EIP-AGRI Focus Group - Sustainable ways to reduce pesticides in pome and stone fruit production

Mini paper 1

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Precision Agriculture – An Enabler for Pesticide Use Reduction

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Introduction

To counteract fruit pests and diseases that could cause 25% to 40% yield loss globally (FAO, 2020), conventional farming relies on numerous pesticide spraying applications, which can lead to spray drift and losses of pesticides into surface waters and the environment. Further, pesticide applications might result in residues, which are among the most important food-related concerns of EU citizens (EFSA, 2010). In fact, more than 45% of food products are found to contain traces of pesticides (EFSA, 2021). At the same time, according to the recent publication of the UN's *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (IPBES), "nature is declining globally at rates unprecedented in human history and the rate of species extinctions is accelerating, with grave impacts on people around the world" (IPBES, 2019). Thus, "1,000,000 species (are) threatened with extinction" (IPBES, 2019), which is in large parts attributed to unsustainable land use and pollution, which includes the excessive use of pesticides. As counter measures, the report demands "promoting good agricultural and agroecological practices; multifunctional landscape planning;...and cross-sectoral integrated management" (IPBES, 2019), all actions that are well complemented by recent advances in precision agriculture.

As such, following the *precision agriculture* (precision AG) cycle of "Sensing, Surveillance and Scouting", over "Fusion, Processing and Decision making" to culminate in "Field Job Execution" in **Figure 1**, modern precision AG systems in pome and stone fruit production have the potential to save more than 30% of pesticides if precision AG approaches are combined, a value that can be even higher if additionally implementing *functional agrobiodiversity*, *orchard redesign*, *redesign of the farm to fork value chain*, and *using plant cultivars and rootstocks with resistance or tolerance to pests and diseases* as discussed in the companion mini-papers (FG44, 2022a) to (FG44, 2022e).

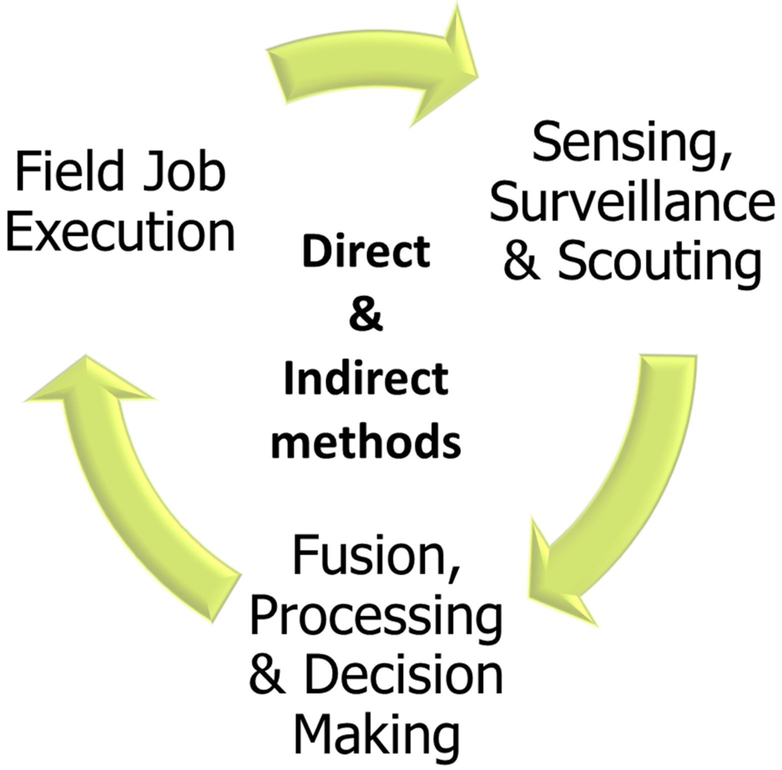

Figure 1: Precision AG Cycle.

Precision AG options to reduce pesticides are diverse and can be subdivided into *direct* and *indirect* methods:

Direct methods include the use of improved technical solutions often in combination with high-end crop protection sprayers to actively reduce pesticide use. As such, precision agriculture components like *decision* *support systems* (DSS) and, disease *early detection systems* (EDS) to determine and afterwards only treat infested areas (Berger *et al.*, 2022a) are direct pesticide reduction examples.

Indirect methods, on the other hand, for example target precise nutrition and irrigation to keep the canopy healthy and vigorous, and therewith making plants/trees less susceptible to pests and diseases. Hence, digital solutions for irrigation (sensors to irrigate at the best time to promote tree growth and contain weed growth), drone detection of areas with nitrogen deficiencies, that can be used for *variable rate application* (VAR) fertilization, variable rate blossom thinning, or precision weed control are just a few examples of such indirect methods.

In this line, the following reviews the state of the art along the *Precision AG Cycle*, and shows in real world Case Studies across Europe how different levels of precision AG are already nowadays successfully deployed to safe on pesticides in pome and stone fruit production.

Keywords:
Scab, *Venturia Inequalis,* prune rust, fire blight, *Blastobasis decolorella*, codling moth, tortrix moth, *Monilia*, precision agriculture, precision spraying, cloud connected sprayer, Smartomizer, spot spraying, variable rate application, VAR, decision support systems, DSS, pest and disease early detection systems, EDS

Sensing, Surveillance and Scouting

Soil sensing

Since many insects and diseases have transitory stages within the soil, improvements in soil sensing may provide useful information for effective pest control. Several foliar diseases, such as apple scab (*Venturia inaequalis*), prune rust (*Tranzschelia discolor*), nematodes, and insects have parts of their lifecycle within the soil. Hence, knowing the conditions that promote population growth or dispersal can provide information on when to treat plant foliage. Being able to detect and quantify early indicators may also provide the capacity to use biological treatments and/or cultural practices. Additionally, suppressive soils can be identified, allowing a better understanding of conditions that promote suppressive soils and their respective disease control.

