculture: sensors (see & spray), robotics and automation, digitalization and big data. These technologies work closely together and are enabled by adequate connectivity as well as improvements in edge computing and the cloud. Precision agriculture provides the opportunity to integrate many of the best practices and techniques to support pollinators, which are discussed in this report. These developments are already making an impact on the adoption of sustainable and pollinator-friendly practices by, for example, defining the optimum areas and connectivity for pollinator and other biodiversity or by improved pest monitoring and product application.

Digital connectivity enables smart farm equipment to connect data from different sources and put them into an optimized order by consulting, for instance, field-specific information from cloud-based farm management software. Sensors and remote sensing collect data from a distance to evaluate soil and crop health, such as the presence of pests or diseases.

CropLife International member companies are actively involved in developing and promoting these technologies. For example, predictive modelling based on real-time data from in-field sensors enables growers and advisers to view emerging hotspots and target crop protection products precisely where and when they are needed.

Another system enables growers to collect, store and analyze data on a single platform. Inputs to crops can be optimised with seed rates, fertility and crop protection applied according to need within a field and across the farm.

Drones are used for capturing images and providing data for permanent monitoring of a crop from planting to harvest. This is combined with the application of crop protection products, so that drones can scan the ground, spraying in real time for targeted application and even coverage using lower volumes of spray.

Precision data can be used to establish field borders, streambank buffers or pollinator habitat on farms to enhance water and soil health and provide habitat for pollinators and birds in a targeted manner. Yield data, soil data, and farm budgets, highlight areas on farms that either are not profitable or cause logistical challenges in farming. Planners can match these targeted areas to habitat practices that best fit the farm operation and production goals.

Conventional insect sampling techniques are time consuming, and identifying large numbers of individual insects can take experts weeks or months. This limits the ability to check the impact of pests and of pollinator and biodiversity enhancement measures. Automation of this process can reduce cost and increase the accuracy and scalability of the analysis.

Conclusion

The report highlights the numerous activities of CropLife International and its members to protect and enhance pollinator populations in agricultural landscape. Some of these are behind the scenes and are not mentioned in common narratives. Examples include processes for identifying and developing new products and product re-evaluation when new information is developed.

There is thorough scientific research into the impacts of interventions on farms to support pollinators. The detailed entomological research in some of these studies is too large to be presented in this report, so links have been included to the original studies which contain the datasets and, frequently, photographs of the insects which were identified. Some projects have been scaled up from research at field level national, even global, projects.

Led by science and demonstrating the effectiveness of the interventions, CropLife International and its members have developed sound best practices with benefits for customers, farmers, and policy makers.

1. Introduction

Innovations from CropLife International and its members to protect pollinators and enhance their future

The benefits of crop protection products have shown [significant improvements since the 1960s](#) (Phillips MacDougall, 2018). The number and variety of these products has increased dramatically, providing farmers with a more extensive and effective pest control toolbox. Meanwhile the human and environmental safety profiles of products have generally improved. Many old products have been withdrawn from the market to meet stricter safety requirements and the development of biological products has grown rapidly in recent years. These changes have contributed to expanding crop production to meet the growing global demand for food. Most of this demand has been met through improved yields, rather than encroaching on non-cultivated land. This is an important step towards meeting biodiversity goals, particularly in biodiversity hotspots.



CropLife International proactively supports and promotes the implementation of Integrated Crop Management (ICM) and, within ICM, the more specific concept of Integrated Pest Management (IPM). These provide practical solutions that allow farmers and growers to maintain production and income while improving their [overall environmental footprint](#) by reducing land and water use and greenhouse gas emissions. Member companies provide customers with safer, more effective technologies to protect against the adverse effects of pests, plant diseases and weeds. They also enable and encourage the implementation of ICM by developing and promoting appropriate products and services.

As major R&D companies, the business models of member companies rely on innovation, from basic research through product development and commercialization. Innovation, when applied to the crop life cycle, ensures the quality of food production while minimizing or reducing environmental impacts. Innovation encompasses all aspects of production, from planting to harvest, and includes improved seeds, crop protection products, digital technologies and more. The goal is to close the gap between average and potential crop yields by enhancing ecosystem services, engaging the sustainable use of biodiversity and successfully managing crop protection.

This report focuses specifically on the role of pollinators in providing ecosystem services and their contributions toward achieving:

- The Convention of Biological Diversity (CBD) [Aichi Targets](#), particularly Targets 7 (sustainable agriculture, aquaculture and forestry), 8 (pollution reduced) and 15 (ecosystems restored and resilience enhanced). These aspects were also covered in the [Report on CropLife International Members' Activities Relating to Biodiversity and Climate](#).
- Targets 7 and 10 of the Post-2020 Global Biodiversity Framework, which are currently being drafted and discussed, i.e., the reduction of pollution from all sources (Target 7) and the sustainable management of areas under agriculture, aquaculture and forestry (Target 10). The latest [public version](#) of the Framework was drafted at the Nairobi, Kenya, meeting of the CBD in June 2022.

The importance of achieving success in food production while reducing environmental impact is highlighted in the recently released [2022 draft report](#) of the United Nations Secretary-General on

Progress towards the Sustainable Development Goals (SDGs). In relation to Goal 2 (end hunger, achieve food security and improved nutrition and promote sustainable agriculture) it concludes:

“In 2020, between 720 and 811 million people in the world were suffering from hunger – as many as 161 million more than in 2019. In the same year, over 30% – a stunning 2.4 billion people – were moderately or severely food insecure, lacking regular access to adequate food. This represents an increase of almost 320 million people in just one year.”

Of course, the protection and enhancement of ecosystem services is not the sole solution to the hunger crisis, but it can make significant contributions to resolving this critical global problem. Crop production itself is an important ecosystem service to be maintained and fostered¹, though it comes with [trade-offs and synergies](#) to other ecosystem services.

Agronomic targets (e.g., increased yield), environmental targets (e.g., biodiversity protection) and socio-economic outcomes (e.g., enhanced nutrition) interact both positively and negatively, further creating the potential for synergies and trade-offs. This much discussed and relevant topic is [extensively evaluated](#) by Kanter et al. (2018).

CropLife International and its members are committed to continued development of more sustainable food systems. They are [working with numerous and varied partners](#) to progress toward the UN Sustainable Development Goals of zero hunger, carbon neutrality and nature-positive agriculture. CropLife International is a partner in the Coalition on Sustainable Productivity Growth for Food Security and Resource Conservation (the SPG Coalition), which was launched at the UN Food Systems Summit in September 2021 to [advance a holistic approach to productivity growth](#) that considers impacts and trade-offs among multiple objectives. These [objectives include](#) food security and nutrition, food safety, food affordability, food access, diet quality, farmer and farmworker incomes and wellbeing, equity and inclusion, food loss and waste, animal welfare, resource conservation, biodiversity, soil health, water quality, resilience and climate change mitigation and adaptation.

Pollinating insects are critical for food production. Through their interaction with plants, they also support other components of biodiversity and ecosystem functions, including soil protection, flood control and carbon sequestration. However, bees and other pollinators face a wide range of environmental pressures. Farmers around the world are uniquely positioned to help address many of these pressures. The practices of IPM and ICM encourage farmers to consider the impact of their management decisions across both the farm and the landscape. Conducting the right environmental measures in the right place while managing them in the right way can make a measurable, positive difference for pollinators and biodiversity, as will be shown later in this report.

CropLife International and its member companies are well-placed to research and develop various aspects of sustainable farming and pollinator protection. Working in partnership and collaboration with academics, institutions and non-governmental organizations, they identify, develop and promote best practices, demonstrate their feasibility and inspire farmers and policy makers to adopt the practices. Farmers are critical for the implementation of best practices, and CropLife International works through various agencies to develop partnerships with them.

This report complements the 2021 [Report on CropLife International Members’ Activities relating to Biodiversity and Climate](#) and focusses on activities that support healthy pollinator populations in the broadest sense.

¹ Food is a provisioning service people obtain from highly managed systems such as crops, livestock and aquaculture, and also from wild sources, including freshwater and marine capture fisheries and the harvesting of wild plants and animals. MEA. 2005 Millenium ecosystem assessment. [Ecosystems and human well-being: biodiversity synthesis](#). Washington, DC: World Resources Institute.

2. Broadening the Toolbox for Growers to Minimize or Prevent Adverse Effects on Pollinators

CropLife International members provide an ever-expanding range of options for farmers and growers to manage their crops. New types of products and services facilitate improved crop management to encourage healthy and diverse pollinator populations, while supporting biodiversity around the cropped area. This chapter takes a broad view of pollinator protection and includes a wide range of direct and indirect approaches.

2.1 Screening for safe and effective active ingredients – building in safety for pollinators

Research begins with the [discovery phase](#), identifying potentially useful chemical compounds and microbes. Modern techniques allow molecules to be designed for precision targeting to perform their function efficiently. This precision is one factor that allows for much reduced doses compared to older molecules.

Through computer chemistry, [hundreds of thousands of chemical structures can be processed per day](#) to find those with characteristics optimal for a crop protection product. Machine learning and artificial intelligence help to run a series of simulations that give insights into how a molecule might interact with target and non-target organisms and the environment. Chemists set the parameters that allow computers to ensure that new pesticides are precise, safe and more effective, for example by recognizing structural alerts for parameters of concern. By reducing the amount of active ingredient that is needed for a pesticide to be effective, CropLife International members are lowering the overall toxicity of crop protection products, ensuring no harm to beneficial insects like honeybees and helping to fight the development of pesticide resistance.

After the design phase, the selected molecules follow stringent product development criteria. Those with potential negative effects are screened out from the beginning, while those that pass this stage continue to be monitored for potential adverse effects as their use parameters become better defined. They must meet increasingly robust thresholds of acceptability at each stage to meet company internal and external regulatory requirements. This process ensures that users can practically manage risks in the field. Eventually, a small number of molecules are ready to be evaluated as active ingredients for possible registration.

The process of screening for effects on non-target organisms, including pollinators, uses validated techniques and is followed by regulatory studies that use [guideline methods](#) that have been evaluated for reliability and replicability by the OECD and other recognized agencies. An accurate picture of potential hazard and risk requires a reliable estimation of exposure and toxicity. This informs the screening process as well as risk assessment. The routes and degree of exposure can differ depending on the formulation of the product and the application method. For example, foliar and soil applications of an active substance may both lead to residues in nectar and pollen, though the levels of those residues will differ. Other [routes of exposure](#) include residues carried back to the hive by pollinators that drink from water sources containing residues (e.g., guttation fluid and puddles), as well as residues in the soil and on flowering weeds. Spray drift and dust from treated seed may also lead to exposure if not properly controlled.

The scale of the effort put into designing and testing a new active ingredient is indicated in the most recent [Phillips McDougall report](#).

- In the [research phase](#), the average cost of screening rose by almost 60% to \$51 m. between 2005-8 and 2010-14 making this the largest single cost in the R&D of a new agrochemical. Chemistry (synthesis) in the research phase increased by 16.7% to \$49 m.

- In the development phase, the cost of environmental chemistry showed the greatest increase, rising by 45.8% to \$35 m. Toxicology costs also increased significantly to \$35 m, while chemistry costs remained flat and efficacy costs declined slightly.
- In registration, the final phase of R&D, average costs, including extra studies required to satisfy EU and US regulators, rose by 32% to \$33 m. between 2005-8 and 2010-14.
- Total R&D costs rose from \$256 m. to \$286 m. in the same period.

The lengthy development process provides a high level of understanding of a pesticide's chemistry and potential risks. Given the amount of data generated, and its thorough evaluation, chemicals used in pesticides are among the best understood of all functional groups of chemistries. In some jurisdictions, data summaries are available from competent authorities, such as the European Food Safety Authority (EFSA), which publishes the Renewal Assessment Report (RAR) for active substances for public consultation, as well as its assessment of the RAR, [on its website](#).

Scientists are constantly developing new crop protection products and re-evaluating old products based on safety, efficacy and economics. The internal policies of member companies drive the continual evaluation of external and internal data, including reports of use in the field, laboratory studies and surveys of scientific literature, to assess the hazards and risks of their products. Under their own policies, companies assess their products according to similar parameters. For example, FMC utilizes a [Sustainability Assessment Tool](#) to determine if new active ingredients and formulated products in the R&D pipeline are "sustainably advantaged." This assessment, along with other stewardship processes and tools, ensures the introduction and continued use of environmentally sustainable agricultural solutions while providing for transparent reporting of sustainability progress.

New information is fed into the periodic review, undertaken by many regulatory authorities, of existing active ingredients and formulated products. Reports of potential adverse effects must be provided to regulatory authorities, and these are considered in amending product labels and the conditions of registration if necessary. Companies also voluntarily restrict or withdraw from the market older products if a high risk that cannot be mitigated has been identified in normal use. For example, in 2019 CropLife International member companies [evaluated their entire range of more than 6,400 crop protection products](#) under a common approach. Fifteen percent of the products were identified as Highly Hazardous Pesticides (HHPs)² and underwent a risk assessment based on local use conditions, focusing on low-income countries. Risk mitigation measures were also evaluated. In specific situations where the risk could not be managed through the proper implementation of enhanced risk mitigation measures and remained too high, or a safer alternative was available, the product was withdrawn from that use or market. [This was not a one-off and companies continue to review their products against their criteria.](#)

Maintaining quality during manufacturing

Manufacturing processes that are managed and implemented well are critical for maintaining high product quality. This is essential to meet safety and efficacy requirements, as well as regulatory requirements and enforcement. For example, poor manufacturing can lead to impurities that increase the toxicity of a product to pollinators. CropLife International and its member companies work with the FAO and WHO through the [Joint Meeting on Pesticide Specifications](#) to support the manufacture of high-quality products. The FAO/WHO specification scheme is regarded as a benchmark representing a global standard of quality. The specifications can be applied as a tool in risk assessment to ensure that products on the market meet minimum acceptable quality standards. The specifications offer responsible manufacturers and vendors protection against inferior products. They also provide an important link between biological efficacy and specification requirements.

² Highly Hazardous Pesticides as defined by the FAO in the [International Code of Conduct on Pesticide Management Guidelines on Highly Hazardous Pesticides](#)

CropLife International has been proactive in working with the OECD, governments and other stakeholders to address [counterfeit products](#). Counterfeit products may be ineffective and harmful to users and the environment, including pollinators, because they are not tested for safety. They may not even contain the active ingredient stated on the label. Counterfeit products should be avoided to support effective ICM and IPM and prevent the potential consequences of unapproved products.

2.2 Formulations to enhance safety to pollinators

The [formulation of a crop protection product](#) contains the active substance with co-formulants that improve its storage, delivery, effectiveness and safety. A co-formulant could be as simple as water in a soluble concentrate or clay powder in a granule. Typically, formulations are more complex.

One of the more recent innovations is “microencapsulation.” Microencapsulation allows greater control over delivery of an active substance to trigger an active ingredient into action in specific ways, for example by temperature, exposure to sunlight or contact with water. Formulations can be designed to reduce the toxicity of an active ingredient to non-target organisms, including pollinators, and, for example, to reduce volatility, which might impact non-target organisms and adjacent crops. Over the years, water has replaced more toxic oil-derived co-formulants in many formulations, further reducing potential adverse effects on non-target organisms as well as improving operator safety.

Seed treatments are specialized formulations that allow release of an active substance from the seed surface or use a pelting system to control release. Risks from pesticides used in seed treatments are minimized through the crop life cycle. Formulation technology allows the minimum necessary dose to be applied to the seeds and provide dust free seeds. Seed drills are adapted to minimize or prevent any residual dust from being spread in the environment at drilling. The following bullet points address best practices for preventing harm to pollinators when handling and drilling treated seed. More details can be found in [this document](#).

