The Eufruit Project: reduction of pesticide residues on fruit and in the environment

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THE EUFRUIT PROJECT

REDUCTION OF PESTICIDE RESIDUES ON FRUIT AND IN THE ENVIRONMENT

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STATE OF THE ART ON INTEGRATED APPLE PRODUCTION IN RESEARCH

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> EUFRIN-EUFRUIT JOINT MEETING : FOCUS ON RESEARCH TO REDUCE THE USE OF PESTICIDES AND LIMIT RESIDUES ON FRUITS AND ENVIRONMENT

EUFRUIT is a Horizon 2020 European funded project, aiming to facilitate access to knowledge and to disseminate existing research and innovation potential for the benefit of the fresh produce sector and consumers. The consortium was created by the members of the informal network called EUFRIN (European Fruit Research Institutes Network), composed of university departments and research institutes for temperate fruit crops, and by representative organisations of the fresh fruit sector.

The project is divided into 4 thematic Work Packages (WP): new fruit cultivars (WP2), pesticides residues (WP3), fruit quality (WP4), and sustainable production (WP5). This document gives an overview of the state of the art from 14 European institutes for on-going research and practices to reduce the use of pesticides, and to limit residues on fruits and the risk to the environment (WP3).

Apple production is the main case study with examples on several topics such as: alternatives (bio-control agents, natural products, semio-chemicals, attractants) to chemical pesticides in orchards and postharvest, physical barriers, functional biodiversity, chemical strategies to avoid residues, innovative spray application techniques, and a system approach where different techniques are combined to reduce pesticide input.

FRUIT PRODUCTION AND PESTICIDE RESIDUES

Pesticides have always been used extensively in fruit production – right from the start of the twentieth century. Trees are long-lived and stationary, making crop rotation impossible, and enabling a wide range of pests and diseases to be continually present, and ready to strike when environmental conditions are right. Also, in the case of fruit, 'looks do matter'; consumers prefer blemish-free fruit, and strict rules apply to the amount of damage accepted on the fruit. Pesticides have enabled control of these diseases and pests and the result is cheap, diverse, abundant and year-round available fruit, which enables healthier lifestyles for the vast majority of consumers.

EUFRUIT, A PARTNERSHIP BETWEEN THE FRESH PRODUCE SUPPLY CHAIN AND RESEARCH

The fresh fruit and vegetable sector is at the forefront of adopting sustainable production methods to cope with societal and environmental challenges and respond to evolving consumers' expectations for consuming healthy and safe fresh produce. To adjust production methods and reduce pesticide dependency, the fresh produce sector is working closely together with researchers to engage in new production methods in order to prevent pests and diseases that might occur, and to be a proactive player in protecting soil, water and biodiversity.

This partnership between the fresh produce supply chain and the researchers is highly relevant for engaging new cultural practices; reducing pesticide dependency and moving towards new biological control systems in the orchards.

The EUFRUIT project is an important milestone for growers and the supply chain to share best practices and knowledge. It is a catalyst to stimulate growers to test and engage in alternative and innovative production models which contribute to more sustainable production methods, minimizing residues on fruit and vegetables supplied to European consumers.

With the scoping of the various initiatives undertaken across Europe, the European growers are best positioned to cope with the stringent EU regulations on plant protection products and maximum residue limits. They can even go beyond this in order to meet additional customers' requirements, to best match the consumer's aspiration for safe, fresh and natural fresh produce.

Pesticide usage during fruit development carries the risk of leaving residues on the fruit that remain traceable after harvest. Strict rules apply as to how close to harvest different pesticides may be used. This ensures that the amount of residue on the fruit does not surpass the maximum residue level (MRL). If fruit contains residues in concentrations higher than the MRL, the fruit is banned from sale. In reality, most fruit (70-90%) contain less than 10% of the allowed MRL – as documented by National Health Safety Reports or private institutions such as the QS Qualität und Sicherheit GmbH, Bonn, Germany (QS, 2015, 2016, 2018). The MRL is set with a safety margin, so that the acceptable Daily intake (ADI) is not exceeded, ensuring that the most vulnerable consumer can consume the produce on a daily basis without health issues. Pesticides are among the most well-examined compounds and both acute as well as long-term toxicity is evaluated. In general, the levels of residue found in fruit are regarded as unproblematic and of no consequence to human health by the National Institutes in charge of overseeing residues in foodstuff (Andersen 2016). A few recent studies aimed at estimating the health consequence of consumer intake of pesticide residues also point to negligible effects. A Danish study estimates the health effect of residue intake to be equivalent to a glass of wine every 6 years (Larsson et al. 2018). An American study also draws attention to the often-overlooked fact that media focus on pesticide residues may lead to reduced intake of fruit and vegetables, counteracting advice given by WHO to increase consumption (Reiss et al. 2012).

However, pesticide residues will remain a constant worry for media as well as consumer and environmental organisations. Apples and peaches are often included on 'dirty dozen lists' for fruits and vegetables that contain the most residues which are regularly featured in the news media (https://www.healthline.com/nutrition/dirty-dozen-foods). In the future, more sensitive analytical methods are bound to reveal more residues than is the case today. Reducing pesticide residues have also become a competitive tool for supermarkets forcing growers to take action. Fruit growers, as well as the scientific community supporting the growers therefore need to address these issues and strive to develop alternatives to the use of pesticides in fruit production. ■

> SUSTAINABLE FRUIT PRODUCTION TO DEAL WITH SOCIETAL AND ENVIRONMENTAL CHALLENGES

FRANZISKA ZAVAGLI,
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ALTERNATIVE PRODUCTS TO CHEMICAL PESTICIDES

USE OF BIOCONTROL AGENTS AGAINST PESTS AND DISEASES

Biological control is based on the use of organisms with capacities to reduce the populations of harmful organisms that cause pests or diseases. Biological control has been in use for many centuries, for example in 1888 with the release of *Rodolia* ladybird beetles to control a scale insect in citrus in California. However, modern use started at the end of the nineteenth century (DeBach 1964; van Lenteren and Godfray 2005). **Four different types of biological control are known** : natural, conservation, classical, and augmentative biological control (Eilenberg et al. 2001; Cock et al. 2010), in order from low to high human intervention. Biocontrol agents (BCAs) might also be classified as **macroscopic**, including insects, mites and nematodes, or **microscopic** including bacteria, viruses and fungi. Both types can be differentiated on basis of the target. Thus, macroscopic BCAs are useful to control only pests, while microscopic biocontrol agents have a wider range of targets, from bacteria, fungi to insects. The use of microbial antagonists is a widely spread control method of diseases in horticultural crops. The main advantage of biocontrol is the reduction of chemical pesticides, minimizing residues in fruits, and the minimization of the risk of development of resistance among pathogen populations. Moreover, they are highly specific to a pathogen and hence considered as harmless to non-target species.