As such, services are entering the market to determine the soil microbiome. Within Europe, there are several that provide diagnostic testing (presence and absence) of plant pathogens in combination with the analysis of soil chemistry and microbiology to lead to successful strategies for disease suppression. While this does not eliminate the need for pesticide application, soil sensing in combination with a *decision support system* (DSS) may improve the timing and selection of pesticides, with the consequence of an overall reduction of pesticide use.

Climate sensing

Weather/environmental sensing equipment is a vital tool, which in sequel enables growers to identify or predict peak infection periods for diseases and pests, allowing growers to make more efficient use of pesticides. By only spraying when the disease or pest is present and/or at its most susceptible stage of its life cycle, growers can both maximise pesticide efficacy and minimise pesticide use, which is a core aspect of *integrated pest management* (IPM). The type of environmental data collected for forecasting in pome and stone fruit includes *temperature, humidity* and *leaf wetness*.

In addition, if growers cannot supply data from a weather station in their orchards, *decision support systems* (DSS) like *RIMpro* can create a 'virtual' weather station for a desired orchard based on data from weather archives and professional weather forecasters. However, with recent advances in technology, growers can now quite cost-effectively purchase their own cellularly connected weather stations, allowing remote access to reliable real time weather data.

Crop and canopy surveillance and sensing

Currently, crop disease diagnose is based on the analysis of symptoms, pest morphology, as well as by immunochemical or metabolic and molecular assays. However, recent advances in new material, miniaturized electronics, sensors and artificial intelligence allow innovative approaches for real-time monitoring of plant health both proximally and remotely. The most widely studied sensing technologies can be grouped into *volatile organic* *compounds* (VOCs) detection, multi-spectral imagining, molecular and immunochemical methods, electrochemical methods and biosensing.

Until recently, research was dominated by the study of remote sensing of crop diseases and stress on large scale by satellite, aerial or drone images. However, remote image may be hampered by weather conditions (cloud coverage/rain, *etc.*), vegetation shadowing and by space resolution. Thus, currently, the development of flexible wearable sensors providing ready-to-use results drove the interest in local sensing (Lee *et al.* 2021), (Li *et al.* 2021) can be used as stand alone or in combination with remote/areal sensing.

In comparison with traditional molecular methods, proximal and remote sensing present numerous advantages, including operational simplicity and rapidity, non-destructivity, and bulk sampling. Drawbacks include a low sensitivity and specificity (Cellini *et al.*, 2017). Therefore, these sensing methods can be considered especially useful to guide prompt and tailored interventions.

Another key advantage of proximal sensing is the ability of monitoring multiple stressors simultaneously, providing, for example, information on plant health, plant needs and physiological activities.

Other portable easy-to-use diagnostic tools that may allow in-orchard-identification of diseased plants are *Loop mediated isothermal amplification* (LAMP) and lateral flow immunoassay devices. They provide a real diagnosis, but are destructive and require sampling, making LAMP more similar to lab diagnosis than remote and proximal sensing. In comparison to lab diagnosis, however, LAMP methods are rapid, portable, and do not require specialized personnel, the main drawback being that they are less sensitive than lab diagnosis.

Turning to biomonitoring, honeybees have been used as biosensors for detection of VOCs with a sensitivity 100 time higher than e-nose. Interestingly, honeybees have also been demonstrated to be able to selectively choose between fire blight infected and healthy apple flowers (Cellini *et al.*, 2019), opening the potential use of pollinators to sniff infected plants. Despite, bees have been used in several studies for monitoring pathogen at the environmental level (Tremblay *et al.*, 2019), (Cunningham *et al.*, 2022). However, the practical use of bees for detecting diseased trees for, in the sequel, tailor human intervention is still limited by their spatial resolution. Nevertheless, an idea for tracking bee visit is offered by the development of *radio-frequency identification* (RFID) that has been reported suitable to sense honeybees' activity (Nunes-Silva *et al.*, 2019).

Traps and scouting

Digital pheromone traps as, for example, provided by *Trapview* (**https://trapview.com/**), *PestTrapp* (**https://doktar.com/**) or *Semios* (**https://semios.com/**), and scouting apps as, for example, provided by SeeTree (**www.seetree.ai/blog/the-growers-guide-to-smart-sampling**) or Fitogar/Ioland (**https://ioland.es/samplers/**) assist in monitoring and deliver inputs to forecasting models for many fruit pest species, *e.g.* sensing spores and moths as detailed in the following:

Moths that are an important threat to fruit crops in Northern Ireland are blastobasis (*Blastobasis decolorella* (Wollaston)), codling moth (*Cydia pomonella* L.), and fruit tree tortrix moth (*Archips podana* (Scolopi). A non-native moth that has potential to cause damage to orchards in Northern Ireland, the summer fruit tortrix moth (*Adoxophyes orana Fischer von Röslerstamm*), has yet to establish itself but is present and breeding already in South East England. A way of monitoring moths' populations is using a combination of beating trays or pheromone lures.

Of the moths active, *blastobasis* can cause the greatest amount of damage in orchards, and can result in 100% crop down grading. The caterpillars feed on the flesh on the apples near the stalk, deposit large amounts of frass on the Bramleys' Seedling fruit, which are particularly susceptible to attack as they have short stalks. To date there are no commercially available sex pheromone lures that can be used to trap flying males. Instead, scouting for this pest is carried out using a beating tray, holding it beneath a branch, which is sharply tapped with a stick. If these moths are present, they will not fly off when they land, but stay on the tray and can be readily counted. Unlike many other pests, there are no economic thresholds set for treatment. Instead *blastobasis* presence alone should be sufficient justification for applying an insecticide. In the case of Northern Ireland, monitoring takes place in June and July when the adults start flying and eggs are laid, so that effective insecticide applications can be performed when the caterpillars emerge.