- Before seeding – communication and outreach.
- Handling and storing treated seeds on the farm.
- Planting practices to:
 - Minimize dust drift prior to planting.
 - Minimize dust drift during planting.
 - Minimize dust drift after seeding is complete.
- Spill and equipment clean up.
- Record relevant information during the seeding operation.

2.3 Registration and approval of products

Regulation should meet the needs of society by providing access to technology in a controlled manner. Regulation provides the opportunity to encourage innovation and enterprise while setting the standards for safety and sustainability. These should be established through pesticide regulations that:

- Ensure there are no unacceptable risks to human health and the environment from the intended use(s) under practical conditions.³
- Foster responsible use and compliance throughout the food production chain.

³ The thresholds for “acceptable” and “unacceptable” risk require a cost-benefit analysis and are societal and political decisions, as well as economic.

- Promote investment in new solutions for agriculture and plant science.
- Facilitate timely access to the technology.

The registration process is the foundation of product safety and use. In direct relation to this report, it also supports and protects pollinator populations.

A comprehensive regulatory framework examines all phases of a pesticide product's lifecycle in detail. As described in sections 2.1 and 2.2, safety is carefully considered by developers at all stages of research and development and by manufacturing companies and regulatory bodies that assess the product and make decisions regarding permitted uses. Before any pesticide can be approved for use, all safety data related to human health and the environment must be submitted to regulatory authorities for their review. The final approval decision on uses, restrictions and labelling should be supported by the appropriate checks to ensure product quality control, based on the standards for registration data and manufacture. The regulatory framework also covers proper handling, transport and precautions during use, including labelling and setting allowable residue levels in food (known as Maximum Residue Limits or MRLs). The OECD provides [templates for regulatory data requirements and testing and assessment of pesticides](#) that are available for use by competent authorities, particularly those with limited resources.

The [regulatory framework](#) should be grounded in science using an evidence-based approach to understanding the product, i.e., it characterizes the product and its proposed uses and makes informed decisions based on full information and evidence. This ensures that the safe use of pesticides can contribute to sustainable food production through appropriate understanding and active management of any risks.

CropLife International member companies are [committed to increased transparency](#) of safety data to improve dialogues with the public, increase understanding and build trust. As a first step, CropLife International and its member companies are developing straightforward ways to enable non-commercial access to safety-relevant information. Two examples from member companies are:

- [Transparency at Bayer](#)
- [BASF regulatory data transparency](#)

2.4 Product handling and application

Product labels and guidance on use

Product labels incorporate both statutory and voluntary (stewardship) restrictions on use. The pesticide registration process has a long history of protecting bees and other non-target pollinating insects from potential adverse effects from pesticides. Competent authorities assess the risk to bees by evaluating each pesticide's toxicity and comparing the level at which adverse effects are observed to an estimated exposure in the environment for each use. Based on information from the risk assessment, the pesticide label includes directions for use and information on any environmental hazards so that, when applied according to the label, any risk to non-target organisms is negligible. CropLife International member companies aim to meet these requirements on their product labels according to the regulations of each country.

For example, when the EPA identifies potential risk to pollinators associated with registered uses of pesticides, it develops mitigation measures to protect any pollinator species at risk. These measures are to be included on the pesticide label and literature to. [Mitigation measures](#) may include:

- Bloom-time restrictions: The pesticide cannot be applied when a plant is flowering because flowers attract pollinators.
- Crop-stage restrictions: Pesticide applications are limited during the phases of a plant's growth when it may be attractive to pollinators.

- Time of day restrictions: The pesticide can only be applied before dawn or after dusk because many pollinators are mainly active during the day.
- Reductions in the rate at which the pesticide may be applied to minimize the risk to pollinators.
- Establishing ground and aerial buffers around important pollinator habitats where pesticides cannot be applied.
- Planting filter strips of untreated vegetation along waterways to help prevent pesticide runoff from destroying plants that pollinators need.
- Disallowing the use of a pesticide within a certain range of pollinator habitat.
- Prohibiting use on specific crops attractive to pollinators.
- Restricting use to professional applicators to reduce accidents or misuse that could improperly expose pollinators to pesticides.
- Imposing spray drift reduction measures, such as setting a maximum windspeed for when applications can occur, lowering the application height for boom and aerial sprayers and selecting nozzle sizes that deliver larger droplets.

The FAO recently accepted a proposal provided by CropLife International to add a pollinator precautionary pictogram to the second revision of the [Guidance on Good Labelling Practice for Pesticides](#). The pictogram is intended to be added to product labels to warn against spraying when pollinators are active or spraying flowering plants attractive to pollinators that might be growing in or near the crop being sprayed. Although no specific trigger language or criteria are given, this pictogram can be used when a risk to pollinators is predicted, or a hazard trigger is exceeded.



The US EPA requires a “bee advisory” box on the [label of certain insecticides](#). This contains advisory language on different routes of exposure for bees (i.e., contact from foliar application and ingestion of nectar and pollen from applications via seed treatment, soil treatment, trunk injection and foliar application); best management practices to reduce exposure to bees, including reducing drift; and information about how to report bee kills to the EPA.

The [EU also has processes](#) for assessing potential risks to bees, providing guidance on labelling and using pesticides and hazard warning phrases. The OECD provides a [compendium of exposure and risk mitigation methods](#) used by member countries under three headings: pesticide labelling, non-label mitigation and education and training.

In future, labels may have barcodes that can be linked directly to an on-board computer to ensure that pesticide applications meet regulatory and stewardship requirements. It is already possible to treat only sections of fields that have reached a threshold level of infection (see Chapter 7).

The practical implementation of such recommendations and guidelines is found in the approach to managing Fall Armyworm (section 3.1).

Education and training

CropLife International, along with its regional and national associations and leading companies, has promoted programs providing training in responsible use of crop protection products for more than 20 years.

As part of its responsible care and stewardship program it published “[Protecting Pollinators Through Good Stewardship Practices: A compendium of guidelines and other documents supporting pollinator stewardship.](#)”

[Training](#) is given in the context of an Integrated Pest Management (IPM) strategy using a participatory approach with an emphasis on training-of-trainers and working in partnership with other stakeholders. Pollinators are covered in general training programs on responsible use and Integrated Pest Management. CropLife International supports programs that typically train around 500,000 individuals each year, up to 8% of whom are trainers. Companies train many more.

Messages about the responsible use of crop protection products reach many millions each year through various media campaigns. Communication is encouraged between pesticide users and their local communities to minimize risks to honeybees. Examples include [Salud Apícola Latinoamérica](#) (Healthy Beekeeping in Latin America), [“Bee” Responsible](#) and [a partnership](#) between the Indian Council of Agricultural Research (ICAR) and one of its extension facilities, the Agricultural Development Trust (KVK) Baramati.

Post-registration monitoring

In some jurisdictions, all registration owners are legally obliged to record and submit to regulators any incidents involving their products, regardless of whether there is a demonstrable link between the incident and the product. For example, [authorization holders in the UK](#) must immediately submit any new information on the potentially dangerous effects of a product or residues of an active substance contained in a product. They are also subject to an annual survey of all human health incidents. In the US, registrants are [legally required](#) to submit reports of adverse effects from their products globally.

It is a condition of membership in CropLife International to adhere to the FAO/WHO International [Code of Conduct on Pesticide Management](#). In addition to the Code itself, technical guidance documents support compliance, including reporting systems for health and environmental incidents resulting from pesticide exposure and post-registration surveillance.

Consequently, all companies maintain records for compliance and stewardship purposes. This allows them to monitor for specific risks that become apparent under large scale use, including effects on pollinators.

Application technology

Technologies that maximize the efficiency of a pesticide, such as allowing the possibility of a reduced dose, and minimize drift are fundamental best practices for application. Beyond these, one example of an application method to minimize risk to pollinators is [Lechler’s DroplegUL](#), which sprays beneath the leaves of flowering oilseed rape rather than on the top of the plant. This has been thoroughly evaluated at [Bayer’s Nauen farm](#). Residue analyses of pollen and nectar showed a clear reduction in the exposure of bee colonies using the DroplegUL method as compared to conventional application. This equipment has the potential to [substantially reduce the exposure](#) of foraging honeybee colonies to foliar pesticide treatments.

Drones and other precision agriculture methods facilitate crop monitoring to scout for pests and determine the optimum time for intervention, if necessary. They also support precision intervention, rather than application at field scale.

In some regions of the world, particularly Asia-Pacific, drones are [increasingly used](#) for spray applications. Unlike hand-held applicators, drones can fly over wet fields and tall crops, moving quickly to specific locations to treat crops more precisely without compacting the soil, damaging the crop or spreading disease. Drones also allow for responsible product use with more accurate dosage and less exposure. The [first autonomous US-built drone precision applicator](#) allows targeted and fully repeatable coverage of the crop. Since it is controlled digitally, it also offers greater safety to the operator and environment. Actionable reporting helps the user refine application and dose parameters in real time.

In Japan, [a drone has been designed](#) to fly along a pre-programmed route 30 cm above the rice stalks at a speed of 5.5 meters per second. It completes spraying a 1 ha. field in just ten minutes, compared to the 90 minutes typically required by conventional methods. An on-board system automatically monitors the growth of each stalk, how well it is photosynthesizing and the seed size and ripeness. It then sprays the precise amount necessary for each individual ear. The system counts the number of seed heads and seeds, instantly calculating the anticipated yield of a whole field.

2.5 Biological products

Biological products are generally considered to be very low risk to pollinator species and are attractive in pollinator protection programs. None-the-less, evaluation remains essential in R&D to ensure that reputation is maintained.

There is no globally agreed definition of the term “biologicals” for crop protection and crop enhancement products, but CropLife International and its member companies cover three classes of biological products:

- Microbials: [Microorganism-based products](#) containing, for example, living bacteria, algae, fungi, protozoa and viruses, or the spores of micro-organisms which produce them; dead cells derived from living micro-organisms.
- Biochemicals: Naturally occurring substances, including products of fermentation processes and extracts from plants; synthetically derived equivalents to naturally occurring substances in regions where these are considered biochemicals, including Canada, the US and, in future, the EU.⁴
- Pheromones: Any endogenous chemical secreted in minute amounts by an organism to elicit a particular reaction from another organism of the same species (due to difficulties in extracting sufficient pheromone directly from insects, pheromone molecules are commonly synthesised).

The term “biologicals” may reference *biopesticides* (insecticides, fungicides, nematocides, herbicides or pheromones that are typically topically applied); *biostimulants*, which mitigate abiotic stresses, enhance a plant’s natural defenses and crop quality and increase nutrient assimilation, or *biofertilizers*, which provide or enhance the availability of nutrients.

Microbials and biochemicals are usually derived from environmental samples and often belong to classes of organisms with a significant history of safe exposure to humans. Toxicological studies indicate that exposure to biologicals is safe for humans when they are used responsibly and properly in accordance with the approved label instructions.

Biologicals can bring some of the required resilience and adaptability necessary to meet the challenges of climate change, food production and socio-economic needs. However, they need to be combined with other technologies and techniques in a farmer’s toolbox. [Biologicals are a key component](#) of CropLife International’s strategy for sustainable agriculture through their use in Integrated Pest Management (IPM)⁶. CropLife International believes that such integrated solutions are necessary to manage pests, diseases and weeds to maintain crop yields and high-quality produce and reduce post-harvest and supply chain wastage, while minimizing potential impact on the environment. The properties of conventional chemical pesticides and biological pesticides are often complementary:

⁴ Proposed [new legislation](#) in the EU also includes recognition that synthesized equivalents to naturally occurring substances can be considered biological products: “‘Biological control’ means the control of organisms harmful to plants or plant products using natural means of biological origin or substances identical to them, such as micro-organisms, semiochemicals, extracts from plant products as defined in Article 3(6) of Regulation (EC) No 1107/2009, or invertebrate macro-organisms.”

- Biological pesticides may be slow to become fully effective so chemical pesticides may be needed during that period.
- Conversely, biologicals can be good at suppressing the early development of a pest population, but chemicals may be needed if there are high levels of pest attack (e.g., of adult, late-instar insects) to decrease the infestation to a level where biologicals can keep the population (e.g., young instars) at an acceptable level.
- Biological pesticides have different and often complementary modes of action to chemicals and allow different mechanisms to control pests to strengthen resistance management.
- The use of biostimulants to strengthen the crop plant's natural defenses can reduce the need for pesticides and increase the efficacy of biopesticides in particular.

2.5.1 Enhancing plant defenses with biostimulants

A strong and healthy crop plant can resist or tolerate pest and disease infestations and compete more effectively with weeds. The examples below illustrate the wide variety of products and effects with the potential to reduce the need for crop protection products and their potential effects on pollinators.

[Biofertilizers](#) include bacteria—added to the seed or the soil or sprayed on the crop—that can pull nitrogen from the atmosphere and convert it to a form that plants can use. Other bacteria are capable of solubilizing phosphorus or calcium in the soil to make it available to plants. Certain biostimulants help plants find nutrients in the soil and then use these nutrients in a more efficient way. Improved nutrition and health may help plants produce or retain more flowers or improve sugar content. Biostimulants can also help plants respond better to abiotic stresses like lack of water, temperature excesses or phytotoxicity. Some biostimulants can act as indirect biocontrol solutions by boosting the natural defences of a plant.

The bacterium *Methylobacterium symbioticum* fixes nitrogen from the air. It is sprayed on the leaves of the crop where it enters through the stomata and colonizes between the leaf cells. By converting atmospheric nitrogen, it provides a constant supply of nitrogen to the plant without requiring the plant to use its own energy. This is a [sustainable, alternative source of nitrogen](#) for several arable crops that reduces dependency on nitrogen uptake from the soil and ensures the plant has access to nitrogen all season long.

The naturally occurring amino acid [proline, combined with potassium](#), is used to protect plant cells, reduce water loss and improve stomata function. This can mitigate the potential impact on yield of such abiotic environmental stresses as drought, heat, salinity and ultra-violet light stresses in maize, soybean, wheat and other crops.

Modern potato varieties are adapted to grow at optimum temperatures of between 14°C and 22°C, with long day conditions. Elevated temperatures beyond 28°C can cause profound effects on several physiological development processes. A [naturally derived biostimulant](#) for potatoes incorporates organic carbon, potassium, calcium, carbohydrates and amino acids to help mitigate drought and heat stresses through key phases of tuber development, thus protecting yield and quality. In research studies, the product increased photosynthesis 24 hours after application under heat stress, and that was associated with increased functionality of the stomata. Hormonal [analysis and quantification showed](#) that treated plants, compared to control plants, had greater concentrations of abscisic acid and cytokinins and lower levels of gibberellic acid at seven days post-application. Gibberellic acid is known to inhibit tuberization, while cytokinins enhance cell expansion and tuber formation.

Amino acids, fulvic acids and micro-elements, combined into a balanced “[plant activator](#),” stimulate new shoots, flowering, fruit formation and harvest. The product also helps plants tolerate biotic and abiotic-induced stresses and improves nutrient absorption. The amino acid promotes plant growth, stimulates photosynthesis and increases fertility and fruit setting. Fulvic

acids carry essential nutrients into plant cells and enhance the activity of antioxidant enzymes involved in plant tolerance to abiotic stress. The product can be used on a wide range of crops in countries including India and Indonesia.