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> LADYBIRDS HAVE A VORACIOUS APPETITE FOR APHIDS

In the case of **macroscopic biocontrol agents,** also known as traditional biological control, the most common strategy of application is augmentative, based on the introduction of biocontrol agents in large populations to obtain immediate control of the pests (Lorito et al. 2010; Parnell et al. 2016; van Lenteren 2012). The most known BCAs in pome fruits are the predatory mites *Amblyseius californicus* to control pest mites, the lacewing *Chrysoperla lucasina* to control aphids and the ladybird beetle *Cycloneda limbifer* also to control aphids. These have been used since 1985, 1995 and 1990, respectively (van Lenteren et al. 2018). However, efficiency is variable and extremely depends on pest pressure. Recently, the trend goes towards conservation biological control that consists of adapting the habitat to attract and retain natural enemies controlling pests in more natural ways (Weller et al. 2002; Mendes et al. 2011), for example by i) adding floral resources, ii) introducing insect hotels or iii) creating artificial habitats for local fauna. This strategy focuses on implementation into organic production, and some projects are already evaluating its commercial applicability with good perspectives in some regions. This kind of strategy, combined with other measures such as the use of permanent environmental covers (netting), should help in a biological production with less chemicals.
Thus, biocontrol of pests is standard practice for controlling infestation in Integrated Pest and Disease Management (IPM) strategies. However, biocontrol methods are not available for the most important emerging pests, such as the spotted wing *Drosophila (Drosophila suzukii)* and the brown marmorated stink bug *(Halyomorpha halys)*. Understanding the natural enemy complex and other biotic factors that cause mortality of these two pests is essential for the development of biological control and IPM strategies.

> GROUND BEETLE *CYLINDERA GERMANICA* CONSUMING A LARVA OF CARPOCAPSE

Microscopic BCAs are usually bacterial or fungal strains isolated from the epiphytic, the endophytic environment or the rhizosphere of the host plant (Cabrefiga et al. 2014, Daranas et al. 2018, Fira et al. 2018). BCAs against several pre and post-harvest diseases are commercially available. In the case of pome fruits, the best studied entomopathogenic species is the bacterium *Bacillus thuringiensis*. However, other biological insecticides are registered in Europe such as the fungi *Beauveria bassiana* and *Paecilomyces fomosoroseus* or *Cydia pomonella Granulovirus*. More recently, other entomopathogenic bacteria, such *as Serratia spp, Pseudomonas entomophila, Burkholderia* spp., *Chromobacterium, Xenorhabdus* and *Photorhabdus* spp. have been studied to control different pests. Another entomopathogenic microorganism widely used is the fungus *Metarhizium anisopliae*. It has the advantage of showing a very limited activity against useful insects such as pollinators. In fact, it can even be used to control Varroa in beehives. However, many microscopic BCAs are still under study and are not yet registered.
Microorganisms, such as *Bacillus amyloliquefaciens, Aureobasidium pullulans* and *Trichoderma harzianum* are commercially available for the control of bacterial and fungal diseases. In this case, different mode of action have been described such as competitive exclusion of the pathogen, production

> SYRPHE LARVA EMPTYING AN APHID

of antimicrobial compounds such as cyclolipopeptides in *Bacillus* spp., phenolics in *Pseudomonas fluorescens,* and pseudopeptides in *Pantoea agglomerans* and *Pantoea vagans*. Other modes of action rely on interference of the pathogen signalling system or induction of plant resistance against diseases. The latter mode of action is exploited by *Trichoderma harzianum* and plant growth promoting rhizobacteria (PGPR).

Fire blight of pome fruits *(Erwinia amylovora), Xanthomonas* diseases of stone fruits and strawberry, and *Pseudomonas* diseases in apple and kiwifruit are well known bacterial diseases of fruit trees. The most widespread biocontrol products are based on bacterial antagonists, in particular *Lactobacillus plantarum* and *B. amyloliquefaciens*. Another promising BCA group are lytic bacteriophages that are effective against citrus canker, for example. Lactic acid bacteria are known to have no environmental nor consumers' concerns because they are already used as food additives to control food-borne pathogenic bacteria in fresh fruit and vegetables. Lactic acid bacteria effective again *Erwinia amylovora, Xanthomonas arboricola* pv. *pruni* and *Pseudomonas syringae* pv. *actinidiae* have already been identified and tested, although not yet registered.

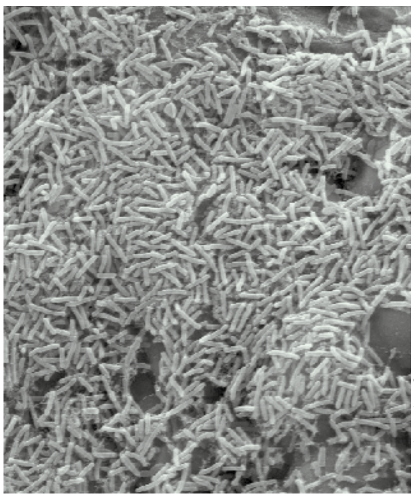
In conclusion : the use of biocontrol in IPM programs can be an alternative to chemical products in agreement with the European Union regulations and more specifically in its Sustainable Use of Pesticides Directive (EC 2009), but their optimal application condition and the efficacy levels have to be improved. A combination of biocontrol with other cultural strategies should result in more environmental friendly production systems.