The other three moth species are monitored using pheromone lures, which are specific for each species. Lures are effective for a period of 3 – 6 weeks and are placed in the middle of a sticky card laid inside a 'delta' trap. The traps are positioned mid-way in tree foliage and are orientated to encourage flow of air through the trap to maximise distribution of scent. If traps are used that cannot be monitored remotely, they are inspected on weekly basis with captured moths removed, and in the case of Northern Ireland, with samples sent to the *Agri-Food and Biosciences Institute* (AFBI, **www.afbini.gov.uk**) to confirm the species of moth. In general, the traps are placed in orchards after petal fall and monitoring continues until August, possibly September for codling moth.

Differences lie in threshold levels for treatment. Since codling moths are potentially more damaging, the usual threshold for chemical treatment is a single catch of five or more moths per trap per week from May to July (first generation, fruit less susceptible) and three per trap per week from August to September (second generation, fruit more susceptible). In contrast, for both *fruit tree tortrix* and summer fruit tree tortrix moth the threshold is set at catches greater than 30 moths/trap/week.

Turning to volumetric spore trap, the severity of infection can be estimated based on the numbers of spores counted on the slide daily, and might be categorised as light (<5 spores), medium (5-10 spores) and heavy scab pressure (>10 spores). In the case of Northern Ireland, spore counts start on 17th March every year, and continue until the ascospore stage of the scab life cycle is finished, which would usually be June, but depending on weather may continue well into July.

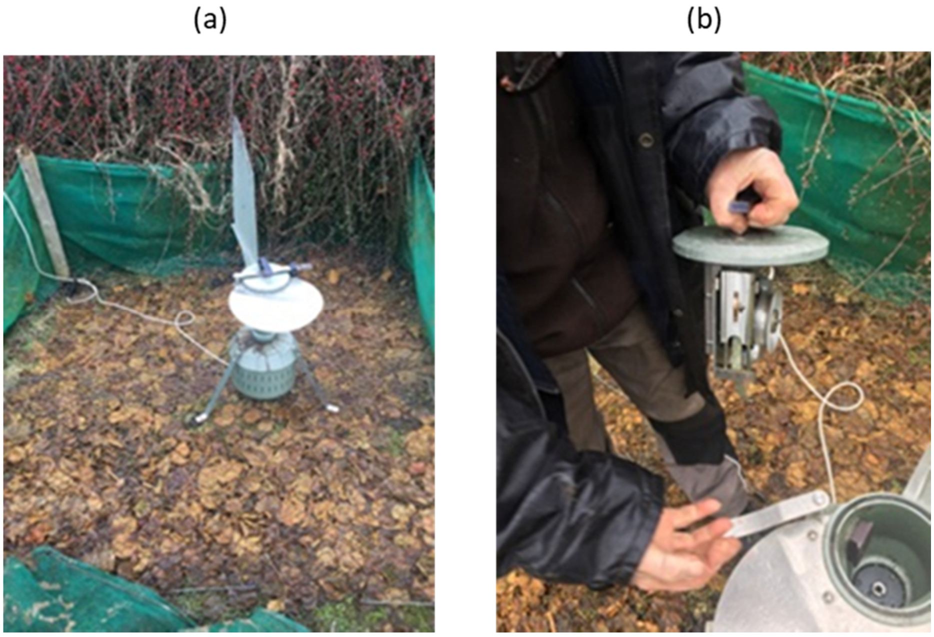

Figure 2: (a) Image of Bukard spore trap sitting on scab infected leaves (LHS) and (b) unit which holds the tacky glass slide used to trap spores.

Depending on the level of trap and scouting process digitalization, implementations might send high resolution pest-captures to central *decision support systems* (DSS) on a daily basis. Hence, growers do not have to visit their traps personally, which reduces work load and travel expenses. From the connected DSS, growers are then alerted in real-time when the forecasting models and thresholds detect that pesticide application might be required.

Processing, Prediction and Decision Making

Prediction and early pathogen infection detection, based on sensor inputs and human scouting as outlined in the previous sections, is a vital part of any integrated crop disease management. The spread of pathogens and the disease severity vary over space and time, and without computer assistance it is difficult to determine the optimal timing and location for spraying and, more importantly, whether spraying is needed at all. Hence,

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decision support systems (DSS) have been developed to consider strategic decisions for pest control even under complex and uncertain conditions, providing precise risk indicators of an epidemic at field level.

Generally, forecasting models rely on the fact that insects and diseases grow when temperature increases above a base level (T_{min}) and stop when temperature exceeds a limit (T_{max}). In between these limits, number of heat units, or *Growing Day Degrees* (GDDs) can be calculated. Research has demonstrated that many stages of an insects life cycle (from egg laying to hatching) are correlated to the number of accumulated GDDs over a period of time, or when spores are being released by fungal pathogens increasing the infection risk.

For example, in apples, the main GDD model available is for codling moths which predicts time from the 1st major catch of moths in pheromone traps to emergence of larvae of both the 1st generation (250 GDD) and 2nd generation (1200 - 1250 GDD). T_{min} and T_{max} data can also be used in a simpler AHDB (*Agriculture and Horticulture Development Board*) model to calculate daily percentage egg development, and spraying takes place when the accumulated daily percentage exceeds 100%. The downside of this model is, it can only be applied to the emergence of the 1st generation.