Seaweed has long been used to supplement nutrients in the soil. For example, spreading collected seaweed is a key component of establishing and maintaining the [machair](#), a rare, bio-diverse coastal grassland unique to the northwestern fringe of Europe that is listed on Annex 1 of the EU Habitats Directive. Seaweed extracts have been available since the mid-1900s. Extract from the seaweed *Ascophyllum nodosum* formulated as a soluble liquid ([Seamac PCT](#)[®]) contains a natural balance of both macro and micro-elements, amino acids and other organic substances, including different polysaccharides that are important in priming the plant to reduce the effects of abiotic stress. Applied at key crop growth stages, it can reduce the effects of abiotic stress to enable the crop to achieve its potential and quality. It is recommended for a wide range of cereal and broad-leaved arable crops and fruit and horticultural crops in the UK.

2.5.2 Developing biopesticides and optimizing their use

Biopesticides complement biostimulants and chemical pesticides in IPM programs. As already mentioned, biopesticides are typically of low toxicity to pollinators and can be used to reduce the number of other treatments to manage pests. There are different forms of biopesticides, several of which are described below.

Living micro-organisms

Micro-organisms produce secondary metabolites that show several biological activities related to survival functions of the microorganism, such as competition, parasitism or symbiosis. There are several possible modes of action among these that can be engaged to produce a biological product:

- Antibiosis, in which the association of two organisms adversely affects one organism, i.e., the target species (e.g., production of toxins, fungal metabolites, production of cell-wall degrading enzymes).
- Toxicity (the direct action of toxins).
- Pathogenicity (manifests in effects like mortality or obvious sublethal effects).
- Induction of plant resistance or tolerance.
- Interference with the virulence of a pathogenic target organism.
- Endophytic growth, where the micro-organism grows in the crop plant and can improve its growth or resilience (e.g., improved nutrient uptake, modulating growth and stress-related phytohormones).
- Root colonization.
- Competition for ecological niche (e.g., nutrients and habitats).
- Parasitization.

They are typically produced by fermentation in a reactor system or fermenter or by making the micro-organism produce the metabolites of interest.

Dead cells of micro-organisms

- Intact cells: The product consists of intact dead cells otherwise identical to a live micro-organism; for example, the spores have been killed by heat. The resulting product is identical in composition to the living product, but the spores are dead. Such a product has stronger initial effects than the living spores due to the rapid release of secondary metabolites as the cells degrade. But the effect is shorter lived because the spores do not grow.
- Filtered cells: The fermentation process may be used to modify the exact metabolic profile, depending on the source of the fermentation starting material (e.g., different batches of soy

flour). The fermentation product is filtered to produce a concentrated broth without cells or spores.

Semio-chemicals

Semio-chemicals fall under the general heading of pesticides for regulatory purposes. They are substances or mixtures of substances emitted by plants, animals and other organisms that evoke a behavioral or physiological response in individuals of the same or other species. They dissipate and degrade quickly in the environment. Different pheromones work in different ways to influence behavior within a species:

- Allelochemicals produced by individuals of one species that modify the behavior of individuals of a different species.
- Pheromones produced by individuals of a species that modify the behavior of other individuals of the same species.
 - Straight-chained lepidopteran pheromones (SCLPs) are a group of pheromones with a distinct structural definition that encompass the majority of known pheromones produced by insects in the order Lepidoptera, which includes butterflies and moths.

Semio-chemicals are applied at maximum concentrations to those found naturally. Insects respond to [pheromones](#) at a discreet concentration range so overexposure can reduce efficacy. They are species-specific and do not disrupt the behavior of other insects, including pollinators, so they fit well with Integrated Pest Management (IPM) strategies. For example, a mating pheromone can be used to flood an area with signals from females, confusing the males and preventing mating to control the population. Attractant pheromones are used to draw pests into traps, bring them to an insecticide bait or monitor their population. Monitoring is particularly useful in helping farmers check for economic thresholds and devise targeted control strategies. They can be used in organic farming and to complement conventional pest control.

Most pheromones are produced synthetically but are identical to natural occurring pheromones. There are numerous examples of commercial pheromones and new research and development amongst member companies:

- BASF has a [range of pheromones](#) for vineyards and other fruit crops.
- Bayer recently [launched a product](#) containing a pheromone combined with natural pyrethrum to control pests in citrus.
- Corteva is working with M2i, a leader in the field of pheromones for biological crop protection, to research, develop and commercialize [pheromone-based insect control](#).
- FMC has [an agreement](#) to acquire BioPhero ApS, a Denmark-based pheromone research and production company.
- Syngenta has collaborated with Provivi, another provider of pheromone-based crop protection solutions, to commercialize a [new mating disruption pheromone](#) to effectively and more safely control pests in rice.

RNA-based products that are externally applied (induced gene silencing)

RNA interference (RNAi) is a biological process that is used by organisms to modulate the expression of genes. This can be harnessed using RNAi to “turn down” the expression of certain genes to produce desired effects. This mechanism is sometimes known as induced gene silencing. [RNAi has many potential applications](#), including in the medical field to fight disease (e.g., SARS-CoV-2) and by the crop protection industry to prevent pests and diseases from destroying crops.

RNA-based products are in development to selectively control pests when applied on or around plants (e.g., foliar, granular or seed treatment applications). Double-stranded RNA (dsRNA) can be used to trigger RNAi in susceptible pests when they ingest or absorb the RNA. These potential

products are applied externally to the plant and are different than crops that have been genetically modified to use the RNAi mechanism.

RNAi is highly specific so these products affect only the target pest and will not trigger the RNAi process in other organisms including humans. As well as being specific to the target pest, the dsRNA required to trigger RNAi faces biological barriers (e.g., does not survive digestion or blood nucleases if absorbed) and is not expected to be absorbed through physical contact.

Examples of externally applied RNAi-based crop protection products may include:

- Direct control agents that are toxic to specific, targeted pests.
- Resistance factor repressors that suppress or prevent a pest from becoming resistant to existing pest-control methods.
- Development disruptors that interfere with the normal development or growth of a specific, targeted pest, such as making it sterile.

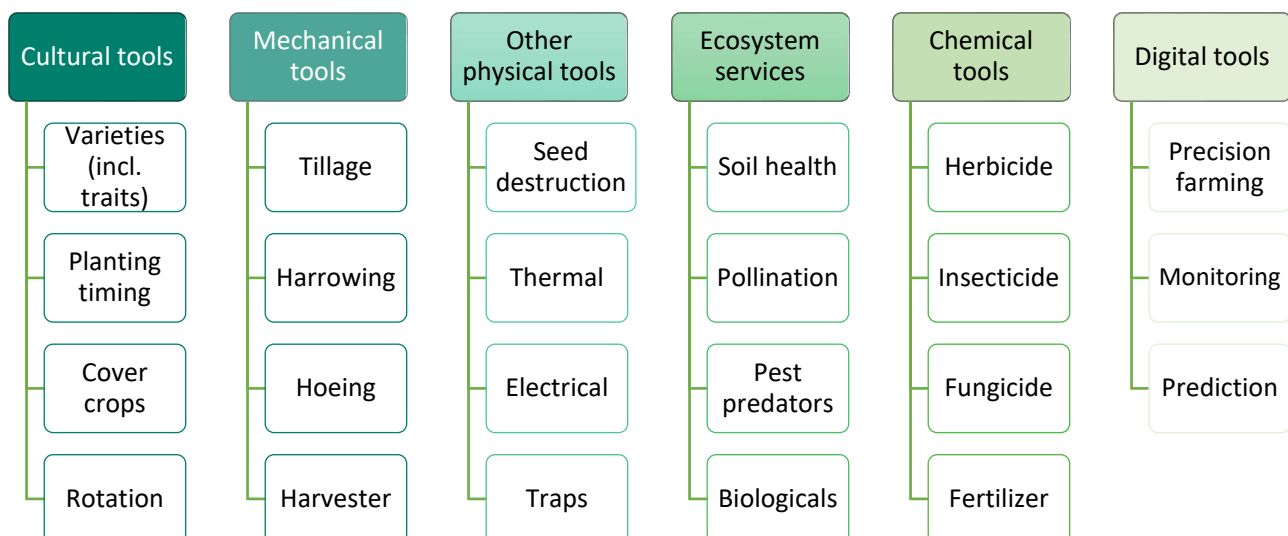
RNAi has been used in [developing products](#) to protect honeybees from the *Varroa* mite. RNA-based *Varroa* mite control will allow beekeepers to target the mite without harming the honeybees, which is an advantage compared to other treatments on the market. (See Section 5.5)

3. Implement Integrated Crop Management & Integrated Pest Management

Integrated Crop Management

Integrated Crop Management (ICM) is a [system of crop production](#) that conserves and enhances natural resources while producing food on an economically viable and sustainable foundation. It is based on a good understanding of the interactions between biology, environment and land management systems. ICM is particularly appropriate for small farmers because it aims to minimize dependence on purchased inputs and make the fullest possible use of local technical knowledge and land use practices. A selection of the tools that may be available to farmers is shown in Fig. 1.

Fig. 1. A selection of tools available to farmers practicing Integrated Crop Management
(Source: Bayer AG)



Integrated Pest Management

Integrated Pest Management (IPM) is specific to pest management and is complementary to ICM. The [FAO defines IPM](#) as 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. IPM is an approach-based method for analysis of the agro-ecosystem and the management of its different elements to control pests and keep them at an acceptable level (action threshold) with respect to the economic, health and environmental requirements. ICM and IPM are broadly beneficial for pollinators and are readily adapted to achieve protection goals for crops, pollinators and biodiversity in general.

Ecosystem services

Ecosystem services are the foundation of sustainable agriculture, providing many of the necessities for a healthy crop and quality produce. Pollinators are essential ecosystem services for crops that rely on pollination.

Farm management can be adjusted to reduce adverse effects on pollinators, for example:

- Agronomic practices that encourage strong, healthy crops.
- Using technologies to identify the occurrence of pest, disease and weed problems at levels that justify intervention and, where intervention is necessary, to target applications where the problems occur rather than across the whole crop.
- Selection of products and application methods that minimize exposure and risk to pollinators and impacts on the flora on which pollinators depend.
- Diversifying the farm system to favor pollinators, such as introducing no-till, using a broad range of crops and crop rotations and maintaining or expanding natural and semi-natural land on the farm and surrounding landscape.
- Interventions to support pollinators specifically, such as the provision of feeding areas (e.g., wildflower strips) and nesting sites (e.g., bare ground and other non-crop areas).

Examples of the research into, development of and promotion of these techniques by CropLife International and its member companies are the theme of this report.

“[The State of the World’s Biodiversity for Food and Agriculture](#)” (FAO, 2019; p.20) points out that while farmers in intensive systems often rent managed honeybees to pollinate their crops, most farmers rely on bee populations maintained by local beekeepers and on wild pollinators.

Pollination services are enhanced by the presence of wild insects even where honeybees are abundant (Garibaldi *et al.*, 2013). Both higher pollinator density and higher species diversity of pollinator visits to flowers have been found to be associated with higher crop yields (Garibaldi *et al.*, 2016). Species diversity among pollinators can also be important in buffering the supply of pollination services against the effects of fluctuations in the populations of individual species (Kremen, Williams and Thorp, 2002). Additional detail from the FAO report is presented in the introductions to the following sub-sections because the research and proposals reflect what is being done by CropLife International members.

Implementation of IPM

CropLife International and its member companies and associations support sustainable agriculture to produce sufficient, affordable food and fiber in an environmentally and socially sensitive manner. CropLife International member companies develop and promote products and services for ICM and IPM and integrate them in best practices in cooperation with many scientists and extension agents. They also provide education and training on the sustainable use of crop protection products. Examples of the scale of training are given in [an overview of IPM](#) published by CropLife International and progress in training is tracked through its stewardship program.

Implementation of IPM lies with farmers who tend to adopt practices they view as practical and valuable to their activities. For farmers, IPM is a site-specific strategy for managing pests. It is a holistic, considered and flexible approach using the best combination of cultural, biological and chemical measures to manage diseases, insects, weeds and other pests. All relevant control tactics and methods that are locally available should be considered and their potential cost-effectiveness evaluated, applying the latest research and technology as well as local knowledge and experience. This allows reduced inputs and often a premium for the farmer, for example in an IPM program on [apples in Albania](#). The two figures below summarize the key components of an IPM strategy (Fig. 2) and the options available for full implementation of an IPM program (Fig. 3).

Fig. 2. Three key components of an IPM strategy (Source: CropLife)

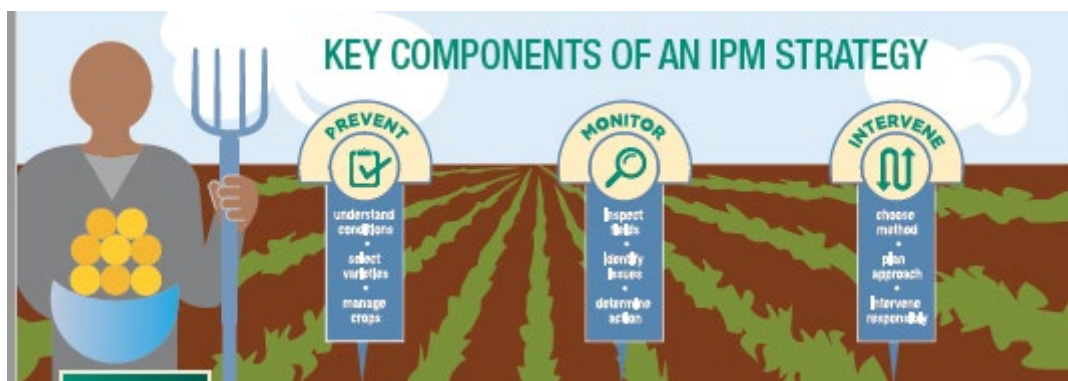
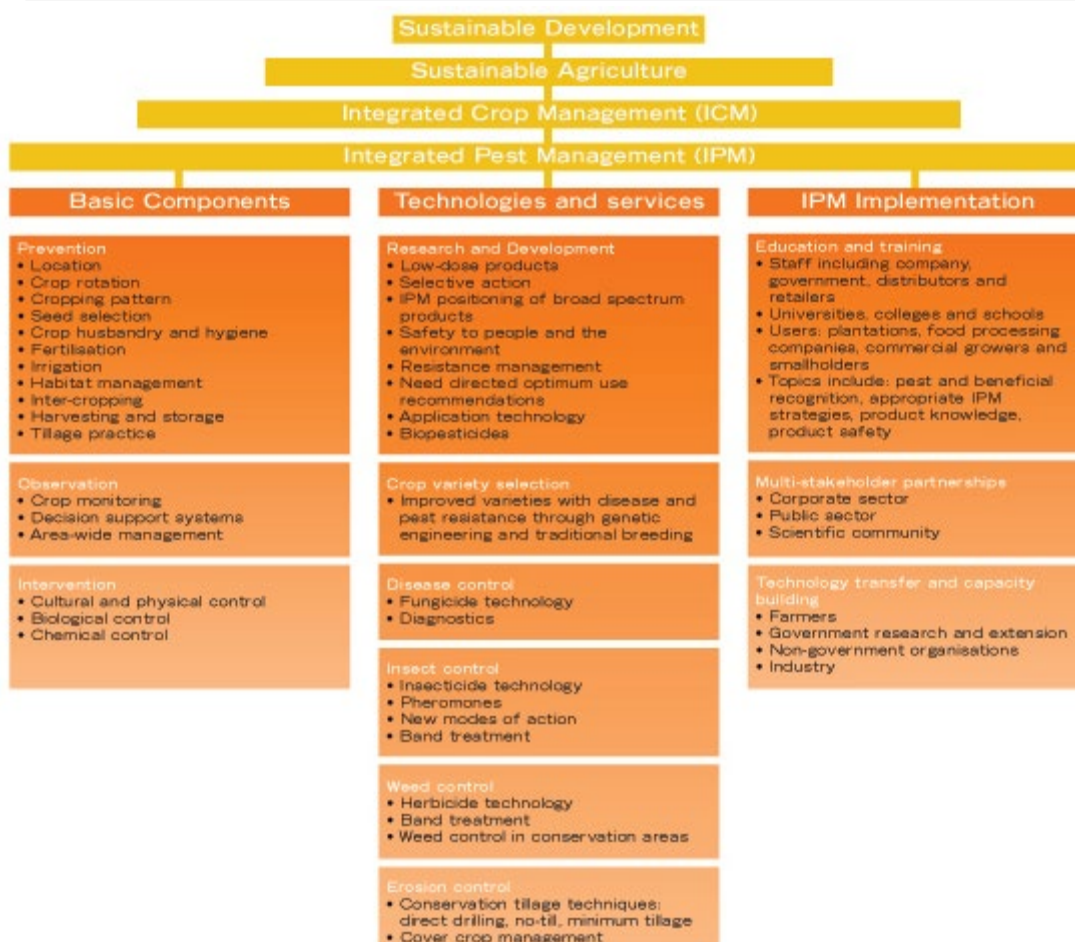


Fig. 3. Tools and services for implementation of a full IPM program in the field (Source: CropLife International)



Natural enemies of pests can reduce the chance of insect pests establishing and proliferating in crops and consequently causing economic damage. For success, a diverse range and abundance of natural enemies is needed to ensure sufficient numbers of the relevant species are present to suppress a particular pest when it arrives. This can be delivered by providing a range of habitats and adhering to IPM principles. Overall, the aim is to deliver the right types of natural enemies at the right time and in the right place. A practical way of providing all of the resources that they need is the "[SAFE approach](#)," which was developed for the UK but is relevant elsewhere. The acronym stands for:

- **Shelter** for overwintering/ dormancy & periods of inactivity/breeding.
- **Alternative prey** for when pests are not present.
- **Floral resources** for energy and nutrients.
- **Environment** should be appropriate for survival with preferred, insecticide-free vegetation cover.