NATURAL PRODUCTS IN CROP PROTECTION

Natural products have a long history of use in crop protection. Nowadays, such **products from plants, animals** (e.g. chitosan) **or minerals** are available for pest and disease control, and some of them could be used in integrated and organic orchards. The consumer's demand for apples produced in a more environmentally friendly manner has generated the need for alternatives for scab control, a disease that still requires a large number of fungicide treatments. Therefore, **potassium bicarbonates** could be successfully used against apple scab, as a preventive treatment or in a "during infection" spray strategy, under favourable primary infection conditions (Jamar et al., 2010). A combination of potassium carbonates with a reduced dose of wettable sulphur can give a good powdery mildew control as well as an increased yield (Foundation KOB, Germany; Kelderer et al., 2016; Mitre et al., 2018). An unsolved problem in organic apple production is fruit rot. Efficacy of pre-harvest application of **bicarbonate, acid clay** (Holthusen 2014a, b) **or laminarin** depends mainly on the regional climate and may generate some phytototoxicity problems. Thus, farmers are reticent to implement such strategies for economic reasons (Agroscope, Switzerland; AU, Denmark).

Natural products such as **plant extracts** keep attracting more attention. However, few suitable commercial products are available. For such products, one of the major challenges to reach the market is standardization of active ingredient(s), and the regulatory requirements for approval. In countries where their use is permitted or approved, standardized neem oil extracts are effective against the rosy apple aphid, one of the most important and damaging pests, which is known for the strains resistant to insecticides in central and southern Europe. Precise timing of application shortly after hatching of eggs in spring is critical. Neem oil based products may in some cases produce inadmissible phytotoxicity on apple leaves, disqualifying it for use in commercial apple production (Trautmann, 2016). Another plant extract product, from *Quassia amara,* is effective against apple sawfly when applied at petal fall (Laimburg, Italy). Extracts from *Equisetum arvense, Urtica* spp., *Glycyrrhiza glabra,* algae, as well as limonene, thymol and laminarin are under evaluation in the control of apple scab in Italy (Laimburg) and Spain (IRTA). In France, laminarin is registered against apple scab and fire blight. Botanical products generally have low toxicity, a shorter shelf life, limited field persistence (repeated applications are needed), has no risk for pathogen/pest resistance, and are considered safe to humans and environment.

Pest and disease management is more than applying the right product at the correct time. What begins as a fragmented set of tactics for the local pest/



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> BACTERIAL BIOCONTROL AGENT COLONIZING PEAR FLOWER SURFACE

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> EXTRACTS FROM EQUISETUM ARVENSE (HORSETAIL) MAY BE USED AS A PLANT PROTECTION

disease complex must gradually form an overall management plan in which various strategies (geographic and climatic considerations, cultivar selection, sanitation) work together. Market prices and production costs also influence the design and viability of such production systems.

THE USE OF SEMIO-CHEMICALS AND ATTRACTANTS FOR PEST CONTROL IN APPLE ORCHARDS

The use of synthetically produced natural products such as pheromones and other semio-chemicals is seen as a means to reduce the use of conventional, chemical insecticides. Insect pheromones are volatile chemicals produced by insects as part of their social signalling system. For example, insects may release pheromones to attract individuals of the opposite sex for mating. Pheromones have been isolated for many insect species and can contribute to pest control either by allowing accurate monitoring of populations or as part of a direct control system, for example in mating disruption.

One pest of apple orchards where pheromones have been used particularly effectively is the codling moth *(Cydia pomonella)* which is a member of the Lepidopteran family Tortricidae, and is one of the most important pests of apples in Europe, and also a key pest for pear. Work to test codling moth control systems have been carried out by NIAB EMR in the UK (Saville *et al*,. 2018). Codling moth can be effectively controlled by spraying with insecticides, but this requires repeat spraying each season as a proportion of the population always remains to re-infest.

One mating disruption system that has been developed is the Exosex CM codling moth pheromone autoconfusion system (Exosect, UK). A lattice of 25 delta dispensers per ha is set out in a grid through the orchards at the start of the codling moth flight, which is usually in May, and can be detected using sex pheromone trap catches.

Each dispenser contains wax powder loaded with the codling moth sex pheromone in its base and a sex pheromone lure. The lure attracts males into the dispensers where they become contaminated with the pheromone-loaded powder which is attracted electrostatically to their bodies. Contaminated males are confused and also attract other males so preventing or delaying mating of females in a process known as false trail following.

An alternative product that works on a similar principle is RAK3+4 (BASF, marketed by Agrovista in the UK). Trials undertaken in the UK by NIAB EMR as part of AHDB project TF 223 (Saville et al, 2018), across a range of farms have indicated that under the right conditions this pheromone can give comparable control to conventional insecticide spray programmes. Thus in two farms over two seasons when one part treated with conventional sprays was compared to another part treated with RAK3+4 mating disruption, the levels of fruit damage were similarly reduced and the numbers of moths were similar. The two products Exosex and RAK3+4 have been found to have similar efficacy.

For effective use of mating disruption, pheromone traps are used to monitor insect numbers and optimise the implementation. This is not ideal as it only gives an indication of whether there is trap shut down (hence no males captured). It does not tell the grower whether females have successfully mated and laid eggs. Pheromone trapping and RIMPro population development models are very useful for monitoring insect numbers season to season. In the UK the RAK 3+4 system also give relatively good control of 2 other common tortricids on apple.

Sex pheromone mating disruption system only gives adequate control of low codling moth populations and should be used in combination with other codling moth control measures, including granulovirus and/or insecticides.