Tools and processes frequently used in Austria

In Austria, for example, the *RIMPro* scab forecasting model is used by many farmers to determine the appropriate time for spraying against apple and pear scab. The up-to-date scab forecast data for apple and pear cultivation are provided by the Advisory Council for Viticulture and Pomiculture in cooperation with the Chamber of Agriculture of Lower Austria. *RIMpro* from is used as the scab forecast program for processing the weather data from 10 weather stations. The scab forecasting program RIMpro is financed by the "Beratungsring für Wein- und Obstbau". Moreover, in this specific Austrian case, the weather forecast model *"Bayer Agrar Weather"* and the *"MoreCast Weather App*" are used to determine the time of pre-bloom spraying against *Monilia* in stone fruit. Also, the free online portal *"Plant Protection Warning Service"* with forecasts on weather as well as disease and pest pressure supports growers in decision making.

Tools and processes frequently used in Northern Ireland

In terms of apple scab (*Venturia Inequalis*) control in Northern Ireland, the combination of climate and the fact that the dominant apple cultivar, Bramley's Seedling, a culinary variety, is moderately susceptible to this disease makes it the major disease affecting Northern Ireland orchards. This fungal pathogen disease can affect both leaves and fruit, reducing tree vigour, yield and fruit quality. Failure to control infections will greatly depress yield and quality of apples produced. As a result, nearly 87% of all fungicides used by growers in Northern Ireland are for scab control.

New infection cycles are initiated by the release of ascospores from fruiting bodies on plant tissue, and forecasting models are based on predicting the maturity of the ascospores and their release. The maturity of ascospores is driven by temperature, but the release of ascospores is controlled by leaf wetness and humidity. Infection periods are times when the minimum environmental conditions based on these factors have been met for infection to take place.

To help growers maximise the efficacy of their spray programme, CAFRE (*College of Agriculture and Rural Enterprise*) Horticulture Development Service sends out alerts known as *apple scab infection periods* (ASIPs) during high disease pressure. The alerts are generated by the scientific institute AFBI (*Agri-Food and Biosciences Institute*, **www.afbini.gov.uk**). ASIPs are based on a combination of a revised Mills table[1] along with assessing the daily ascospore release with a Bukard volumetric spore trap (see **Figure 2**). The environmental data (leaf wetness and temperature) needed to calculate infection periods with the Mills table is collected on site.

A number of models have been created since the 1940's to identify apple scab infection periods (ASIPs) based on the Mills table such as METOS (**https://metos.at/agriculture-crops/**) and ADEM (Apple Diseases East Malling) (Berrier *et* Xu, 2003) which rely on data collected from local weather stations. These models provide 'real time' warnings, but other models such as RIMpro (**https://rimpro.cloud/**) use data from weather forecasts to give growers advanced warning of potential infection periods 3 to 4 days in the future. This data

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[1] Mills in the 1940s created a table which could be used to identify infection periods based on duration of leaf wetness, temperature and relative humidity.

can then be used in METOS or ADEM models by growers, or supplied directly to RIMpro to inform the growers of potential apple scab infection periods.

Field Job Implementation

Precision fertilization

Since nutrient deficiencies or surpluses are often site-specific, these localized areas can first be identified using a combination of *near-infrared* (NIR) sensors and drone-based spectral maps to optimize fertilization on an individual basis. This can provide an overview of the nutrient supply of the entire plantation and roughly classify which areas have high, low, or no nutrient requirements as indicated in **Figure 3**.

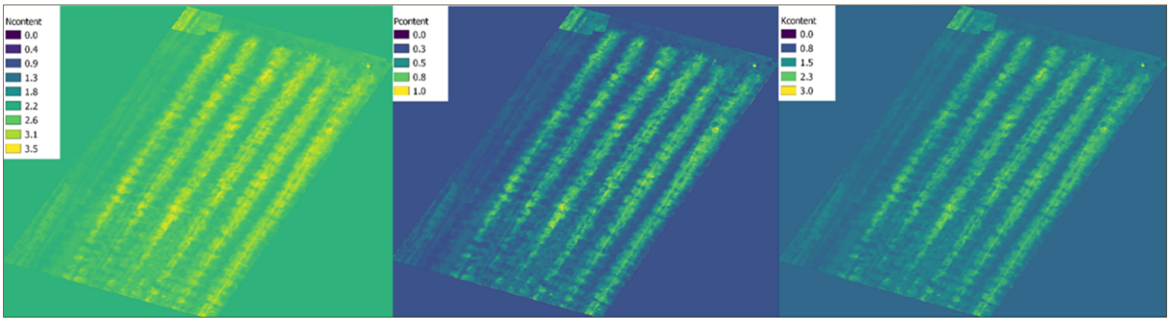

Figure 3: Spectral drone maps of a cherry orchard. (a) Leaf content in % nitrogen (N), (b) Phosphor (P), and (c) Potassium (K), [source: IfU GmbH Privates Institut für Umweltanalysen 2021].

For the subsequent fine diagnosis of these previously defined areas, handheld devices based on NIR technology can be used. These handheld devices allow a quick and non-destructive measurement of the foliar nutrient content on site to define the fertilizer requirement map in detail. Regular monitoring of the N status of the tree (*e.g.*, with non-destructive hand-held NIR sensors) is recommended. At the beginning of the season, at the time of flowering and at the beginning of fruit development, the N demand is highest. As the season progresses, the N content in the leaf usually decreases evenly, which is a good indicator that the fruits are developing well, and that sufficient nitrogen is being stored in the wood.