Recommendations are given for creating and managing a wide range of habitats that can be found in the farming landscape. The range of habitats described demonstrates the number of options available for farmers to develop more diverse habitats on their farms.

To develop this into a full IPM program requires further steps. Another [UK guide](#) does this using eight principles of IPM to enable practical techniques that achieve sustainable crop production with reduced pesticide inputs:

- **Step 1** Prevention and suppression
- **Step 2** Monitoring
- **Step 3** Decisions based on monitoring and thresholds
- **Step 4** Non-chemical methods
- **Step 5** Pesticide selection
- **Step 6** Reduced pesticide use
- **Step 7** Anti-resistance strategies
- **Step 8** Evaluation

Although these principles were developed for the UK, they can be applied anywhere in the world. The organizations that developed these guidance documents are supported by various members of CropLife International.

Innovative technologies support the implementation of IPM, for example in scouting for pests and diseases. Drones with photosensitive scanners are used to identify when and where to treat weeds, pests and diseases, and pesticide can be applied directly by the same drone, in real time, if the selected threshold for application is achieved. This topic is covered by Chapter 6: Digital Farming and Precision Agriculture. Although the benefits of ICM and IPM are clear, robust benefit data are valuable to engage growers and encourage them to implement best practices to support pollinators and biodiversity in general. The [LivinGro® R&D International Biodiversity Pilot Project](#) was launched in 2020 to:

- Create scientific field data to demonstrate that modern agriculture, biodiversity and healthy soils are not mutually exclusive.
- Develop scalable protocols to create optimal conditions to enhance arthropods and microbiota biodiversity and contribute to securing crop yield using cover crops.
- Demonstrate how growers will get return on investment from biodiversity measures to different cropping systems:
 - Vertical crops: Spain and Chile (26 trials) stone fruits, olives and grapes.

- Row crops: Argentina, Germany and Mexico (80 trials) rotational crops, including corn, oilseed rape, soybean, sugar beet and wheat.

At the end of the study, the comprehensive range of data will be evaluated by both Syngenta and independent scientists from the five pilot countries, with final reports available in 2024. The findings will be published in peer-reviewed scientific journals.

3.1 Data requirements for alternatives to pesticides and their use in IPM

There are numerous traditional and novel techniques proposed or used as alternative crop protection methods. Most alternative methods are unregulated and often not as well researched for their environmental impact as regulated methods. Some have a place in IPM programs, but all have an impact on biodiversity with associated hazards and risks to non-target species and the environment that are commonly assumed to be negligible.

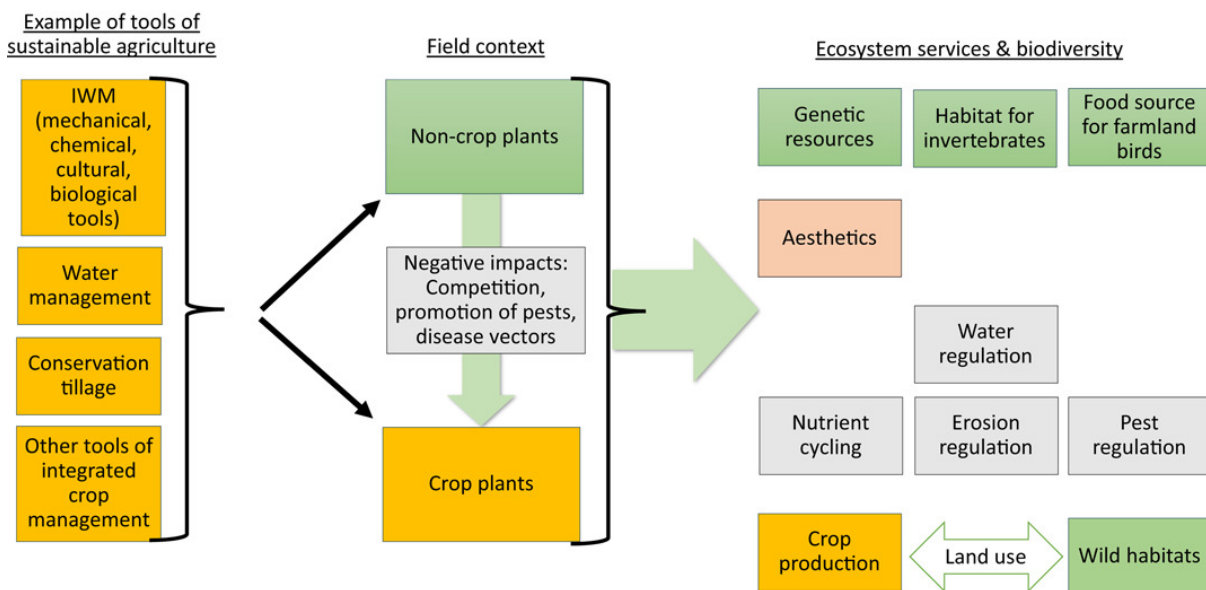
For example, soil solarization is a broad spectrum, untargeted method of controlling soil pests. Despite research into its benefits for controlling soilborne pathogens and improvements in soil nutrients and microbial activities, there has been much less research into its impact on biodiversity.

Mechanical weed control has advanced to be capable of high levels of weed control, reducing the flowering of weeds to levels akin to herbicides. This has direct effects on biodiversity (e.g., removing flowering weeds) but also indirect effects via trophic interactions that can [adversely affect](#) soil structure, soil erosion and soil dwelling organisms. These need parallel assessments to ensure environmental protection goals are not compromised.

Combining tools to achieve protection goals

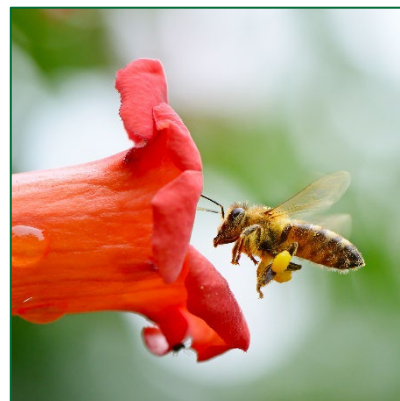
It is the combination of tools within a local agronomic context that creates the interface between the cropped field and the environment. The environmental implications of selecting one or another tool must be understood to make informed choices to achieve the desired protection goals. CropLife International and its members support the assessment of existing and future tools in a consistent, evidence-based manner to support the protection goals, including pollinators and biodiversity. For example, Fig. 4 provides a schematic related to integrated weed management.

Fig. 4. Considerations to inform operational EU-specific protection goals – an example for non-target terrestrial plants (Source: Society of Environmental Toxicology and Chemistry)



3.2 Expanding pest management programs to further reduce risk from insecticides

The benefits of ICM for crop yield and quality and for reducing inputs and the volume of insecticide used are shown in three CroPLife International case studies in three distinct geographies and farming systems: apple crops in Trentino in northern Italy and in New Zealand and palm oil plantations in Malaysia. A very different example of IPM is in the management of fall armyworm in Africa and Asia. Finally, there is an example of cooperation in promoting IPM in Taiwan.



Trentino – Integrated Fruit Production

The Integrated Fruit Production (IFP) guidelines for apples were [introduced in Trentino](#) in 1991. With the very high participation of cooperatives, the apple crop in Trentino was almost completely managed by IFP standards in 2013. Under the guidelines, insect pests and diseases are managed by combining sampling, thresholds and pest forecasts with biological and cultural control methods and the use of selective pesticides. The use of selective insecticides facilitated the biological control of mites by predatory mites so that typically, only a single miticide treatment is necessary.

Codling moth has two generations per year. Mating-disrupting pheromones, combined with insecticides, are used in orchards with high pest pressure (30% of the area). In orchards with low pest pressure, pheromone applications were not economically feasible. The most common situation includes an application of an insect growth regulator at the first egg-laying period and two more treatments using insecticides with a different mode of action.

A spring insecticide treatment against psyllids is mandatory because they are vectors of apple proliferation (AP) disease. AP occurs in all countries of central and southern Europe, but its highest incidences are in Trentino and southwestern Germany. The disease causes important economic losses due to small fruit size and poor taste.

In Trentino, uncontrolled codling moth would damage 50-90% of the apples and apple scab could damage all the apples. Apple production in Trentino remains generally profitable and provides a major contribution to the economic and social standards of the province. By preventing damage from insects and pathogens, pesticides play an essential role in the economic and social well-being of the region.

New Zealand – Integrated Fruit Production

Pesticides are used in New Zealand's apple orchards to produce the high-quality fruit necessary for good financial returns and to ensure complete absence of key pests and diseases to satisfy the phytosanitary requirements of importing countries. There is zero tolerance for live codling moth in apple exports to Taiwan, China, Japan, Thailand and India.

In 1996, [New Zealand's apple industry launched](#) the Integrated Fruit Production (IFP) program, which introduced major changes in insect and disease management. This included a shift from calendar schedules of insecticides and fungicides to justified use only, based on monitoring and threshold-based applications of new selective insecticides. A national network of weather stations provides data for black spot infection risk to facilitate correctly timed curative fungicide sprays. In addition, forecast weather information is used to time protectant fungicide sprays in advance of likely infection periods. At the time of the report, all New Zealand apples are now grown under either IFP methods (91%) or organic production systems.

Implementation of IFP reduced the number of insecticide sprays by 40-50% to just 4-6 between 1996 to 2003, depending on variety and region. However, the average number of insecticide applications increased in 2007-08 and 2008-09, prompted by a reduction in the threshold for spraying codling moth.

In the IFP program, fungicide use decreased by 45%. Although the number of fungicide applications remained high, many protectant sprays were replaced by lower-rate curative sprays. However, overall fungicide use volume increased from 31 kg/ha to 34 kg/ha due to the high rates of lime sulphur used in organic orchards. The use of insecticides and fungicides in the IFP program assured high quality apples from New Zealand for the export market.

Malaysia – Monitoring Pest Thresholds in Oil Palm

In Malaysia, oil palm is grown by both smallholders and plantations. Oil palm is a perennial crop that is very attractive to many pests. Leaf-eating caterpillars are among the most important insect pests. They include bagworms and nettle and hairy caterpillars, all of which feed mainly on the palm fronds. High population levels can lead to the complete skeletonization and death of the fronds. A damage of 50% will cause a yield decline of around 43% over the next two years. Even a lower amount of damage, such as 10-13%, can also cause significant losses.

Under normal conditions, caterpillars are effectively kept below the economic damage threshold by their natural enemies, including predatory or parasitic insects and diseases caused by viruses and fungi. Heavy pest attack is often the result of a breakdown in the balance of nature. Generalist predators may not totally prey on the oil palm caterpillars and instead feed on other insects available in the ecosystem.

In dry conditions, dust interferes with predators and parasites in search of hosts. Some parasitoids are commonly attacked by hyperparasitoids, which reduce their numbers. As a result, parasites and predators do not fully control the caterpillar populations in all years and locations.

Outbreaks of pest caterpillars are sporadic and localized. A monitoring and surveillance system for oil palm has been used in Malaysia for many years. By monitoring an outbreak, the area in which damage is occurring is delineated. [Chemical intervention](#) is only used when populations reach threatening levels. At this stage, trunk injection of a systemic insecticide is undertaken. From there, the insecticide is translocated in the sap and carried up into the leaf tissue. This means that only the leaf-feeding caterpillars are killed, but not their natural enemies.

Overall insecticide use is low, with no more than 5% of the total area of oil palms receiving application in any one year. Insecticide application averages about once in a planting generation (around 25 years).

Africa and Asia – Fall armyworm control (FAW)

FAW is a serious lepidopteran pest of maize and can seriously affect other crops.

The [USAID and CIMMYT \(2021\) guide](#) for the integrated pest management of fall armyworm in Asia is one of many examples guiding the use of pesticides to minimize risk to pollinators. It advises:

- a) Use pesticides, if available, that are less toxic to bees and other insect pollinators (see
 - a. pesticide selection guideline published with Jepson *et al.* 2020).
- b) Use a non-application zone around natural ecosystems, establish vegetative barriers or
 - a. use other effective mechanisms to reduce spray drift.
- c) Apply only when insect pollinators are not foraging on the field or after flowering plants
 - a. that attract insect pollinators are managed.
 - b. Substances should not be applied when weeds are flowering, or until flowering weeds are removed by other means.
 - c. Substances should not be applied when the crop is in its peak flowering period or
 - i. at a time of peak attractiveness to bees (*e.g.* as a source of aphid honeydew)

- ii. available drinking water.
- d) Where beehives are used, temporarily cover these with impermeable sheets (*e.g.*, plastic sheeting) or move them during application; provide hive bees with a clean water source outside the treated area for at least 24 hours following application.

Of the pesticides in use against FAW in Africa and Asia, fourteen are classified as low risk, but two of these (Spinosad and Spinetoram) require mitigation for pollinator hazards. Although they are highly toxic when sprayed directly on honeybees and other pollinators, dried deposits of Spinosad are of low toxicity to bees visiting three hours after application (Mayes *et al.* 2003) and similarly for Spinetoram, as documented in the manufacturer's label. It is of note that Spinetoram and Spinosad are naturally derived from a soil bacterium through fermentation, so care is needed even when using biological products.

Therefore, the application method and timing need to be considered when [mitigating risk to pollinators](#). For example, flowering weeds should be controlled prior to maize tassel emergence to prevent attracting honeybees into the maize. When the tassels start to emerge, if the crop is at risk, insecticides should be applied early in the morning before honeybees become active or at dusk, when fewer bees are in the field. Other approaches for minimizing injury to bees when using Spinetoram or Spinosad are described in the guidelines.

IPM promotion in Taiwan

CropLife Taiwan, China [successfully implemented an IPM program](#) that won the country's first IPM award by partnering with the government's Council of Agriculture. The collaboration is part of the government's own 10-year policy to reduce pesticide use by half and encourage environmentally sensitive farming.