Plants also produce volatile signalling chemicals (semiochemicals), for example when attacked or physically damaged to stimulate defence responses in distant parts of the plant. These semiochemicals may be generally attractive to insects as they indicate the presence of a food source. Therefore another use of semiochemicals is to encourage natural predators of pests. In the US a product containing methyl salicylate is marketed as PredaLureTM to attract hoverflies which are very effective predators of aphids. Trials carried out by NIAB EMR and the Natural Resources Institute, University of Greenwich have confirmed the effectiveness of PredaLureTM in increasing hoverfly numbers and have started to identify chemical combinations with increased efficacy. ■

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> PHEROMONE DISPENSERS FOR MATING DISRUPTION, TO PREVENT MALE INSECTS FINDING FEMALES

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ALTERNATIVES TO POSTHARVEST TREATMENTS

Postharvest treatments are applied to reduce fruit losses during storage and shelf life. Most common practices are drenching of fruits in fungicide solutions or thermonebulization of fungicides inside storage rooms. However, both techniques are increasingly viewed critically since they leave detectable pesticide residues on fruits.

An alternative is the **nebulisation of biological control organisms** (BCOs) inside storage rooms. However, the efficacy of BCOs is still limited (max. 50 % against *Neofabraea* spp.) and quite variable depending on the deposit distribution inside the storage room. The distribution depends on the airflow, the injection nozzles, the position of the fogger and ventilation, as well the position of the bins inside the room (Ambaw et al., 2017). Further optimisation is needed for a more precise distribution of the BCOs in storage rooms and bins.

Compared to BCOs, **hot water treatments** work completely free of any agent. Instead, thermal energy, in the form of heated water, prevents the development of storage rots and storage scab. Experiments performed by Maxin et al. (2012a) showed that the effect of hot water treatment is not only based on reduced spore germination, but also on a stress-induced physiological response of the fruits against fungal attacks. Hot water dipping (HWD) showed high efficacies (> 75%) against most storage rot pathogens on apples and pears when applied at temperatures between 48 and 52 °C for 2 to 3 minutes (Giraud et al., 2012 ; Maxin et al. 2014, Mathieu-Hurtiger et al., 2014 and 2016 ; Edelenbos and Holthusen, 2018). However, HWD was never implemented on a larger scale in fruit industry, since energy consumption is relatively high, while treatment volumes are relatively low. Research in recent years has focused on short hot water treatment (HWR) (Maxin et al. 2012b). Compared to HWD, HWR with temperatures between 54 and 58 °C for 20 to 30 seconds gave slightly lower efficiencies while the energy consumption was reduced by at least 50% and treated volume was doubled (Holthusen, unpublished). Recently a commercial HWR machine became available which can be integrated into existing grading lines and can handle at least 10 t apples h-1. The same technique can also be used to prevent the development of Monilia rots on peaches. Treatments with temperatures between 56 and 60 °C for 15 to 60 seconds gave efficacies between 50 to 90% (Lurol et al., 2018). In 2017, a new on-line hot-water spray system was developed to treat several tons of fruit per hour with an optimisation of the different parts of the machine to reduce the operating costs.

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> NEBULISATION OF BIOLOGICAL CONTROL ORGANISMS INSIDE STORAGE ROOMS

Cleaning of fruits to remove pesticide residues is a completely different postharvest approach. It could be considered as a compromise between the need for plant protection in the orchards and the demand of food retailers for residue-minimised products. Experiments to wash and brush fruits with water, soaps, and acids were performed at different sites. Depending on the washing agent and pesticide investigated, residues were reduced by between 20 and 95%. In general, washing agents were somewhat more effective than water. Water itself gave reduction rates between 20 and 50%, depending on temperature, washing duration and chemical characteristics of the pesticide (Regis, 2012). Warm water was more effective than cold water (Regis, 2012) and the efficacy was always improved by mechanical brushing (Holthusen 2014a, b). Efficacy of residue reduction was independent from the time of treatment either directly after harvest (Bertolini and Folchi, 2016) or after six month in ULO storage. **However, no technique was able to reduce the residues below the detection limit. Therefore, the key objective of reducing the number of residues, as demanded by food retailers, has not been achieved.** ■

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> IMPROVING FRUIT QUALITY BY HOT WATER TREATMENTS INTEGRATED INTO EXISTING GRADING LINES

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> WASHING AND BRUSHING TRIALS TO REMOVE RESIDUES FROM APPLES

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PHYSICAL BARRIER

During the vegetation period, fruit growers carry out treatments with plant protection products (mainly fungicides, insecticides and acaricides) to protect the plants and fruits against the damage caused by diseases and pests. Over the years, the fruit industry has been forced to look for alternatives for chemical plant protection products, for various reasons; for example that certain plant protection products have been eliminated as a consequence of new authorization procedures. In the case of other products, it has been found that they have lost their efficacy due to the occurrence of resistance against different pests and diseases. Moreover, the market demands fruits without detectable residues of plant protection products.
In recent years different research stations in Europe have investigated various physical methods for controlling pests and diseases on different fruit crops. Some of them were introduced into the orchards by growers, others are still at the experimental stage.

> PLASTIC COVERS COMBINED WITH HAIL NETS TO PROTECT FRUITS FORM RAIN AND LIMIT APPLE SCAB AND FRUIT ROT

> APPLE SCAB IS OF MAJOR ECONOMIC IMPORTANCE

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> CODLING LARVAE ENTRIES MAKE THE FRUIT NOT MARKETABLE

Generally speaking, we have to distinguish between excluding nets and plastic covers. The concept of **excluding nets** (e.g. in France called Alt'Carpo) is based on a barrier effect. The fact that lots of apple orchards are protected with hail nets, to prevent them from meteorological damage and for increasing fruit quality, offers the possibility to completely cover the orchard, installing anti-insect nets on sides in a strategy to use this cover as a physical barrier to avoid *lepidopera* (codling moth, oriental fruit moth, leaf rollers) and *diptera* (Mediterranean fruit fly) which are both common pests. In southern areas with more generations of the moths, the technique of using the excluding net spreads quite rapidly. The nets show positive results against the cockchafer, bees as vectors of fire blight, fruit flies and *Halyomorpha*. Efficacy depends on the pressure of the pest, the type of net system, mesh width and time of application and can reach up to 100%. Three year trials carried out in the Girona area (Catalonia) have proved that these pests have been partially, and sometimes totally, kept under control with this technology. Besides, the use of this