The NIR maps can be used for precise orcharding to reduce fertilizer use. Especially, targeted fertilization can lead to a more uniform vegetative and generative development of the trees. From an economic and ecological point of view, it is urgently necessary to avoid overfertilization, especially with the main plant nutrient nitrogen. This is because, in addition to the ecological consequences, such as nitrate leaching into the groundwater, too much nitrogen leads to unfavourable N ratios in the tree and the tree strip.

Moreover, excessive nitrogen supply leads to excessive shoot growth with insufficient generative growth (poor fruit coloration, fruit storage disorders) and trees with strong vegetative growth are more susceptible to diseases in the growing season and frost damage in winter. However, developed frost cracks in winter are entry points for pathogens (fruit tree canker, pseudomonas, blood lice, *etc.*). Moreover, aphids always appear first on young vital shoots. So the number of these new shoots should be reduced to a minimum without negative economic consequences. This reduces the leaf area infested by aphids, so that insecticides can be saved (*e.g.*, black cherry aphid in stone fruit: 50%; blood aphid in apple: 50%). When nitrogen fertilizer is applied as needed without excessive shoot growth, the total leaf area to be treated with pesticides is reduced - that is, less pesticide and less spray water are needed. In consequence, targeted fertilization leads to the cost savings: labour hours, pesticide, water, diesel, among others.

Moreover, if too much nitrogen is fertilized instead of being applied as needed, a nutrient surplus is created in the soil, which promotes weed growth. And this, in turn, requires increased effort in weed control. Weed control by mechanical hoeing, however, results in higher nitrate release, which can lead to N imbalance in the tree before harvest and, thus, can negatively affect yield. In addition, nitrate release from hoeing can in turn promote weed growth. And these weeds in turn again compete with the trees for nutrients and water.

Having with precision fertilization a clear example of an indirect method to reduce pesticides, in stone fruit fungicide use can be reduced by 15-20% against spray spot disease. In pome fruit fungicide use can also be reduced by 20-30% because the intervals between scab sprays can be extended. This is because when applying fungicides against scab, it is important to maintain the coating; if the leaf continues to grow, it must be sprayed again because new unprotected leaf area has formed. At the same time, this can also reduce fungicide use against powdery mildew by 20-30%.

Precision blossom thinning

A high number of flowers leads to a higher number of fruits, which are often too small for marketing. In addition, the tree can be weakened by too many fruits and has a higher nutrient requirement. Therefore, it is advantageous if all trees in a production unit have the same number of buds and fruits. Reducing blooms is an effective way to maximize the harvest potential of trees. Since flower density varies from tree to tree, thinning should be adaptive.

With tree-specific mechanical blossom thinning, higher yields can be achieved with the best fruit quality. A stereo camera mounted on the front of the tractor records the existing blossom density per individual tree. This information can be used to control the rotation speed of the rotating spindle brush, which mechanically knocks off the blossoms as it passes. Depending on the density of flowers, the spindle rotates faster or slower and knocks off more flowers when it passes a heavily flowering tree, as for example demonstrated in the SmaArt project (Pflanz, 2020).

Too many flowers/fruits on one tree weaken the tree and make it more susceptible to pests and diseases. Too much variation in the fruit set of trees within a row or field encourages tree heterogeneity, which increases fertilization, irrigation, and pest management effort.

Precision irrigation

Irrigation becomes more and more important due to the draught periods caused by climate change. Targeted irrigation can also lead to a reduction in the use of pesticides. This is because too much water can promote shoot and weed growth.

The aim is irrigation according to the demand of the trees without economic and ecological disadvantages. Incorrect irrigation can, for example, have the following negative effects: If the dripper is too far from the tree, irrigation will encourage weed growth rather than tree growth. Overwatering can cause waterlogging and lack of oxygen in some soils, which can negatively affect root growth, cause root death, or nutrient leaching. Lack of water, on the other hand, leads to desiccation, prevents the absorption of nutrients from the soil, and leads to a lack of fruiting.

The ineffectiveness of irrigation depends on the field capacity. Subtracting the dead water content from the field capacity gives the usable field capacity. The usable field capacity reflects the plant-available water in the soil. Field capacity depends on soil type, bulk density, soil organic matter, and the thickness of a soil horizon.

There are two types of soil sensors that can determine field capacity. These rely on two different measurement methods to determine the moisture or plant available water in the soil. There is the TDR (*Time Domain Reflectance*) and the FDR (*Frequency Domain Response*). Both are based on the measurement of the dielectric constant. The TDR method measures the transit time of a high-frequency electromagnetic pulse through the soil volume and the FDR method measures the water content indirectly by measuring the dielectric constant.

For a representative calibration of these sensors in the field, it is important to know certain soil properties (soil type, bulk density, average rooting area) at the different sensor depths. It is always nice to have soil sensors at different depths to observe water drainage. An additional weather station on the plantation can measure rainfall amounts and evapotranspiration rates and, together with the data from the soil sensors, provide an irrigation recommendation. Such sensors can be used to reveal the dynamics of plant-available water in the soil and, thus, derive irrigation recommendations based on need.

A respective screenshot of the irrigation data dashboard used at Schwitzky Fruit Farm is displayed in **Figure 4**.

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FIELD CAPACITY DEFICIT -10.0

RUN-OFF 26

SATURATION --

WATER LOSS 7

ET PER IRRIGATION 0.1

Figure 4: Soil sensor values of plantation with water deficit
[Source: Agranimo – Dashboard showing data from Schwitzky Fruit Farm].

If one wants to use other soil herbicides (alternatives to glyphosate), it can be helpful to monitor the water saturation of the upper soil, because classic soil herbicides only work when the soil is sufficiently moist.