CropLife Taiwan, China implemented various strategies, including training farmers in pesticide resistance management. It worked with the Bureau of Animal and Plant Health Inspection and Quarantine (BAPHIQ) to have the Mode of Action (MOA) classification printed on pesticide labels, resulting in a regulation that was approved in 2019. The MOA classification helps farmers apply the right product in the right quantities at the right time and the information on the label is convenient for farmers to access. Additionally, CropLife Taiwan, China is looking for an opportunity to collaborate with and leverage its farmer education program to expand and enhance the pesticides rotation concept laid out in the MOA management system.

Member companies also engage in education and advocacy to enhance farmer awareness of the importance of using personal protection equipment.

Future stewardship plans include continuously seeking to align CropLife International's IPM policy with that advanced by the Taiwan government and to leverage resources to reach more farmers with IPM education.

4. Plant Breeding to Enhance Crop Resilience

CropLife International member companies invest in innovative, leading-edge research and development to develop beneficial crop varieties. The commercial development of transgenic crops with specific toxicity for certain insect pests is relevant to pollinators, the subject of this review.

Several CropLife International members have contributed to technology development, regulatory safety standards and resistance management. The [OECD BioTrack Product Database](#) (2022) of transgenic events shows that the majority of commercialized transgenic events have been registered and placed on the market by these member companies. This technology is widely out licensed among these companies and other seed breeders to be incorporated in their crop varieties. The companies continue to develop and commercialize new versions of the technology with broader scope beyond the management of pests, diseases and weeds. Other activities include:

- Performing safety studies according to criteria set by authorities, including measuring potential effects on non-target organisms like pollinators.
- Producing an adequate volume of quality seed for farmers that meets or exceeds the standards required by regulatory authorities.
- Supporting farmers in meeting best practices or industry standards on resistance management, including monitoring the efficacy of the traits and resistance development, and the use of dual modes of action and refuges of crop without the trait.
- Creating a foundation of technology and knowledge and a baseline of regulatory know-how that helps others to develop the Bt trait in important food crops, such as eggplant and cowpea.

The CropLife International website provides a [summary of some of the developments](#).

4.1. Tolerance of pests and diseases

Bacillus thuringiensis (Bt) an entomopathogenic bacterium, was first commercialized as an insecticide in France in 1938 ([Ibrahim et al. 2010](#)). Subsequently it was widely used as a biological product for insect pest control worldwide in many crops, including those grown in organic agriculture. The spores of the bacterium are sprayed over the crop and infect the target insect pest. Years of experience have demonstrated the safety to non-target insects such as key pollinators. For example, [Libardoni et al. \(2021\)](#) recently demonstrated the safety of two commercial products to Africanized honeybees.

Transgenic crops have been developed that express compounds with specific toxicity for certain plant insect pests. They are mostly proteins, known as *Cry* proteins, and often crystal proteins of *Bacillus thuringiensis* (e.g., [Pigott, King & Ellar, 2015](#)). Bt spores are also used as an insecticide in organic agriculture, but the effect of a single spray rapidly declines in the field. Transgenic crops offer a more effective way to deploy the active ingredient.

Technology developers can express the active ingredient selectively in specific tissues: leaf (for pests that feed on leaf) or root (for pests that feed on roots) or phloem sap (for sap-sucking insects). It is possible to reduce or avoid expression in pollen, and several transgenic events do that by using a gene expression mechanism (such as promoter P35S) that does not express in pollen. This is another design element that avoids harm to pollinators.

Gene editing is being used to make crops more resilient to attacks by pests and diseases in a range of horticultural and arable crops, as well as crops grown mainly by smallholder farmers.

Box 1. Gene editing as a tool for global advancement in crop production

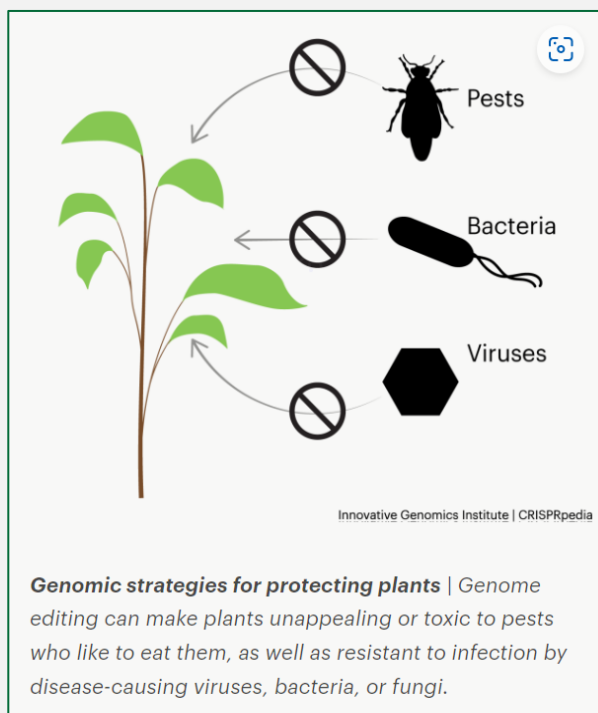
Plant breeding requires foresight and innovation because the breeding process, no matter which method is used, can take years of selection and evaluation before a new variety is ready for farmers. Gene editing is an additional plant breeding tool to improve efficiency compared to more traditional breeding methods. It enables more rapid and efficient development and delivery of new varieties adapted to changes in climate and that contribute to a healthy, safe and secure food supply.

Genome editing encompasses a variety of techniques, such as CRISPR–Cas9, that add, remove or replace DNA at precisely targeted locations within the genome. Gene-edited crops with specific desirables are developed using these technologies. CRISPR tools avoid many of the side effects of older plant breeding techniques because they are so precise. They can be used to make small edits to the DNA present in plants without adding any foreign DNA. A review of the technologies and their applications in agriculture can be found in the [“CRISPRpedia” pages](#) of the Innovative Genomics Institute website.

Gene editing is a research tool that aids discoveries about genetics and gene interactions which, in turn, can decrease the cost and time of initial research and development. With these efficiencies,

plant breeders can [develop more choices](#) for farmers and respond in a much shorter time to [rapidly changing needs](#), such as drought tolerance or pest resistance. Access to diverse seed choices helps farmers select the optimal varieties for their land, fight pests and diseases and adjust to changing climate patterns.

A recent example is the development of [powdery mildew-resistant wheat](#) in China. Gene editing was used to knock out a gene that makes wheat susceptible to the fungal disease. This change also stunted the plant's growth. However, one of the edited plants grew normally. Researchers found this was due to the deletion of a portion of chromosome that meant the expression of a gene involved in sugar production was not repressed. Subsequently, the researchers removed that portion of the chromosome and the gene that makes the plant susceptible to powdery mildew, creating fungus-resistant wheat varieties that do not suffer from restricted growth.



Several CropLife International member companies are using gene editing in their R&D programs.

- **Bayer's** [R&D focus areas for gene editing](#) include improvements to plant architecture, disease resistance, stress tolerance and plant growth, and development across its row crop portfolio. One example is short stature corn, developed through multiple technology approaches including traditional breeding, gene editing and biotechnology.
- Genome editing technology is being [used by BASF](#) to gain knowledge and improve organisms with both agricultural and industrial applications. Both conventional and biotechnology plant breeding methods are optimized in seed research, including the use of advanced tools for genome editing, such as CRISPR-Cas9 or other genome editing technologies.
- **Corteva** published [CRISPR Genome Editing Guiding Principles](#), and summarizes collaborations with institutes and companies in partnerships and licensing agreements involving CRISPR technology in crop breeding and research. These include a project with the International Maize and Wheat Improvement Center (CIMMYT) that will apply CRISPR to address maize lethal necrosis disease in sub-Saharan Africa. This disease has reduced maize production on some farms by up to 90%. Under an agreement with Amfora, Inc., the emphasis will be on food products, such as high-protein wheat and rice. Increasing the protein content of such crops reduces their starch content, which can address the growing consumer demand for plant-based protein and may help control consumers' blood sugar levels by reducing the glycemic response.
- **Syngenta** researchers published a paper in Nature Biotechnology in 2019 about their [discovery of a genome-editing technique](#) called haploid induction editing. This refers to using haploid induction, which occurs naturally in wheat, corn, barley, tobacco and other plants, combined with a genome-editing technology such as CRISPR-Cas9. It enables breeders to modify crops at various stages in the seeds research and development process more quickly than with introgression, the traditional method of transferring desirable genes from one crop variety into another, which can take up to seven years to complete.

4.1.1 Safety to pollinators and other arthropods

Only a small amount of the expressed Bt protein is needed to produce the desired effect. The protein is degraded during digestion by humans and other grazing animals. Protein remaining in the discarded parts of the crop after harvest is degraded in the environment.

Over more than 20 years of planting transgenic crops, laboratory and field-based studies have provided extensive experience on the non-target effects of crops producing these Cry proteins. Most of these studies demonstrate that the insecticidal proteins deployed in transgenic crops cause no unintended adverse effects to natural enemies. Several studies indicate that insect-resistant genetically modified plants currently available are unlikely to represent a risk for pollinators (for example, [Arpaia et al., 2021](#)). Bt proteins appear not to harm natural enemies, including arthropod predators and parasitoids. Therefore, Bt technology represents a powerful tool for IPM programs ([Romeis et al., 2019](#)). Furthermore, Bt crops can replace synthetic chemical insecticides for target pest control, creating an environment supportive of the conservation of natural enemies.

Regulatory authorities and assessors, such as EFSA in the EU and the EPA in the US, require testing the Bt protein for target and non-target effects. For commercial approval, the trait must not be toxic to pollinators.

The EPA's assessment found that Bt crops pose no significant risk to the environment or to human health ([Mendelsohn et al., 2003](#)) and field experience supports this conclusion. The test guidelines for larval and adult honeybees and non-target arthropods are applicable to crops containing the Bt proteins as part of the environmental safety studies and risk assessment ([EPA 1996](#)). For example, cotton is an insect-pollinated crop, and only very small amounts of pollen containing the Cry1Ac protein can drift out of fields. Pollen containing Bt (Cry1Ac) protein, at relatively very high dosages, was not toxic to the test species representative of organisms likely to be exposed to such pollen (e.g., lady beetles, green lacewings and honeybees).

Similarly, [EFSA \(2016\)](#) had no safety concerns for non-target arthropods and other non-target species for a range of Bt proteins (Cry1Ab, Cry1F, Cry34Ab1, Cry35Ab1 and mCry3) in the context of the single maize events. Considering both insect sensitivity and exposure, the [OECD \(2007\)](#) concluded that:

- Numerous field tests indicated that Bt maize had no adverse effect on naturally occurring predators or on certain maize pests.
- A review of large-scale field tests in commercial cotton have not revealed any unexpected non-target effects other than subtle changes in the arthropod community caused by the effective control of the pests.
- The cultivation of Bt maize (Cry1Ab) poses no great risk to the monarch butterfly.

Box 2. Applying the technology

Types of pests managed: Grazing insects, sapsucking insects, stem and fruit borers, corn root worm.

Examples of insect-resistant crops:

- Insect-resistant Bt cotton and Bt maize have been grown commercially since 1996 and Bt soybean since 2013.
- Bt brinjal (eggplant) entered the market in Bangladesh in 2014 and was grown by 65,000 farmers in the 2020-2021 season. A survey in 2018 documented a 37.5% reduction in pesticide costs as well as yield and income improvements ([Conrow 2021](#)).
- Nigeria became the first country to register pod borer-resistant Bt cowpea for commercial use in December 2019, providing the opportunity for significantly less insecticide use ([Conrow 2019](#)), and Ghana approved the crop in 2022 ([USDA 2022](#)).

Replacing synthetic chemical insecticides with Bt crops for pest control supports the conservation of natural enemies. Bt crops can contribute to more effective biological control of both target and non-target pests as part of an IPM strategy.

When Bt varieties of cotton, brinjal and corn are grown, the fields receive less insecticide spray, so there is less potential for harm to pollinators. As part of an overall IPM strategy, Bt crops can contribute to more effective biological control of target pests without harming non-target insects.

In addition to protecting non-target insects, the benefits of growing Bt crops are:

- More income for farmers.
- More agricultural production through increased or more reliable productivity, without encroaching on more land.
- Enhanced food security.
- Reducing risks from mycotoxins, which are poisonous to humans and screened in the food chain to ensure maximum residue limits are not exceeded.

4.1.2 Reduction of the volume of insecticide applied due to GM insect-resistant crops

These technologies supported a reduction of insecticide use between 1996 and 2018 (Table 1), effectively replacing insecticides to control important pests in certain crops. This is particularly evident in cotton, which was typically intensively treated with insecticides to control bollworm and budworm pests. In maize, the insecticide use savings have been more limited because the pests that the technology targets tend to be less widespread in maize than budworm and bollworm pests are in cotton. In addition, insecticide use was already lower in maize because the products were considered to have limited effectiveness against some maize pests, such as stalk borers, that occur within the stalks where sprays are not effective.

Table 1. Effect of growing insect-resistant crops on global insecticide use and its environmental impact (Adapted from Brookes & Barfoot, 2020)

Crop	Period of commercial growing	Target pests	Baseline for insecticide use	Reduction of active ingredient (million kg) ¹	% reduction of insecticide used ¹	% change in EIQ ²
Maize	1996-2018	Stalk borer, rootworm etc	Insecticides targeting stalk borers and rootworm	-112.4	-59.7	-63.0
Cotton	1996-2018	Bollworm	All insecticides used on cotton	-331.0	-32.2	-34.2
Soybean	2013-2018			-14.9	-8.2	-8.6

Negative sign = reduction in usage or EIQ improvement.

¹ Saving relative to the amount reasonably expected to be used if the crop area had been planted with conventional seed. Details of the method for making these estimates are given in [Brookes & Barfoot 2020](#).

² As measured by the indicator, Environmental Impact Quotient (EIQ) developed at Kovack et al. and updated annually, (e.g., Brimmer et al., Kleiter, Biden, et al.). Full references provided in [Brookes & Barfoot 2020](#).

In 2019, 190.4 million hectares of transgenic crops were planted around the world in 29 countries ([ISAAA 2019](#)). Of this total area, 57% contained Bt as an insect resistance trait, including:

- Transgenic Bt cotton sown on 25.7 million hectares, of which 11.9 m ha were planted in India. This equates to 94% adoption by farmers who benefitted from handling much less insecticide product as well as spraying less into the environment.

- A significant area of soybean was planted with insect resistance traits in Latin America. Although soybean is largely self-pollinating, pollinating insects forage in flowering soybean and there is evidence that pollinators can enhance productivity where insecticide use is absent (Milfont et al. 2013). Thus, the reduced need for insecticide use in crops with the traits may benefit yield as well as the environment.
- Around 100,000 ha of insect-resistant brinjal (eggplant) were grown in Bangladesh for the control of fruit and shoot borer (Brookes & Barfoot 2020).

The main environmental benefits have been through the effects of reduced insecticide use, which the transgenic crops replaced the need for (Brookes & Barfoot 2020). As [Brookes & Barfoot 2020 report](#), other benefits are:

- Reduction of greenhouse gas emissions through reduced fuel use and the spread of reduced tillage systems.
- Additional soil carbon storage/sequestration due to increased adoption of reduced and no-till production systems in North and South America, leading to enhanced soil quality, reduced levels of soil erosion and increased carbon retention in the soil.
- Conserving natural habitats by growing more without needing to use additional land.