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> THE KEEP IN TOUCH SYSTEM® COVERS THE TREES AGAINST THE RAIN AVOIDING DISEASES AND EXCLUDES THE PESTS WITH A NET

netting system can help to introduce biological control of other pests such as aphids through the use of auxiliary fauna. Therefore, excluding nets are a good tool that allows a reduction of chemical sprayings on the orchards, especially insecticides. In a French long term project called "ECOPHYTO pomme", excluding nets around orchards combined with *Bacillus thuringiensis* and granulosis virus application achieved in total a 40-50 % reduction of chemical insecticides. Sometimes, the nets are simply positioned on the trees, in other systems they are fixed around the orchard. Mesh size differs between fruit growing areas, from 2.2 x 5.4 to 3 x 7.4 mm. A smaller mesh size may offer a better protection. Depending on the fixing systems and the time of application during blooming, it is possible to influence fecundation and crop load. But there are also some negative side effects, such as an increased incidence of woolly aphids *(Eriosoma lanigerum)*. European productions of cherries and soft fruit have been invaded by *Drosophila suzukii*. In this case, the use of net systems with mesh sizes of 0.8 x 0.8 mm became an imperative to protect the harvest. In most cases, these nets allow a drastic reduction in the number of treatments with insecticides, and hence a considerable reduction of residues on the fruits. In some cases, the combination with mating disruption and/or insecticide treatments is necessary. Given that excluding nets can be regarded as a further development of the hail net systems, the concerns are few and in general the growers quickly accept the implementation of these systems.

Plastic covers protect the orchards and fruits against rain and consequently against infection by diseases caused by fungus and bacteria. Since the end of the 90's cherry orchards are covered close to harvest in order to avoid cracking of the fruits. In the case of apples and pears, field trials are conducted at the University of Aarhus (Denmark), CTIFL (France), and Laimburg Research Centre (Italy). The main objective is to cover the orchards during the whole season against scab, *Neofabrara* spp., *Alternaria, Marsonina,* sooty blotch and sooty mold, thereby reducing the number of treatments as much as possible. The results gained until now are very encouraging. In Italy and France, successful disease control has also been achieved for *Pseudomonas syringae* on kiwis and for *Monilia* on apricots.

Similar to the excluding nets, there are systems which cover only the crown of the trees and others which are combined with hail nets covering the whole orchard. The results differ depending on the system, time of opening, pressure of the different diseases, variety, combination with other treatments etc. Some trials showed a negative influence on the yield and the quality of the fruits (colour, sugar, acidity) due to the reduction of the photosynthetically active irradiation under the covers. Powdery mildew shows a tendency to increase below the plastic covers.

Plastic covers also show a huge potential in reducing the use of pesticides in the orchards. From a technical point of view, the plastic covers are still not ready for widespread commercial use. There are concerns with respect to negative side effects on yield and quality, the incidence of pests and diseases other than the main targets and the technical implementation of the systems. However, the major limitations for this technology are the costs. The plastic cover requires a stable structure able to resist windy conditions and the lifetime of the plastic cover is limited to a couple of years. Further concerns are with regard to ecological sustainability. The carbon foot print for example is unfavourable in comparison to the treatments with pesticides using the traditional spraying equipment. A further aspect, discussed mainly in tourist areas, is the visual impact on the landcape of orchards with plastic covers. ■

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FUNCTIONAL BIODIVERSITY IN ORCHARD HEDGEROWS TO FOSTER CONSERVATION BIOCONTROL

Orchards are complex agro-ecosystems with multiple biological layers including fruit trees, herbaceous ground covers, and hedgerows, which can all be under the influence of crop management practices. Hedgerows lining orchards provide opportunities to design plant assemblages to foster the diversity of insect food-webs through the provision of a variety of habitats and resources, and **conservation biocontrol** of insect pests through the presence of natural enemies (Simon et al., 2010).

The design and evaluation of an experimental hedgerow (1995-2005) in pear orchards in South-Eastern France to control the pear psyllid *Cacopsylla pyri* as well as entomological surveys on various tree species led to the identification of three main principles to consider in the design of 'pest suppressive' hedgerows around orchards (Simon *et al.*, 2010 ; Simon *et al.*, 2009). Firstly, plant species that can host key pests and diseases (e.g., hawthorn *Crataegus monogyna* that hosts fireblight) should be banned to avoid detrimental effects on the orchard and surrounding crops. Secondly, plant species that host a rich and/or abundant natural enemy complex should be selected. This can be estimated based on local references from previous surveys and on known specific plant traits. For example, hairy leaves are generally associated with a rich arthropod community since hairs offer shelter and/or trap pollen as an alternative food, (e.g., hazelnut trees *Corylus avellana* host a rich and abundant natural enemy complex). Food resources such as pollen and nectar are also important for natural enemy fecundity and fitness. Thirdly, local rather than exotic plant species are likely to be a source of natural enemies for the orchard. Plant species assemblages in hedgerows should provide natural enemies with diverse habitats and/or food resources such as pollen, nectar and alternative preys all year round. This encompasses evergreen leaves and hollow or intertwined stems (e.g., ivy *(Hedera helix)*) as wintering habitat; early, season and late flowering; and species hosting specific herbivores as alternative preys as food resources. Because many tree species offer several types of resources, a 'moderate' diversity (e.g., 12 species in our case study) ensured that there was more than one tree species to support each type of resource all year round.