Moreover, insufficient irrigation leads to drought stress in the trees. For example, in the Jonagold apple variety, the leaves curl up and in sweet cherries in general, the leaves droop conspicuously. This allows more light into the tree strip, encouraging the growth of light-germinating weeds, which in turn leads to a higher effort in weed control.

In summary, monitoring soil moisture is one way to control tree shoot and weed growth, and another indirect method to reduce pesticide use in pome and stone fruit. Adapted irrigation can regulate tree shoot growth in a way that saves fungicides and insecticides. In addition, targeted irrigation can help reduce weed growth and, thus, to indirectly reduce herbicide use.

Precision spraying

Spraying accounts for approximately 30% of costs in specialty crop production and has a direct impact on harvest quality and market selling price. However, with conventional application equipment, treatment failure is still error prone to incorrect use. Faulty spraying operations due to wrong settings and treatment execution in unfavourable weather conditions are still common practice despite of the detailed instructions given on the compound labels as well as provided by many national and international organisations (Balsari *et* Wehmann, 2018). Errors may entail spray drift (ISO, 2005) and other excessive release of pesticides that may cause serious health problems, especially to sprayer operators/farmers (PAN, 2012) and that enter the food chain, pollute the environment, and endanger biodiversity. Further, treatment failure can cause dangerous pest resistances. As such, studies with conventional spraying equipment indicate that in many cases over 50% of pesticides are not reaching the target organisms, with considerable negative effects for biodiversity, bee life, bystanders, and the ecosystem as a whole (Cunha *et al.*, 2012).

Thus, sprayer manufactures around the world started to include precision agriculture technology to their conventional sprayer range, converting atomizers/nebulizer sprayers (*i.e. air blast* and *mist blowers* sprayers) into proactive cloud connected *Smartomizers*, with elements and features combating the application error problem.

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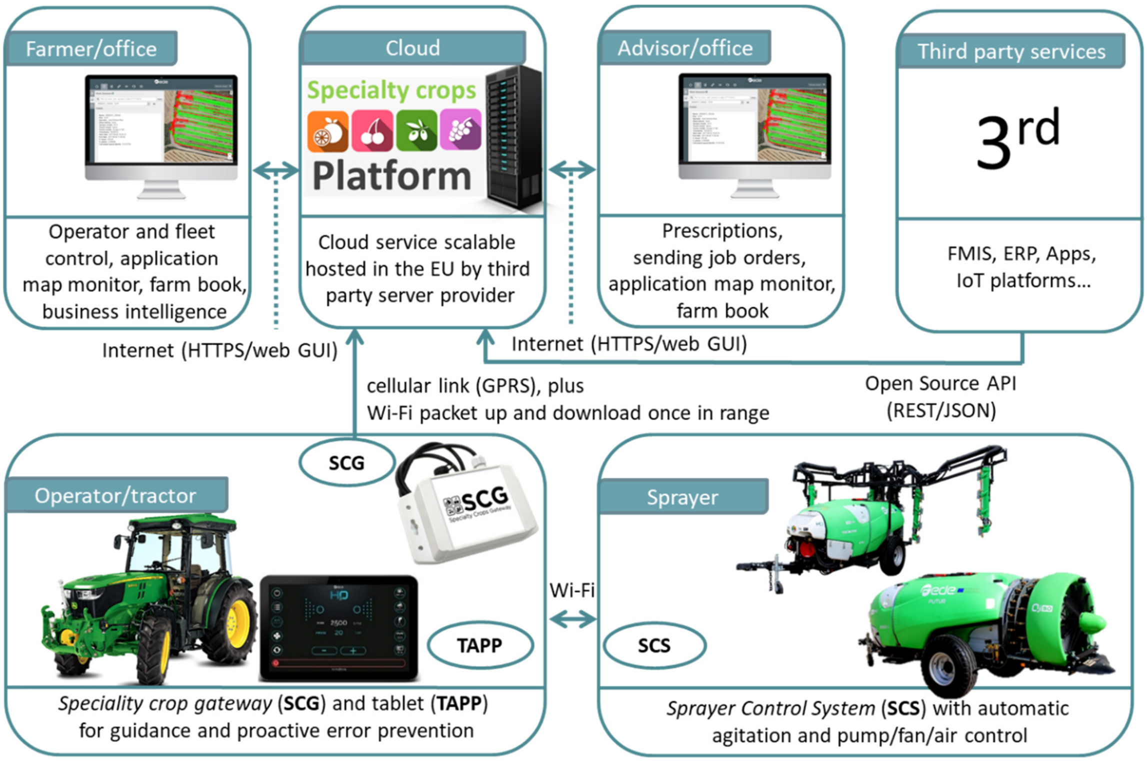
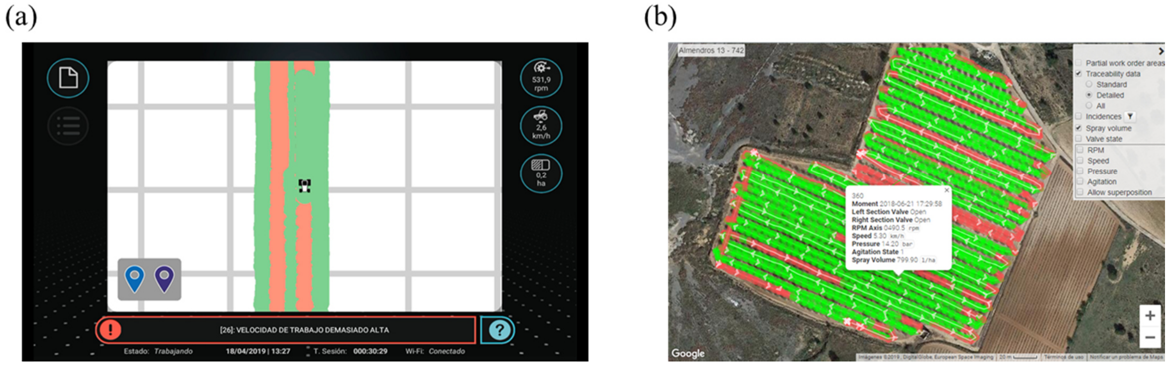


Figure 5: Conceptual deployment view of cloud connected sprayers / *Smartomizers*, based in this example on *Fede* spray components, source (Berger *et al.*, 2019).