4.2. Native resistance from crop diversity and crop wild relatives

Crop wild relatives (CWR) are wild plant species that are related to food, fodder and forage crops, as well as to other species of socio-economic importance, such as forestry species, medicinal and aromatic plants, condiments and ornamentals. They include crop progenitors and are a potential source of traits beneficial to today's crops ([Maxted et al. 2008](#)). Given their importance in agricultural research and development, their conservation is important ([Hunter & Heywood 2011](#)). *In situ conservation of CWR* can counter genetic erosion and allow the continued evolution of new adaptive traits, as well as the maintenance of the breadth of genetic diversity present in the many species of crop wild relatives, which is the basis for enhancing the adaptation of crops to new and changing agro-environments.

CropLife International and several of its members have contributed as donors to the [Crop Trust](#), which is “dedicated to conserving and making crop diversity available for use globally, forever and for the benefit of everyone.” It supports the collection and promotion of plant genetic resources for food and agriculture in gene banks in a coordinated and efficient manner. The collections include land races and crop wild relatives and are used to characterize genetic diversity and discover valuable resistance and tolerance genes, among other purposes.

Researchers are [studying opportunities](#) in wild cotton progenitors to reduce the impact of drought and salinity stress, which is said to lead to over 30% of total loss in cotton production. Upland cotton suffers from eroded genetic diversity due to intense selection and inbreeding. To break the bottleneck, the wild cotton progenitors offer unique traits that can be introgressed into the cultivated cotton, thereby improving their performance.

4.3. Initiatives to improve crop resilience

Adapting to climate change and to changing social, economic and political circumstances requires crop resilience to stresses to ensure reliable food production. Crop wild relatives, new breeding techniques and broadening the range of crop species that are cultivated can combine with ICM and IPM to develop the foundation for a reliable food supply. Examples of new developments in crop resilience are given in this section.

4.3.1 Drought tolerance

Unfavorable rainfall conditions are an important cause of maize yield gaps and losses in farming systems of Sub-Saharan Africa, as more than 90% of fields are rain-fed and not irrigated. The two main solutions on the market ([CIMMYT 2022](#)) are Drought Tolerance Maize for Africa (DTMA), which has enhanced ability to withstand periods of acute soil drying, and Water Efficient Maize for Africa (WEMA), which is adapted to growing under conditions with a low supply of water. Breeders, including some CropLife International members, developed these seed technologies to outperform common non-tolerant varieties under the severe to modest levels of water stress and shortage that routinely occur in dry climates and intermittently in wet climates. Scaling programs that have taken place for DTMA and WEMA in several major African growing areas have generated large increases of maize grain production and demonstrated crops' resilience to dry spells and low rainfall. Progress in access to meteorological and market information for farmers on the continent, together with local knowledge, offers powerful means for [supporting the decision](#) on when to invest in drought-tolerant maize. A [study in Zimbabwe](#) (Lunduka et al. 2017) found that smallholder farmers who changed to drought-tolerant varieties gained an extra income of US\$240/ha at no additional cost, equivalent to the price of more than nine months of food.

WEMA aims to develop drought-tolerant and insect-resistant maize using conventional breeding, marker-assisted breeding and genetic engineering. The insect resistance component is included to protect the yield "advantage" achieved through drought tolerance with protection from insects, which are more likely to inflict damage to crops during droughts. WEMA is a public-private partnership coordinated by the African Agricultural Technology Foundation involving research institutes from Kenya, Mozambique, South Africa, Tanzania and Uganda. The [WEMA varieties](#) are marketed royalty-free by local seed suppliers to smallholder farmers in South Africa and all farmers in sub-Saharan Africa. Royalties apply if the varieties are sold to commercial farmers.

At the research level, targeted changes in gene expression in tobacco resulted in up to 25% improvement in water use efficiency. [Research is progressing](#) on other commodity crops, including rice and wheat, and traditional crops, including sorghum, yam, cowpea and bananas. Cotton is also a [target for research](#) given its need for large amounts of water during its growing season.

4.3.2 Salt tolerance

Rising sea levels due to the changing world climate are altering the salinity of coastal waterways and soils, especially in Southeast Asia. These soils are excellent at holding water, making them ideal for rice paddies. A new generation of advanced seed hybrids is being developed to adapt to these higher salt levels because salt-water prevents the roots of rice seedlings from developing properly, which reduces crop yield. [Arize® rice hybrids](#) are less susceptible to diseases and abiotic stresses and tolerate a higher salt content in water far better than conventional varieties. They are now available in countries in Southeast Asia and Africa, as well as India.

4.4. Conclusion

The potential to enhance a crop's natural tolerance of pests and diseases and resilience to other stresses can reduce the need for agronomic practices that may adversely affect pollinators.

Development studies, regulatory trials and commercial use have demonstrated that transgenic crops that manufacture Cry proteins equivalent to those produced naturally by strains of *Bacillus thuringiensis* have no or negligible impact on pollinators or other non-target arthropods. Their use has demonstrably and considerably reduced the need for insecticide applications, thus lowering the potential of crops to affect populations of domestic and wild bees and other pollinators. Through this benefit the crops contribute to IPM.

The increasing knowledge about and use of biostimulants has the potential to modify the natural defense mechanisms of crops to increase their tolerance of insect pests to support IPM programs. Such products are among the contributions that CropLife International members make to minimizing the impacts of agriculture on pollinators and wider biodiversity and developing sustainable agriculture.

5. Ecosystem & Landscape Scale Action

CropLife International and its members demonstrate to farmers and other stakeholders that there are feasible practices for improving agricultural and broader ecosystems and the landscape. They cooperate with the public sector, non-governmental organizations and other stakeholders to identify and promote best practices, inspire farmers and propose best practices to policy makers.



5.1. Improving pollination to improve crop yields

Insect pollinators play a fundamental role in the production of many fruits, vegetables and field crops and numerous studies have valued insect pollination as an ecosystem service for agricultural food production at both global and national scales. In general, the available data indicate that pollination stability will increase in landscapes with a diverse and abundant pollinator community. However, the positive pollination effect on crop yield can be reduced or hidden when other factors affecting crop yield, such as soil nutrients, micro-climate, water, pest or disease status are suboptimal ([Klein et al. 2006](#)). Agricultural land use is not always expected to reduce pollination services. Some wild bees may benefit from agriculture, such as ground-nesting bees that use disturbed areas for nesting. Pollinators may benefit from pollen-rich crop fields, such as oilseed rape, or from ecosystems in which agricultural areas provide a greater diversity, continuity or abundance of floral resources than original habitat types (e.g., [Winfree et al. 2007](#)).

A meta-analysis of the data on more than 40 crops grown in 600 fields across the populated continents found that wild pollinators were twice as effective as honeybees for a range of crops to produce seeds and fruit, including oilseed rape, coffee, onions, almonds, tomatoes and strawberries ([Garibaldi et al. 2013](#)). Healthy pollination can improve quality as well as yield, as seen in apples ([Garratt et al. 2013](#)).

The spatial scale of measurement of biodiversity benefits, i.e., transect, field or farm level, and controlling for yield loss can drastically change the evaluation of biodiversity benefits of on-field (organic farming) vs off-field (flower strips) schemes. Comparing data at the transect level may lead to misleading conclusions because flower strips, which comprise only 5% of conventional fields, support fewer bees than large organic fields. However, a 50% cereal yield loss of organic farming can be considered as equivalent to yield levels of 50 ha of conventional plus 50 ha of flower strips. This would promote 3.5 times more bees than 100 ha of organic farming. A balanced understanding of the ecological and economic effects and effectiveness of biodiversity measures should consider the various scales of the evaluation ([Batáry & Tscharrntke 2022](#)). Most studies have not considered these factors, which may account for results that suggest greater bee, hoverfly and butterfly diversity in areas where organic production is practiced than in areas where it is not.

Pollinators also appear to be important in reducing the variability of yield. A recently published meta-analysis combined variability information from 215 experimental comparisons between animal- (primarily insect) pollinated and wind- or self-pollinated plants in apple, oilseed rape and fava bean ([Bishop, Garratt & Nakagawa 2022](#)). Animal pollination increased yield stability by an average of 32% per unit of yield at between-flower, -plant, -plot and -field scales. Evidence suggests this is because yield benefits of [animal pollination](#) become progressively constrained closer to the maximum potential yield in each context, causing clustering. The increase in yield stability with animal pollination is greatest when yield benefits of animal pollination are greatest, indicating that managing crop pollination to increase yield also increases yield stability.

Research projects undertaken by CropLife International members have applied a range of management techniques that expand and support many of the conclusions from these and other literature sources.

Box 3. IPM CASE STUDIES

IPM in intense pear cultivation in Belgium

IPM was extended into Integrated Pest and Pollinator Management (IPPM) in a [study in intensive pear culture](#) in Belgium ([Belien et al. 2021](#)). The four-year study examined the impact of IPPM elements (i.e., mixed hedgerow nesting boxes for mason bees, *Osmia* spp.) in an intensively managed pear orchard to demonstrate their impact in modern commercial fruit cultivation. The publication reports full application details of the chemical products used over the years and provides an extensive overview of the insects found and their role as pests, beneficials or neither. The outcomes of visual observations during transect walks and molecular analysis of pollen collected by mason bees showed the importance of additional floral resources for the presence of mason bees and other pollinating insects in the orchard environment.

Assessments of the quality of the pears indicated that insect-mediated pollination had a significant positive impact, with a tendency for higher quality pears in the close vicinity of *Osmia* nesting boxes. The pear orchard demonstrated the importance of an adjacent mixed hedgerow as a habitat for beneficial arthropods to enhance integrated pest control. This scientific approach to a practical demonstration is expected to support the acceptance and adoption of IPPM principles in commercial intensive pear production cultivation.

Madhu Sandesh project in India

CropLife India partnered with the Indian Council of Agricultural Research (ICAR) and one of its extension facilities, the Agricultural Development Trust (KVK) Baramati, in a pilot project called "[Madhu Sandesh](#)" ("honeyed message" in the Marathi language). Subsidized beehive rentals and training in both IPM and the responsible use of crop protection products were provided to pomegranate growers and onion seed producers to improve crops by promoting awareness and utilization of pollination services as well as good stewardship.

Many farmers who are dependent on pollinators for crop production do not fully realize the benefits of pollinators. Through this project, CropLife India promoted a holistic understanding of the need for crop protection products to co-exist with the environment and incentivized farmers to use these products responsibly. The project made pollination services available to farmers planting pollination-dependent crops by establishing an apiary and starting a hive rental program with crop-specific training at one of India's leading farmer institutes. It also promoted the tangible benefits of pollination, IPM and responsible use to the broader farming community.

Pomegranate farmers who rented beehives saw their yield increase by 35%, while the training they received helped them reduce inputs, resulting in higher margins and potential environmental benefits. A higher quality crop with more even maturation was reported by 90% of the farmers. As

a result, the net income of pomegranate farmers increased by 42%. Onion seed producers in the project saw an average yield increase of 17% and their income improved by more than 18%.

An impact assessment found that farmers involved in Madhu Sandesh had better knowledge of pollinator benefits and of IPM and responsible use. They were also more willing to rent beehives and pay for protective equipment.

Chanthaburi Pollinator Project in Thailand

The [Chanthaburi Pollinator Project](#) in Thailand combined a beehive rental program with training on the responsible use of pesticides to selected farmers in the province of Chanthaburi. Farmers in the project increased average yields by 19.5% and 27.1% for rambutan and longan, respectively, compared to farmers who did not rent hives.

Kiwi fruit in China

The kiwi fruit orchards of China's Sichuan province used to be pollinated by hand because the pollen from female kiwi flowers is not very attractive to bees. However, kiwi plants pollinated by honeybees produce higher yields and better quality fruit that has more juice and seeds ([Howpage, Spooner Hart & Vithanage 2001](#)).

Working in partnership with the Institute of Apiculture Research (IAR) at the Chinese Academy of Agricultural Sciences in Beijing, bees were introduced to the kiwi orchards, raising yields and producing better quality fruits. [Tailored protocols](#) for the kiwi orchards were integrated with training, stewardship and the use of the right Syngenta protocols and products.

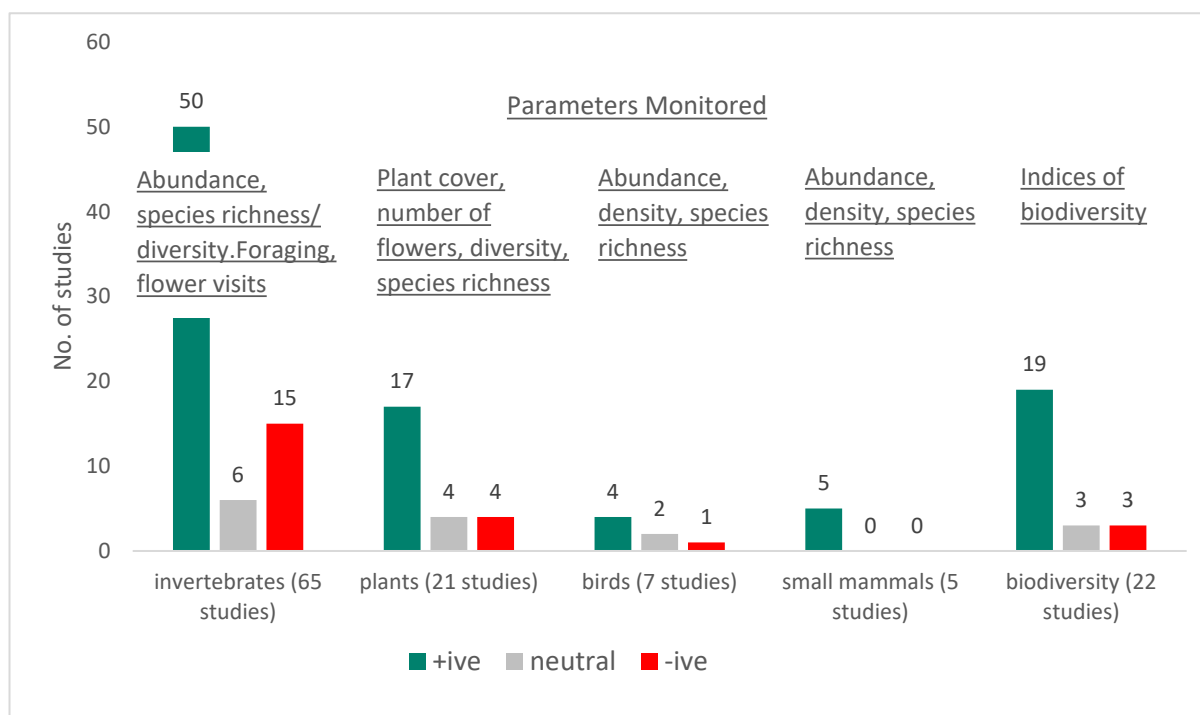
5.2. Increasing pollinator abundance and diversity

Several CropLife International member companies have been active increasing pollinator abundance and diversity, using their own work and published research to develop programs for the field.

The State of the World's Biodiversity for Food and Agriculture ([FAO 2019](#)) provides an overview of pollinator management in agriculture systems in section 5.6.7. The abundance and composition of bee communities on farms may be sensitive to the availability of nesting resources. Most wild bees nest in the ground, in plant stems or in various kinds of cavities. Ensuring that a range of nesting sites, either natural or artificial, are available will encourage wild bees to move into an area and remain there. For example, in the case of ground-nesting bees, bare patches of soil and minimal tilling activity will encourage nesting. Ground-nesting bee species normally place their brood cells in the top 30 cm of the soil, which means that they may benefit from no-till systems or tilling at the appropriate timing and depth. Highly diverse plant communities can provide ideal foraging resources for pollinators. Enhancing plant diversity by intercropping and leaving weedy herbaceous ground cover can increase the availability of nectar and pollen resources. Hedgerows can supply nesting resources for many pollinators in the form of dry branches, stems, logs or exposed soil banks or other patches of bare ground. Generally, increasing the heterogeneity of any landscape increases the potential for pollinator richness.