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> WINTER RESOURCES IN MULTI-SPECIES HEDGEROWS INCLUDING HABITAT AND FOOD RESOURCES PROVIDED BY LAURUSTINUS (VIBURNUM TINUS) EVERGREEN FOLIAGE AND HAZEL TREE POLLEN, RESPECTIVELY

In the INRA experiment, this approach was determined to be successful for managing orchard pests such as mites, pear psyllids and some aphids. However, other (bio)control methods should be used in conjunction with functional biodiversity to control pests such as Tortricids (e.g. codling moth *Cydia pomonella*) that can cause severe fruit damage at low population levels. The efficiency of conservation biocontrol in orchards can also be limited due to low numbers of natural enemies reaching the orchard, which might be caused by a higher attractiveness of hedgerows and by the use of pesticides, and can be influenced by the age and management of hedgerows that can alter functional biodiversity (Simon *et al.*, 2010). Previous work (Simon *et al.*, 2010; Simon, 1999) highlighted that natural enemy arthropod diversity inside the orchard was affected by plant diversity both within (i.e. lining hedgerows) and beyond (i.e. tree species in nearby environment) the orchard scale, attesting that biotic interactions occur at larger scales.

> GREAT TIT IN NEST BOX

On the other hand, ESTEBURG experiments revealed that herbaceous plant borders attached to an orchard not only give shelter to natural enemy arthropods but also to such devastating pests as the common green capsid *(Lygocoris pabulinus)*, being responsible for deformed fruits in the "Altes Land" fruit growing area. While only the larvae of the first generation attack the apple fruitlets during blossom and shortly after, the second generation mainly develops on herbaceous plants underneath or beside the apple trees. Experiments since 2014 demonstrated that the common green capsid could be more effectively controlled by mowing such herbaceous plants during larval development of the second generation than by insecticides (Mohr *et al.*, 2016). In some cases, plant biodiversity inside orchards therefore might be a hurdle for the production of marketable fruits.

If conservation biocontrol should be established in orchards on the basis of the principles proposed, further research is needed to better understand and manage biotic interactions at different spatial scales.

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ADAPTATION OF CHEMICAL STRATEGIES TO FULFIL RESIDUE REQUIREMENTS

During the season, chemical treatments are performed to control pests and diseases in the orchards. Throughout the years more and more concerns about the effect of the chemical products on the beneficial insects in the orchards have been raised and in the 1990s the concept of IPM was introduced to fruit growers. Selectivity of chemical products for beneficial insects was a key factor and much research was performed to determine the selectivity of the different chemical products. Based on this research, several products were banned for fruit production and only selective products were still allowed.

Since 1 September 2008, the maximum residue limits on fruits have been harmonised within Europe (Regulation No 396/2005). However, for about 10 years now, producing fruit according to IPM strategies is no longer sufficient. The public and governmental concern about residues is still growing and has already led to increasing pressure to reduce the residues on the fruits. The competition between retailers concerning residue levels, eventually combined with a maximum of active ingredients present on the fruit, is an issue which has a stronger impact than the official MRL (Maximum Residue Limit). In addition, there are further restrictions for export to specific countries. The challenge is how to manage pests and diseases in the post blossom period until harvest. Furthermore, because fruits of the same orchard may have different sale channels, the fruit growers are challenged to present a spray schedule that meet all these restrictions together.

> FRUIT ROT DISEASES ON APPLES : NEOFABRAEA ALBA

To reduce residues as much as possible, studies have been carried out by different research institutes (including pcfruit, Laimburg, ESTEBURG (Holthusen, 2014a)). For example, for the different available products, pre-harvest intervals are determined to attempt to reach the LOD (limit of residue detection). Surprisingly for classic protectants long pre-harvest intervals must also be taken used to obtain this LOD (research pcfruit, ESTEBURG (Holthusen and Valenta 2016)). Another issue is the use of cocktails of treatments and the impact on residues at harvest; for example the use of surfactants and specific leaf fertilizers which can influence the residue level at harvest (research pcfruit). Furthermore, the application stages of the culture and the number of applications are also important factors influencing the residue levels on fruits (pcfruit). For example, results obtained in the Project FRUIT.NET, developed in Catalonia by IRTA, the Association of fruit producers (AFRUCAT) and the Department of Agriculture (DARP), indicated that rationalization of treatments during production and avoiding treatments during post-harvest resulted in the reduction of residues on fruits. Thus, in 1998 using conventional strategies, 85.2% of products applied during production exceeded the LOD by more than 10%, while in 2016 using the FRUIT.NET strategy, less than 8% of products passed the LOD by more than 10%. The results of these research programs are very important and lead to the elaboration of specific “green” pesticides lists and “guidelines” for applications throughout the season.

> HEALTHY AND SAVE FRESH FRUITS ARE THE CONSUMERS EXPECTATIONS

As one product may have a different registered dose rate or number of applications in different countries this is a research topic that is ongoing in different European countries and some guidelines may differ between countries. For example, in Germany the guideline is named « guideline for controlled integrated production in pome and stone fruit ». In the UK the guidelines are the Apple Best practice guide (http://apples.ahdb.org.uk/) from AHDB

As the development of new products is an ongoing topic and as analytical methods become more and more accurate for detection of lower residues, this leads to a change in the LOD according to new analytical methods or extraction procedures; this research should therefore continue in the future to help the fruit growers maintain their livelihoods. ■

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EFFICIENT INNOVATIVE SPRAY APPLICATION TECHNIQUES

New innovative application techniques are used to significantly reduce the emission into the environment of crop protection products, and to minimize pesticide residues on fruits. It is also possible to reduce the amount of crop protection agents used as these new application techniques ensure a better and more uniform crop coverage. In cooperation with spray machine manufacturers and the agrochemical industries, new application techniques for fruit crops via **crop-dependent spraying** based on crop volume or crop row volume dosage, and **adjusting spray parameters** (such as air speed and nozzle type) are developed.

In Germany, pesticide usage in pome and stone fruit is generally adapted to the Crown Height of the trees. However, a model to adapt the spray volume further to the tree density as well as sprayer specific parameters (reduction up to 25%) resulted in lower fruit quality compared to the normal spray application. Field experiments were conducted over several years in five commercial orchards. Tremendous losses due to apple scab occurred in one of the orchards in two of the three experimental years, where the new model was used. Although, no general increase in damage was observed, a higher potential production risk was clearly demonstrated if spray volume was reduced. The possible spray volume reduction was disproportional to the increased risk of damage and therefore cannot be recommended for commercial fruit production (Huhs et al., 2014; Huhs, 2015).