The proactive spray system in **Figure 5** connects physical IoT (*Internet of Things*) devices on the implement side - in this case a *sprayer control system* (SCS) (**Figure 5**, bottom right) with a control *touchscreen interface* (TAPP) and a *speciality crop gateway* (SCG) in the tractor's cab (**Figure 5**, bottom left). The SCG contains a global satellite system receiver to guide the operator in real time and to log positioning data during operations for back-office analysis and treatment tractability. Apart, the SCG constitutes a node on the edge network that connects via a cellular link to a private Cloud marked *Speciality Crops Platform* (SCP) (**Figure 5**, top left). This way, farm managers and/or advisors connected to the SCP via web GUI (*graphical user interface*) can perform actions like sending prescriptions and job orders to the tractor operators and machines in the field, as well as monitoring results and post processing data, for example, to automatically produce the farm book that records all plant protection product treatments. The tractor mounted SCG also enables limited control and traceability of non-data capable sprayers, which are hooked up to the tractor's *power take off* (PTO).

If a high-end intelligent sprayer, a so called *Smartomizer*, with embedded *sprayer control system* (SCS) is connected to the SCG, the work order contains sprayer configuration data that allows the sprayer's actuators to adjust the sprayer to field and crop dimensions. Moreover, interoperability of the SCP with *decision support systems* (DSS) or with *farm management information systems* (FMIS), is assured through *application programing interfaces* (APIs), in the specific example on the basis of REST/JSON technology (**Figure 5**, top right).

During spraying application the *touchscreen interface in the tractor's cab* (TAPP) allows real-time job control through both visualization of the application and by receiving warnings in case any critical parameter differs from its expected value (*e.g.* tractor forward speed, *revolutions per minute* (RPM), agitation, pressure), as indicated in **Figure 6** (a). Relaying the machinery and treatment data to the farm management back office allows treatment analysis, while the data is additionally securely stored in the SCP database to allow for full treatment traceability. As such, **Figure 6** (b) shows a typical treatment result map as accessible from the back office GUI.



[26]: VELOCIDAD DE TRABAJO DEMASIADO ALTA

Estado: Trabajando 18/04/2019 | 13:27 T. Sesión: 000:30:29 Wi-Fi: Conectado

360
Moment 2018-06-21 17:29:58
Left Section Valve Open
Right Section Valve Open
RPM Axis 0490.5 rpm
Speed 5.30 km/h
Pressure 14.20 bar
Agitation State 1
Spray Volume 799.90 1/ha

Imágenes ©2019 , DigitalGlobe, European Space Imaging 20 m Términos de uso Notificar un problema de Maps

Figure 6: (a) In cab *touchscreen interface* with proactive operator guidance system (TAPP).
(b) Traceability data of completed treatment in the *Speciality Crops Platform* (SCP),
based in this example on Pulverizadores Fede spray components, source (Berger *et al.*, 2019).

Apart from the significant advances that can already be achieved adjusting the sprayer manually to crop dimensions, the future of spraying clearly goes in the direction of *autonomous spraying*.

While for many years rudimentary crop sensor enabled autonomous sprayers on the basis of *Ultrasound* or *LiDAR* stayed mainly academic prototypes without widespread commercial adoption due to robustness and price-point barriers (Gil *et al.*, 2007; Balsari *et al.*, 2008; Wenneker *et al.*, 2009; Lorens *et al.*, 2010; Doruchowski *et al.*, 2011; Chen *et al.*, 2013), dropping prices for especially LiDAR and 3D stereo vision cameras have made it possible for sprayer manufacturers and spray component suppliers to develop commercial autonomous *variable rate application* (VAR) spraying systems, some of which also perform fine-grain air adjustments and individual nozzle control (Zhu and Ozkan, 2019; He *et al.*, 2019; Chen *et al.*, 2020; Fessler *et al.*, 2020; Manandhar *et al.*, 2020; Warneke *et al.,* 2020; Nackley *et al.*, 2021).

Future developments, will go into the direction of combining autonomously driving and autonomously spraying, with first concept sprayers already appearing in pome and stone fruit production[2]. On the one hand, combining driving and spraying autonomy has the big advantage of precise forward speed control that can be optimized for with respect to the ongoing spraying operation. On the other hand, driving autonomy will allow for a bigger distance between the sprayer operator and the actual spraying action, which increases spraying safety and makes spraying more time efficient as a single operator will be able to handle a fleet of sprayers simultaneously.

While the combination of fully autonomous spraying and driving are certainly very interesting from an operator safety and efficiency point of view, possibly even higher pesticide savings may be realized by a more seamless interconnection between autonomous spraying and precise *decision support systems* (DSS) that indicate precisely where, when, and what to spray, but, most importantly, also when to opt with confidence for not spraying at all.

Conclusion

Precision AG in combination with other approaches like *functional agrobiodiversity*, *orchard redesign*, *redesign of the farm to fork value chain*, and *using plant cultivars and rootstocks with resistance or tolerance to pests and diseases* as discussed in the companion mini-papers (FG44, 2022a) to (FG, 2022e), has the potential to help reduce the use of pesticides in pome and stone fruit production without jeopardizing harvest quality nor quantity, which is very much in line with the EUs moves in the direction of a *Sustainable Use Regulation*[3].