A meta-review of 80 studies on the effects of flowering strips on invertebrates, including pollinators, and other wildlife showed a clear benefit from their implementation ([Alix et al. 2013](#)). Benefits to one or more wildlife groups were shown by 64 of the studies. The summarized data are shown in Fig. 5. These benefits are consistent with the results of research by CropLife International members reported in sections 5.2.2 and 5.2.3 of this report.

Fig. 5. Outcome of 80 studies on the effects of flowering strips on wildlife and biodiversity (Adapted from Alix et al. 2013)



Note that numbers do not add up as effects could be positive, negative or neutral on different species or groups in the same study.

CropLife International member companies have researched and promoted the methods referenced in the State of the World's Biodiversity for Food and Agriculture. Since they are not large-scale land managers, they cannot work alone to achieve the necessary scale to have significant impact. The following section describes some of the research, the enhancement methods and some of the partnerships and collaborations.

5.2.1 Promoting biodiversity in apple, potato, cabbage and leeks

A Bayer CropScience Food Chain project investigated the effects of perennial flowering strips on the local biodiversity of an apple orchard and the effects of annual flowering strips on local biodiversity in potatoes, cabbages and leeks.

Apples

The perennial flowering strips in apples at a site in Saxony [developed a species-rich fauna](#) of wild bees, wasps, butterflies, hoverflies and flies that are parasitic to caterpillars and fruit flies, including endangered species from the Red List. The flowering strips had a strongly positive effect for bumblebees and their parasites. The number of species and individuals of bumble bees increased over time and parasitic species occurred for which there previously had been insufficiently large host populations. Many of the detected species were beneficial for apple cultivation and the parasitization of pest species was greater in the presence of wildflower strips.

Potatoes

Annual flowering strips were created in 2014 and 2015 next to potato fields in southern Lower Saxony. The population of wild bees, butterflies and hoverflies was relatively impoverished and there were only a few fairly common generalist species. This reflects the location of the trial in the agricultural landscape remote from biodiverse areas and illustrates the importance of promoting near-natural habitats within the agricultural landscape. However, insect species with a short generation time were able to use the flowering strips for reproduction. The insect biomass produced

in this way is of [immense importance for the local food chain](#) and has a direct impact on the reproductive success of endangered birds.

Cabbages

A [similar trial](#) was carried out from 2012 to 2015 with mixed flowering strips and pure cornflower strips next to or within cabbage fields near Köngen (Baden-Württemberg). The results were like those from the potato trial, with an impoverished fauna of wild bees, butterflies and hoverflies due to the relatively remote location of the local agricultural landscape and absence of near-natural landscapes. As in the potato trial, insect species with a short generation time were able to use the flowering strips for reproduction. In contrast, beneficial insects were species-rich, such as true wasps and wasps that parasitize caterpillar and aphid pests of cabbages. The proven supply of pollen and nectar to these species by the flowering strips increases their lifespan, their activity, their reproductive capacity and thus ultimately their parasitization performance.

Leeks

In leeks, the fauna was [severely impoverished](#). There were few relatively undemanding and common species of wild bees, butterflies and hoverflies. As in the cabbage and potato studies, other insect species with a short generation time were able to successfully use the flowering strips for reproduction.

In all four studies, the introduction of wildflower strips encouraged the presence of pollinator species and other insects in the crop. In apples, the perennial wildflowers not only encouraged pollinators but also parasitoids of apple pests, which have a potential effect on the yield and quality of the crop. The vegetable crops were sited away from near-natural habitats and were relatively poor in the abundance and number of species of pollinators, but insects with short life cycles had sufficient time to reproduce in the wildflower strips. In cabbages, the populations and success of beneficial insects, including parasitoids, were improved by the wildflower strips.

5.2.2 Enhancing biodiversity of farmland through supporting habitats for pollinators

The results of Operation Pollinator in Agricultural Landscapes were reported in the "[Report on CropLife International Members' Activities Relating to Biodiversity and Climate](#)" (Garnett 2021). Two additional projects under the Operation Pollinator umbrella are reported here.

Partnership with Delta F.A.R.M.

While farm landscapes often lack the diversity and abundance of flowers that pollinators require, research has shown this trend can be reversed. To support pollinator communities within agricultural land, wildflower field margins provide a range of foraging habitats, with diverse pollen- and nectar-rich nutrition, as well as adequate nesting and breeding areas.

Delta F.A.R.M. is an association of growers and landowners in northwest Mississippi dedicated to conserving and enhancing wildlife and natural resources. This is the first time that Operation Pollinator in the United States has included habitat creation alongside farmland. Independent monitoring shows that habitat creation for pollinators can increase bumblebee numbers by up to 600% in specific instances, butterfly numbers by 12-fold and other insects more than 10-fold within three years. As pollinator species and their needs vary from country to country, wildflower seed mixes are designed to create habitats to suit local conditions and native species.

As part of the [partnership](#), Syngenta will provide Delta F.A.R.M. with grower training, choice of seed mixes and agronomic support for selected local farmers in northwest Mississippi. Delta F.A.R.M. will assess the effectiveness of the additional foraging habitat and nesting sites on marginal land or non-productive farm areas. In addition to restoring populations of pollinating insects, these wildflower margins will create habitats for small mammals and farmland birds. With careful site planning and management, these practices help reduce soil erosion and protect water resources.

Flower margins increase insect populations in agricultural environments

A [study](#) was carried out with different crops, including fruit trees, horticultural crops, vineyards and cereals, over three years on ten agricultural plots in Spain and Portugal. The study was a cooperation between Operation Pollinator, the Higher Council for Scientific Research (CSIC), the Higher Technical School of Agricultural Engineers of Madrid and the Murcian Institute of Agricultural Development (IMIDA). The plots were planted with herbaceous species selected for each climatic zone and known for prolific production of pollen and nectar to attract a variety of pollinating and beneficial. Insects were sampled from each planted flower margin and identified in the laboratory. They were classified as pollinators, beneficials or endemics. Over the three years there was a significant increase in the diversity of insects of all groups in the different crops due to the wildflower margins (Table 2).

Table 2: Increase in number of species over a three year period

Order	Examples	% increase over 3 years
Hymenoptera	bees, wasps, ants	170%
Lepidoptera	butterflies	96%
Coleoptera	beetles	115%
Diptera	flies	252%
Neuroptera	lacewings etc	66%
All species		130%

5.2.3 Multi-functional field margins

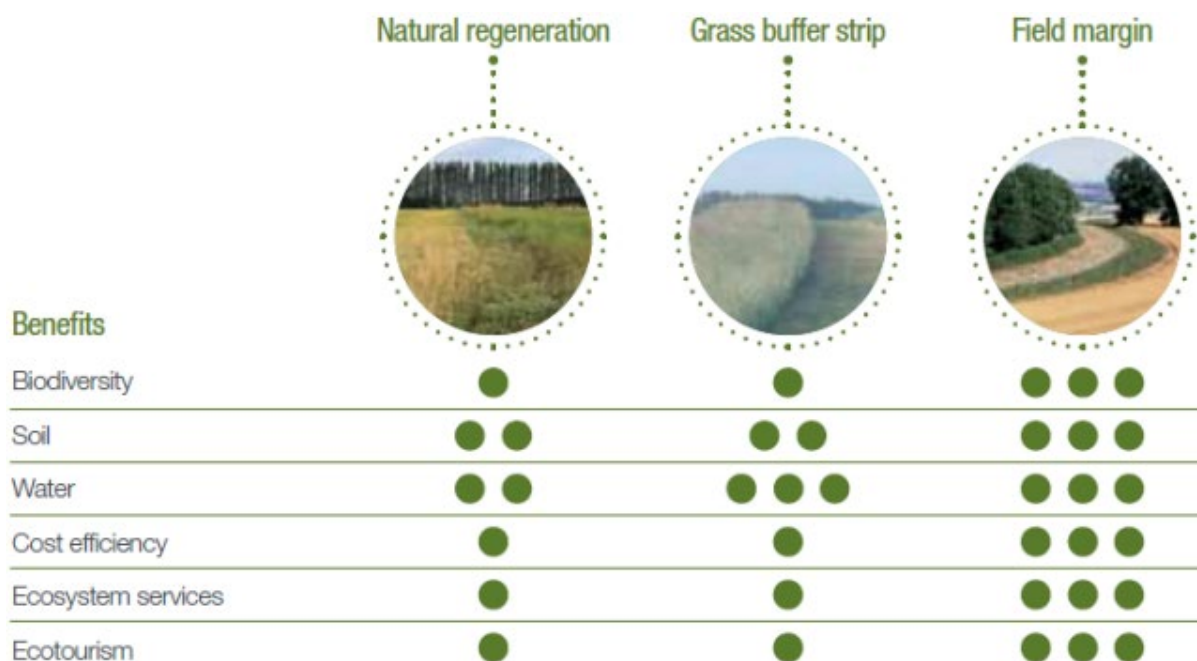
In 2018, Syngenta, together with Arcadis and Biodiversity International, developed a paper titled "[Multifunctional Field Margins: Assessing the benefits for nature, society and business.](#)" MFFMs include, but are not exclusively, pollinator enhancement schemes under the "Operation Pollinator" program described in 5.2.2. The objective is to encourage farmers to manage less productive farmland alongside fields and waterways, reintroduce local species, provide buffers for soil and water and connect wildlife habitats. This enables sustainable intensification on the more productive land.

The MFFM concept is designed to enhance Ecological Focus Areas (EFAs) in agricultural landscapes with high potential biodiversity impact. Management practices relate to a network of biotypes/habitats at farm scale and have benefits for the soil, water and climate as well as biodiversity. Proactive management of MFFMs [delivers multiple benefits](#) (Fig. 6, next page) to biodiversity by reintroducing local species, boosting numbers of pollinators and beneficial insects, increasing earthworm populations and activity and providing food sources for birds and small mammals. Water and soil management were also enhanced through reduced nutrient and pesticide run-off, improved use of water by crops, decreased flooding, preventing erosion/soil loss, preventing sediment from contaminating surface water and increasing climate change resilience.

Field margins can provide benefits for ecosystems in intensive arable areas as part of agri-environmental programs aimed at preserving or restoring habitats for specific animals and plants or increasing biodiversity in general. However, intensive agricultural regions have the lowest share of implemented agri-environmental programs. The key to achieving biodiversity goals is increasing the participation of farmers in these programs. To understand the factors favoring the implementation of MFFMs, 653 farmers in different parts of Germany were asked to indicate the key aspects that needed to be addressed in the design of their ideal field margin and their attitudes towards agri-environmental programs. Awareness of the impact of their activities and positive attitudes lead to a [more environmentally conscious management](#) of field margins.

The following sections review some practical applications of MFFMs.

Fig. 6. Relative benefits of different MFFM interventions in field management
(Source: Syngenta)



5.2.4 Ecological enhancement for pollinator diversity

Wildflower areas and strips of diverse composition

The Report on CropLife International Members' Activities Relating to Biodiversity and Climate (2021) shared results from a study on improving pollinator species richness in intensively cultivated agricultural areas in Baden-Württemberg in the Upper Rhine valley in Germany. A peer reviewed paper on [this study](#) (Buhk et al. 2018) was omitted from that report. In summary, the results of the ecological enhancement measures between 2011 and 2016 show that providing a continuous supply of wildflower areas and strips, including a combination of annual, winter-hardy and perennial wildflower mixes, on 10% of the arable land can make a valuable contribution to supporting the numbers of species and individual wild bees and butterflies and their species diversity. Notable increases in the number of wild bee species and individual bees were recorded in the first years of the project.

The number of species increased in both study areas. In Rheinmünster, the average number of bee specimens was some 90 times higher in 2016 than at the start of the project and at Dettenheim it was 23 times higher than in 2010. The number of species, and especially numbers of individual insects, can be subject to considerable natural fluctuations between years due to different weather conditions and other parameters. The presence of endangered wild bee species in the wildflower areas of the experimental plots is particularly significant. The maximum number of species recorded at the Dettenheim site was a total of 28 in 2016. The highest number recorded in Rheinmünster was 26 species in 2015. The combination of annual, winter-hardy and perennial plants and the composition of the wildflower mixes, which were tailored to the needs of the local wild bee fauna since 2013, had a positive impact on species numbers.

The increase in the numbers of butterfly species and specimens was less pronounced than for wild bees. At Dettenheim, a significant increase in species numbers was observed in 2012 and the highest

number to date was in 2016. In Rheinmünster, the numbers of species rose continuously to the highest in 2015. Endangered species of butterflies were also recorded.

The bee banks proved to be less successful because they were used as nest sites only when the vegetation was cleared on a regular basis.

Overall, the studies show that targeted ecological enhancement of intensively farmed landscapes with wildflower areas and strips of diverse composition—using different sowing strategies—can greatly increase the species diversity of pollinators.

Introducing nesting sites for wild bees

Creating flowering areas to promote wild bees is now a well-established practice that should be complemented by the provision of specific nesting sites. In spring 2017, various nesting aids were installed in four orchards in the growing area near Dohna, Saxony (Germany). They included mounds of earth with steep walls for species nesting in the soil, sandy areas for sand specialists and insect hotels of different constructions for species nesting above ground in deadwood, especially for the mason bees, which are particularly important as fruit tree pollinators.

Wild bees and wasps were monitored as having similar same nesting site requirements. The [survey](#) was supplemented by monitoring specific antagonists to bees and aculeate wasps, such as parasitoids, which allowed a more differentiated assessment of the population structure of the host species.

The recording of the 17 selected insect families revealed a total of 243 species from 14 families; no species could be found from three families. The evaluation of the insect populations ranged from “disturbed” to “extinct” since none of the faunas was categorized as undisturbed. For the agricultural landscape, however, this represents a positive result compared to intensive arable crops. In particular, the fauna of wild bees is still largely intact in its species composition, although clearly disturbed in terms of the number of individuals.

All tested nesting aids were used by wild bees and wasps to create nests. Though the report details the individual species found, in summary, 10 nest-building species could be detected as colonizers in the sandy areas, hotels were used by a total of 22 nest-building species and 9 antagonistic species and the mounds and steep walls were inhabited by 39 species, including 24 (25%) of the nest-building wild bee species detected in the orchards.

The study demonstrated that the mounds of earth and steep walls were the best way to promote wild bees and [wasps](#) in fruit growing. They represent a very significant improvement in the number of nesting sites. Insect hotels play a crucial role in promoting mason bees as pollinators in fruit growing. The sandy areas are the least suitable, but they provide a nesting substrate that is otherwise not available in the orchards.

Operation Pollinator multi-functional landscapes in the UK

The “Green Headland” project started in 2016 and has investigated ecosystem services provided by seed mixture plants on headlands, consequent effects on biodiversity and the crop and incorporation into IPM programs. The project is now extending into nutrient and carbon capture.

Environmental seed mixtures have been sown on 4,000 ha to support 134,000 ha of farmland. It is noted that these headlands enrich rather than create habitats. Of the numerous species of insects found on the green headlands, 99 species were found to play some part in pollination and over 140 were known predators or parasitoids of crop pests at some point in their lifecycle. Green headlands seeded with wildflowers and grass headlands were found to be somewhat complementary. There were more pollinators in the former and more beetles and predators in the latter; the green headlands had more individuals while there were more species in the grass headlands.

Since penetration of the insects into the cropped field declined rapidly within 25 meters of the headland, trials were initiated with strips of headland seed mixtures seeded in the field. These

resulted in increased numbers of insects in the field. This [finding](#) can help promote IPM by improving the ingress of predators and parasitoids into the crop.