In another approach, sprayers equipped with sensors to detect gaps inside and between trees were tested. If gaps were detected single or multiple nozzles were switched off, allowing a saving of up to 69% of spray volume, depending on shape, density and development stage of the trees (Kämpfer et al., 2014). However, testing the equipment in commercial orchards resulted in an excessive increase of scab infection at least at one site, even though the spray volume reduction was below 10%. Again, the system worked in one of the two investigated orchards but disproportionately increased the risk of fruit losses and therefore cannot be recommended for commercial fruit production (Huhs et al., 2018).

Despite some negative results, if tested and applied correctly, these new tech-

> SPRAYER'S PERFORMANCE ASSESSMENT

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> TUNNELSPRAYERS TO REDUCE EMISSIONS INTO THE ENVIRONMENT

> FIXED SPRAYING SYSTEM ON APPLE TREES DEVELOPED BY CTIFL IN A PROJECT CALLED PULVÉFIX

niques significantly reduce emissions into the environment and the exposure of bystanders and local residents, while retaining a high level of biological efficacy, and avoid overdosing on leaves and fruits. These goals are achieved through a combination of technology and a decrease in the amount of applied product. It is estimated that this will result in application techniques in the high drift reduction classes of at least 95%.

However, knowledge on the process of spray deposition within a crop canopy, and the effect of different spraying systems is still lacking. Hence, a better comprehension for dosage per surface area of land into a deposition range on leaves is needed. This process will integrate crop dimension parameters, such as the Crown Height model, the Tree Row Volume model, the Tree Row Density model, the Leaf Wall Area model and also models based on grids crossing different vegetation indicators (BBCH stages, canopy width and height classes). This should result in a lower spray volume (lower dose) and avoid over spraying of a crop and thus minimizing the risk of high pesticide residues levels on fruits.

In France for example, the use of the Leaf Wall Area model allowed a reduction in the use of plant protection products from 1 to 22% for the same quality at the harvest than the reference treated at full dose (Verpont, Le Maguet, Bellevaux, 2018). The grid model also assessed in the French project PulvArbo seems to be very interesting (8 to 26% reduction of the plant protection product use). Achieving reduced used of pesticides through effective application techniques is one thing, making this reduction possible at the producer level is another thing. Implementation of these evolutions of practices will pass through information, awareness and training of different actors.

Besides adopting the spray application system, the orchard training system can also be adjusted. Currently, research is carried out on 2D fruit walls for better mechanical pruning, thinning and harvesting. With this training system the canopy is more uniform and shallow. It is expected that drift and residue can be reduced at higher levels compared to spindle trees.

A different approach is the use of a **fixed spraying system**: taking into account regulatory and societal developments, the actions of the French project Pulvefix aims to study an innovative method of applying crop protection products using a fixed system of over tree micro-sprinklers, tested initially in apple orchards. Besides the development of an optimized, efficient and sustainable prototype, this project aims to evaluate the technique in terms of its agronomic, environmental and economic performances. The first results are very encouraging and even if there is still some work to do to optimize the application quality (homogeneity of deposits), the control of pests and diseases is good. This new way to apply pesticides will have a very important impact on drift reduction : drift trials carried out in 2018 at CTIFL showed a drift reduction of more than 95% at 5 m (and no more drift at 10, 30, 40 and 50 meters from the last row of the orchard). ■

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> DRIFT REDUCTION IN ORCHARDS SPRAYING WITH INNOVATIVE SPRAYERS

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LONG TERM TRIALS TO REDUCE THE USE OF PESTICIDES AND COMBINE ALTERNATIVE TECHNIQUES

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> LONG TERM TRIALS TO EVALUATE A COMBINATION OF ALTERNATIVES TECHNIQUES TO PESTICIDES : OVERVIEW OF THE BIORECO SYSTEM EXPERIMENT IN APPLE ORCHARDS

Fruits have to be protected against a series of pests and diseases, which is impossible with a single technique. Different approaches such as prophylactic measures, beneficial insects, mechanical intervention, bio control products, and less susceptible varieties are used. Despite the implementation of these measures in integrated pest management (IPM), the use of pesticides is still necessary. The quality requirements of the market are increasing and the risk for significant economic losses is too high to give up the use of pesticides. This is in contradiction to consumer expectations for residue free fruits and minimal pesticide use. EU Member States have to establish conditions to promote low pesticide-input pest management strategies and applied research institutes may play an important role to bring innovative pest management strategies to practice. Long term trials with combinations of alternative techniques can be used to compare the agronomic performance and the economic feasibility of these strategies to actual growers' practices. Several partners of the EUFRUIT project have established such trials. EUFRUIT work package meetings and the knowledge platform have been used to exchange results among researchers, advisors and farmers from different countries.

Long term system experiments can be used to assess the efficiency of sets of methods combined to control crop pests with the objective to reduce the use of pesticides while maintaining yields. The BioREco orchard (2005-2015) was the first system experiment in fruit tree production in France that developed such an approach and addressed the control of the major pests and diseases of apple, i.e. scab *(Venturia inaequalis)*, codling moth *(Cydia pomonella)*, and powdery mildew *(Podosphaera leucotricha)* (Simon *et al*,. 2017 ; Simon *et al*,. 2011). Three systems (Conventional, CON; Low Input, LI; Organic, ORG) were planted with three apple cultivars differing in disease susceptibility (Smoothee, a Golden Delicious type cultivar susceptible to scab; Ariane, a scab-resistant cultivar; and Melrose, a low-susceptibility cultivar) that were implemented in each of the systems (i.e. 9 plots in total). Seceral ways to limit the use of pesticides were used according to the systems. Both plant-mediated processes (through cultivar choice, tree training, supervised fertilization and irrigation), and natural enemy-mediated processes (through selective pesticide use and reduction of the frequency of mowing in the orchard alleys) were considered. Direct measures against pests included sanitation practices and alternative methods to synthetic pesticides, such as mechanical weeding, mating disruption, microbiological and biological control with granulosis virus and entomopathogenic nematodes respectively against codling moth. Lastly, an acute assessment of the risk of fruit damage was achieved in the plots based on forecasts and meteorological conditions, observations in orchards and the use of models of prediction of the risk of damage (scab, codling moth).