Monarch butterflies

Monarch butterflies (*Danaus plexippus*) draw particular attention as a flagship species in North America. They are important pollinators for many types of wildflowers while feeding on nectar. Loss of milkweed and other nectar plants along the monarch migration route reduces the resilience of the monarch population to predators, parasites, pathogens and weather events. Environmental stressors and habitat loss have caused declines in monarch numbers since the 1990s. This has stimulated numerous actions to protect, conserve and restore monarchs during migration and the breeding season. The participation of CropLife International member companies in some of these projects was covered in the Report on CropLife International Members' Activities Relating to Biodiversity and Climate. (2021).

Additional projects include:

- [Farmers for Monarchs](#) is a collaboration consisting of national organizations representing farmers, rancher, and landowners; businesses working along the agricultural supply chain; researchers and academic institutions; federal and state entities; and conservation organizations. Farmers for Monarchs is committed to making progress through voluntary efforts to restore, enhance, and protect monarch habitat while maintaining productive agricultural operations. It is supported by five CropLife International member companies.
- Milkweed is critical to monarchs as it is the only plant on which they will lay their eggs, and it provides food for their larvae. To support milkweed and preserve biodiversity, the [Living Acres #MonarchChallenge](#) was launched in 2015, providing farmers with practical best practices for establishing and maintaining milkweed plants on land not reserved for crops, as well as play areas of golf courses and other agricultural areas. More than 35,000 milkweed stems have been donated by the program and over 5,000 farmers have learned about their role in protecting biodiversity.
- Sharing the Butterfly Experience partners Bayer Hawaii for an annual [Monarch Butterfly Kit giveaway](#) to raise awareness about the importance of monarch butterflies in agriculture.
- By working with students, the [Corteva Agriscience Grows Pollinator Habitat Program](#) planted nearly 90 acres of habitat, primarily along monarch migration routes, in collaboration with the National 4-H Council and Pheasants Forever. New critical habitat for grassland birds, monarch butterflies and other pollinators will continue to be created while serving as outdoor educational spaces for students and employees.

A [recent study](#) investigated the monarch breeding population in North America by compiling over 135,000 monarch observations between 1993 and 2018 from the [North American Butterfly Association](#)'s annual butterfly count. It examined spatiotemporal patterns and potential drivers of adult monarch relative abundance trends across the entire breeding range in eastern and western North America. Researchers found no evidence of a net downward trend in summer monarch abundance. Declines were indicated particularly the US Northeast and parts of the Midwest. Numbers in other areas, notably the US Southeast and Northwest, were unchanged or increasing, yielding a slightly positive overall trend across the species range. Negative impacts of weed control appeared to be counterbalanced by positive effects of annual temperature, particularly in the US Midwest. Population growth in summer may be compensating for losses during the winter and changing environmental variables offset mortality and reproduction. The authors suggest that density-dependent reproductive compensation when lower numbers arrive each spring maintains a relatively stable breeding population.

5.3. Landscape connectivity

The Convention on Migratory Species (CMS) defines ecological connectivity as “the unimpeded movement of species and the flow of natural processes that sustain life on Earth” (CMS 2020). Ecosystems cannot function properly without being connected, and without well-functioning ecosystems, biodiversity and other fundamentals of life are at risk. The disruption or absence of ecological connectivity occurs because of human-induced “fragmentation,” the breaking up of a habitat, ecosystem or land-use type into smaller and smaller parcels. The International Union for Conservation of Nature and Natural Resources (IUCN) publication “[Guidelines for conserving connectivity through ecological networks and corridor](#)” provides best available practices to reduce fragmentation and enhance connectivity (IUCN 2020).

Wildflower strips and other interventions at field level can make valuable local contributions to biodiversity. Connecting these at farm level has a greater impact, but connectivity at a landscape or regional level is necessary for the greatest potential to enhance biodiversity. The importance of this was assessed in “[Landscape Connectivity: A call to action](#)” featured in the “Report on CropLife International Members’ Activities Relating to Biodiversity and Climate” (Garnett 2021).

Box 4. Landscape Connectivity

Flower strip networks offer promising long-term effects on pollinator species richness in intensively cultivated agricultural areas

Intensively cultivated agricultural landscapes often suffer from substantial pollinator losses, which may be leading to a decrease in pollination services for crops and wild flowering plants.

Conservation measures that are easy to implement and accepted by farmers are needed to halt a further loss of pollinators in large areas under intensive agricultural management.

A [replicated long-term study](#) is reported involving networks of mostly perennial flower strips covering 10% of a conventionally managed agricultural landscape in southwestern Germany. A large variety of seed mixtures and temporal variation in seeding time ensured continuity of the flower-strips by using perennial seed mixtures.

These measures showed considerable success in the richness of wild bee and butterfly species over an observation period of 5 years. Overall species richness of bees and butterflies and the numbers of specialist bee species clearly increased in the ecological enhancement areas as compared to the control areas without ecological enhancement measures. A three- to five-fold increase in species richness was found after more than 2 years of enhancement of the areas with flower strips. Oligolectic bee species increased significantly only after the third year.

The increase in pollinator abundance suggests that these measures may be instrumental for the successful support of pollinators. This may be because the measures ensure the availability of a network of diverse habitats and foraging resources for pollinators throughout the year, as well as nesting sites for many species. The measures are applied in-field and are suitable for application in areas under intensive agriculture.

Biotope networking in Rommerskirchen – achieving more together

The [Biotope Networking initiative](#) in the Rommerskirchen area near Düsseldorf, Germany, aims to interlink and connect habitats at landscape level, beyond the individual farms. The project connects habitats that are being established with existing semi-natural structures and biodiversity hotspots in the landscape, such as waysides or uncultivated patches of land. The networking of food and nesting resources is important to promote the spread and conservation of many species.

Critical to [creating the network](#) is fostering communication among the farmers and involving the municipalities in the activities. This exchange between the participating farmers is promoted to

coordinate and optimize the implementation of measures and to achieve the best possible networking of the measures. The Rommerskirchen municipality supports the initiative with publicity.

Non-crop land – utility rights of way

Electricity transmission and gas and oil pipeline rights of way (ROW) can be managed using [Integrated Vegetation Management](#) (IVM) for pollinators with a two-zone system: a wire or pipe zone and a border zone. Selective herbicides or cutting are used to maintain the wire and pipe zones to develop a “prairie-type” habitat, while the border zone is managed for shrubs. This zone division creates native prairie and shrub communities to optimize pollinator and bird habitat. Mowing and cutting release greenhouse gases and encourage sprouting of trees and invasive plants, whose live root systems can damage gas pipes. When annual mowing is replaced with IVM, forbs germinate and provide pollinator food. Managing ROW with IVM develops them as pollinator and wildlife connectors and greenways. Integrated Vegetation Management Partners has a number of such projects; for example, working with Bayer to create extensive pollinator habitats.

Further practicalities

Although not study by a CropLife International member, [Marini et al.](#) (2022) confirmed the conclusion that to implement successful biodiversity conservation strategies, management should take place at landscape scale since most organisms have a high mobility and local farmers and citizens of the area should be involved. In this case, 16 olive growers in the municipality of Calci, Italy, were organized into a “farmer cluster” to define biodiversity objectives and reach a coherent landscape management plan. A farmer cluster is a community of farmers in the same region who share knowledge and support and motivate each other to improve biodiversity and the ecological health of their farms. Farmer clusters have become increasingly popular in the UK. The European [FRAMEwork project](#) aims to introduce farmer clusters to another eight European countries to scientifically evaluate their effectiveness. The project will also develop this concept further to deliver “advanced farmer slusters” in nine countries by providing a new level of technological support.

An example involving a CropLife International member is a new USDA-NRCS Regional Conservation Partnership Program (RCPP) project launched in August 2022. It aims to increase the capacity of agricultural land in California to support wild and managed pollinators. The [Pollinator Partnership](#) leads the collaboration, which includes the Almond Board of California, Bayer CropScience and the California Farm Bureau Federation. It plans to engage growers across the 10 counties in the project area. The project partners will use a GIS tool to guide practice implementation, including planting new pollinator habitat, expanding the use of IPM and prescribed grazing.

5.4 Ensuring healthy pollinators

Managed honeybees are considered livestock but also play an important role as pollinators. The health and nutritional condition of honeybee colonies (*Apis mellifera* L.) depends largely on management practices and is influenced by multiple factors. A [study](#) was set up in Santa Fe, an intensively cultivated area of Argentina, to identify the stressors that lead to the loss of honeybee health and the consequences on the colony’s productivity. Measurements were made of different aspects of management practices, hive productivity, clinical observations related to diseases, presence of sanitary gaps in the apiaries, colony strength, weather and infestation rates by *Varroa* mites. The information was collected from 53 apiaries over two seasons. The results show correlations of many of the management practices with health condition and honey yield. The amount of honey harvested was directly related to a beekeeper’s practices. The most important

factors affecting the productivity were nuclei preparation⁵, the number of combs in the brood chamber, a bee queen change, disinfecting beekeeping material and environmental stressors. The authors propose a holistic approach to improve bee health and increase the productivity of honeybees.

Varroa mites

Although the number of honeybee colonies has increased across the globe over the past 60 years, bee health issues remain a challenge. One of the main causes is a mite, [Varroa destructor](#). A bee colony in a mite-infested beehive typically collapses within three years if there is no human intervention. Besides the threat posed by the *Varroa* mite itself, the mites carry diseases, particularly viruses, which spread among bees during their social interaction in the hive and weaken the colony.

Finding solutions to combat this mite is difficult because, despite a number of promising ideas, it has not yet been possible to develop simple and long-lasting treatments. Various biological, physical, chemical and biotechnical options are available to combat the *Varroa* mite in the hive. By combining the few effective control measures with good beekeeping management practices (integrated apiculture), it is possible to reduce the harm caused by *Varroa* and to control the impact of this parasite. New technologies such as RNAi (RNA interference) show promise in highly specific control of *Varroa* (see 2.5.5).

6. Digital Farming & Precision Agriculture

Digital farming and precision agriculture cover a wide range of activities from farm to consumer, as [summarized in a report](#) by the Oliver Wyman company for the World Government Summit in 2018.

At a practical farm level, four primary technologies are proposed to [define precision agriculture](#): imagery and sensors, robotics and automation, digitalization and big data, and biologicals. The first three technologies work closely together and are enabled by adequate connectivity, as well as improvements in edge computing⁶ and the cloud. The report assesses the investment of CropLife International member companies in a range of digital and precision farming technologies. The member companies often partner with other technology-based businesses to develop tools that can be taken up at a large scale because they make sense to farmers.

Precision agriculture provides the opportunity to integrate many of the best practices and techniques to support pollinators discussed in this report. These developments are already making an impact on the adoption of sustainable and pollinator-friendly practices, sometimes directly. Two examples of impact are defining the optimum areas and connectivity for pollinator and other biodiversity (e.g., 5.3) and improving pest monitoring and product application (e.g., 5.2, 6.2).

6.1 Precision farming and drones to enhance the application of crop protection products

Ulrich Adam, the secretary general of CEMA, the European association of agricultural equipment manufacturers based in Brussels, prepared a [short article](#), which is summarized here, on precision agriculture and drones for crop protection products for CropLife International.

Around 80% of new farm equipment sold at the time had some form of precision farming component to allow farmers “to do the right thing in the right place at right time with the right amount.” Applying crop protection products with precision equipment benefits crops through more

⁵ Nuclei are small colonies created by splitting large colonies. They are used for several purposes, including caring for spare queens, raising replacement queens and controlling or preventing swarming.

⁶ Edge computing is a distributed computing paradigm that brings computation and data storage to the sources of data. This is expected to improve response times and save bandwidth. It is an architecture rather than a specific technology. [Edge computing - Wikipedia](#)

targeted input applications both in place (only where necessary), time (to optimize the effect or avoid contact with non-target organisms, including pollinators and beneficial insects) and the environment (using the exact dose and, potentially, fewer inputs). It also benefits the farmer by reducing input costs and workload while improving safety, comfort and net profit. For example, farms in Germany using advanced digital, precision technology have reported higher yields per hectare with reduced herbicide and diesel use by 10% and 20%, respectively.

Digital connectivity enables smart farm equipment to connect data from different sources and put them into an optimized order by consulting, for instance, field-specific information from cloud-based farm management software. Sensors and remote sensing collect data from a distance to evaluate soil and crop health, such as the presence of pests or diseases.

Drones are used mainly for capturing images and providing data, allowing for permanent monitoring of a crop from planting to harvest. The data is processed in the cloud and translated into useful information, such as plant health and pest infestations. This helps farmers react faster to threats such as insects and fungi by saving time for scouting their crops and allows the application of variable doses of pesticides in real time. Drones can monitor any type of crop in any geographical area under any weather condition. The images are higher quality and more precise than those from satellites. It is expected that the use of agricultural drones will grow significantly in the coming years as they offer a wide range of applications that improve precision farming. They also can potentially replace human application of crop protection products, minimizing farmer exposure.

In addition to determining pest outbreaks, drones can be used to apply crop protection products. Although they are not allowed to spray pesticides in Europe, drones can be used to distribute biological agents like wasp eggs. The application of pesticides by drones is promising for use by smallholder farmers who often rely on backpack sprayers. In Japan, for example, drones are used for aerial spraying. Drones can scan the ground, spraying in real time for even coverage. The result is that aerial spraying can be five times faster with drones than traditional machinery, while using lower volumes of spray.

As indicated in Section 5.1, CropLife International member companies are actively involved in developing these technologies, as shown in Episodes 8 to 10 of "[Innovations in Crop Protection](#)." Examples from CropLife member companies include:

- Using predictive modelling based on real-time data from in-field sensors, the [Arc™ farm intelligence app](#) enables growers and advisers to view emerging hotspots and target crop protection products precisely where and when they are needed for more sustainable and cost-effective control. Data is gathered from sensors, drones or aerial imagery, then analyzed to optimize and forecast insect management. The service is currently available in 16 countries (June 2022).
- [FieldView™](#) enables growers to collect, store and analyze data on a single platform. Inputs to crops can be optimized with seed rates, fertility and crop protection applied according to need within a field and across the farm. [Digital tools to analyze crop performance and maximize return \(climate.com\)](#)

6.2 Precision placed field borders and pollinator habitats

A [new project](#) funded by the Regional Conservation Partnership Program (RCPP) in Missouri will highlight the interdependence of agriculture and conservation by providing cost-share opportunities for producers to use precision data to establish field borders, streambank buffers or pollinator habitat on their farms. The project is a multi-member partnership, including Bayer, to enhance water and soil health and provide essential habitat for pollinators and grassland bird species on agricultural land. It also helps producers avoid the need for natural resource regulatory requirements.

Through this program, a conservation planner will use yield data, soil data and farm budgets to highlight areas on farms that either are not profitable or cause logistical challenges in farming. Once these areas are identified, planners can match these targeted areas to habitat practices that best fit the farm operation and production goals. Funding opportunities include federal and state dollars with incentive payments from private industry partners.

6.3 Automation of insect sampling and identification

Monitoring pests in the field allows variations of infection levels of pests and diseases to be identified, supporting the implementation of IPM. Conventional sampling techniques are time consuming and identifying large numbers of individual insects can take experts weeks or months. This limits the ability to check the impact of pests and of pollinator and biodiversity enhancement measures. [Automation of this process](#) can reduce cost and increase the accuracy and scalability the analysis. Automatic image recognition allows the determination of the number of insects visiting a crop or non-crop area. It can also identify species and determine the net biomass. An [automated soil-insect sensor](#) allows a live feed of insects in pit-fall traps to provide a measure of soil health.