Compared to the regional reference, it was possible to reduce the use of pesticides by an average of 38 to 45% by combining a low-susceptible or disease-resistant cultivar, a set of alternatives to pesticides and an acute assessment of the risk of fruit damage. This reduction was achieved for similar yield levels in LI and CON systems. The yield was lower in the ORG system where fruit damage may be higher. The abundance and diversity of the studied biological communities (earthworms, earwigs, spiders) varied depending on the system and year. More generally, the environmental impact of the systems was reduced by decreasing the use of pesticides. Production costs were higher in LI and ORG than in CON systems, but without price premium in LI. Finally, the LI system required a specific

> THE ECOPHYTO PROJECT LED AT CTIFL BETWEEN 2012 AND 2017 COMBINED RAIN COVERS AND EXCLUSION NETS

context and access to information for its implementation. This multi-criteria evaluation (Simon et al., 2011 ; Alaphilippe et al., 2013) highlighted the strengths and limits of the experimental systems. It also emphasized decisive choices made at planting, namely the choice of the cultivar, the importance to combine alternative methods to control pests and to adjust cropping practices to biotic and abiotic conditions using orchard survey and decision support tools (Simon et al., 2017 ; Alaphilippe et al., 2013).
Also in France, a national network on pesticide reduction in apple orchards started in 2012 within the ECOPHYTO national program. The idea was to evaluate 27 systems located in six different regions during six years. A system is an orchard where several products, techniques, strategies are combined to reduce the use of pesticide. On each location, the low input systems are compared to an orchard representing the conventional practices. On average between 2013 and 2017 the low input strategy achieved the reduction of the "global treatment frequency indicator" (TFI) as follows:
– max. 40 % reduction with a scab sensitive variety, where some treatments during the first and second scab contamination periods could be avoided, combined with mating disruption and biocontrol agent insecticides (low codling moth pressure) and adapted treatments against aphids.
– more than 58 % reduction with a scab sensitive variety, by using a rain cover against apple scab combined with mating disruption and different types of insecticides (chemicals and biocontrol agent) or combined with an exclusion net and limited complementary insecticides against codling moth (low pressure). The same level of reduction was also obtained by adapting the doses of all products to the trees' volume and stage. In each case, the protection against aphids was adapted to their pressure.
– between 55 et 65 % reduction with a scab resistant variety, where the main apple scab protection had been covered by natural products combined with exclusion nets or/and mating disruption depending on the codling moths pressure.
– More than 75 % reduction with a scab resistant variety produced in an organic production system or by adapting

> FLOWERS STRIPS AND HEDGES IN BORDER OF ORCHARDS TO DEVELOP BENEFICIAL INSECTS


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> EXPERIMENTAL APPLE ORCHARD WITH HAIL NETS COVER COMBINED WITH AN INSECT PROOF SIDE NET ON ITS RIGHT HALF

doses with conventional products, both combined with exclusion nets or mating disruption (Zavagli et al,. 2018).

In Northern Germany, regional programs on pesticide and pesticide residual reduction in apple started in 2009. Five different plant protection systems were evaluated in one orchard over five years. The focus was on preventing detectable pesticide residues at the time of harvest. The average number of detectable residuals could be reduced to 1.4 when application was completely stopped or switched to organic pesticides only after blossom, compared to 3.3 detectable pesticide residues when synthetic pesticides were applied up until harvest. Fruit losses were high after 5 month of cold storage when no pesticides were applied after blossom (more than 40% due to storage diseases). Using fungicides authorized in organic production after blossom reduced fruit losses by more than 60% while synthetic fungicides reduced losses by up to 70% (Holthusen, 2014a).

In Switzerland, during a nine-year period, Agroscope tested a Low Residue crop protection strategy for apples with the objective to reach comparable yields to the Integrated Production; a production without residues on fruits. This Low Residue (LR) strategy was compared to the Integrated Production (IP) and the Organic Production (OP). Attributes of the economic sustainability have been evaluated in order to compare all three strategies. With the chosen plant protection, fertilizer and thinning programs in the LR strategy, it was possible, even with susceptible varieties such as Golden Delicious, to reach a yield comparable to the IP-strategy. However, the pack out for Golden Delicious was about 10% lower and for Topaz even 20% lower in the LR strategy compared to the IP strategy. All varieties showed significant losses due to storage diseases (mainly *Gloeosporium* rot) in the LR and the OP strategy. The evaluation showed that the lower pack out for the LR strategy adversely affects the profitability. Unlike for the OP strategy, there is no premium price to compensate the lower yield and the higher production risk of the low LR-strategy. A premium price for low-residue production might be justified by environmental advantages. Results showed that by choosing the adapted cultivar it should be possible to increase the pack out after storage and decrease pack out loss with positive consequences on the income variability, leading to a better economic sustainability (Goelles et al., 2015).

In Catalonia, since 2011, a cooperative project between the Agriculture Department of this region, IRTA and the fruit sector, FRUIT.NET, is running to optimize the use of pesticides and minimize the residues in apples, pears, peaches and citrus. In the case of apple production, the project is based on predictive models for apple scab (apple), on the priority of use of alternative methods (mating disruption, mass trapping) to chemicals and on avoiding the longer remaining active ingredient treatments close to harvest. The results of the program are promising: in apples the use of insecticides was decreased by up to 35 % and the use of fungicides was reduced by 24%, achieving a low residues level on fruits at harvest (less than 20% of MLR).

It is assumed by the EUFRUIT researchers that a further reduction of pesticide use is possible by optimizing the combination and application of alternative products and technologies. Thus, some of the long term trials described above are continuing to implement new methods. New demonstration orchards, such as those of an Interreg project in the Lake Constance region, are planted. These trials will lead to practical recommendations for growers and demonstrate eco-friendly fruit production systems to retailers and consumers. ■

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