Following the *precision agriculture* (precision AG) cycle of "Sensing, Surveillance and Scouting", over "Fusion, Processing and Decision making" to culminate in "Field Job Execution" in **Figure 1**, modern precision AG systems can indirectly save pesticides, *e.g.* through precision fertilization, precision irrigation, and precision blossom

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[2] **ELWOBOT** is an autonomously driving fruit and vineyard robot with a modular energy supply and electric drive https://www.youtube.com/watch?v=q9Uqe36SsT8; **GUSS**, Autonomous orchard sprayers https://www.youtube.com/watch?v=30nupRuOtdk&t=2s; **John Deere** prototype with **Fede** sprayer here https://youtu.be/sZ0UC6m-pzM;**VitiBot**, https://youtu.be/i8byHtUNbZQ

[3] EU web page "*About the sustainable use of pesticides*" hosting a wealth of related links, including links to the Sustainable Use Regulation proposals: https://food.ec.europa.eu/plants/pesticides/sustainable-use-pesticides_en

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thinning, or in a more direct way through precision spraying in combination with decision support systems that indicate pest risk levels and precise space-time windows where spraying would be highly advisable to keep pests at bay.

As such, with the help of case studies from Portugal, Spain, Ireland and Poland it has been shown that precision AG attributed pesticide savings ranging from 17.65% to over 30% can readily be achieved with present day equipment.

Looking at farmers' payback on precision AG technology investments, economies of scale benefit larger farm operations. There, strategies that merely reduce a small amount of pesticide can lead to operational savings that quickly offset precision AG investments and integration expense. Putting it the other way round, larger farms have more area to divide technological expenses, leading to a lower cost per ha for integration of new technologies. As such, large farms are often in the role of early adopters with the potential of lighthouse effects before precision AG technologies trickle down to medium and small farms as well. Here it has to be acknowledged that small farm investments into precision AG technology does not always pay off quickly. Hence, for small farms financial barriers to precision AG adoption can on the one hand be overcome with the help of subsidies/incentives for the acquisition and adoption of precision AG technologies. On the other hand, barriers might be overcome through collaboration and shared usage. Especially, sharing has the potential to provide small fruit growers with access to specialized machinery to reduce labour and increase both efficiency and profitability. To assure that all sharing-partners have access to the equipment when most needed, careful advanced planning is needed, and industry is ready to provide multi-actor software solutions that allow planning and result tractability with data accessible to small hold farmers as well as application service providers alike.

Introduction and correct use of precision AG technology has to go hand in hand with qualification of farm managers, advisors, as well as farm operators. Also, already the correct and efficient use of existing equipment can size very measureable pesticide reduction benefits. Thus, train-the-trainers programmes, the introduction of precision Agriculture related issues in the education of ongoing agronomists, but also field days and peer-to-peer events where lighthouse farmers pass on their experiences, can have a great impact.

Besides, EU wide harmonization on how to measure pesticide reduction could help to drive precision AG innovation and development. However, any regulation on the means to achieve reductions bears the danger of stifling out of the box thinking and innovation. Also, when it comes to certification, self-certification is key to allow an efficient and high-pace innovation velocity.

Decision support systems (DSS) prediction and early pathogen infection detection models already help growers maximise the efficacy and targeting of their spray programme. However, models have still improvement potential, especially in terms of higher precision of disease models, and fusion of data from different sources could help to increase their prediction quality. Also, the representation of guidance information could be simplified to be better interpreted and followed in practical usage situations. Moreover, looking at what is currently already possible with very precise selective spraying, a seamless connection between DSS and machinery in the field, paired with an increasing portfolio of curative products, could help growers in precisely reacting to pest outbreaks.

Looking ahead, the introduction of autonomously driving and spraying equipment, will, on the one hand, allow variable forward speed control, which adds an important parameter to the optimization of the variable rate application spraying process. Further, fully autonomous sprayers will favour the adoption of bio-pesticides that often require more frequent and very timely spraying operations to keep pests at bay. While first autonomously spraying and driving sprayer concepts appear on the horizon, here we have a clear research line where further funding from the EU could stimulate pesticide reductions and raise EU industry competitiveness.

Summing up, with the *Green Deal* (EC, 2019) and the *Sustainable Use Regulation*[4] the EU has set important directions and Precision Agriculture technology is an enabler of significant pesticide reductions within the transition to a *net zero agriculture* that sustainable delivers food security to the world population while

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[4] EU web page "*About the sustainable use of pesticides*" hosting a wealth of related links, including links to the Sustainable Use Regulation proposals: https://food.ec.europa.eu/plants/pesticides/sustainable-use-pesticides_en

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contributing to "a prosperous and inclusive society where economic growth is decoupled from resource use" (EC, 2019).

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Annex - Case studies

Case – Olive farm in Portugal[5]

The farm *Herdade do Outeiro* is part of *Nutrifarms* (**www.nutrifarms.pt**), a world leader in high-quality olive oil production, with over 7 000 *hectares* (ha) of modern irrigated olive groves in southern Portugal (Alentejo) and Morocco (Marrakesh). Its *vision* is "to manage its farms and mills with the most innovative and sustainable techniques in order to obtain products of excellence".

The precision AG spraying equipment under test at *Herdade do Outeiro* includes an *in-cab tablet based operator guidance and proactive application error prevention system*, precise adaptation of the sprayers to vegetation mass (expressed in terms of *tree row volume* (TRV)), real time back office monitoring of application parameters, as well as the option to correct faulty treatments through partial re-treatment of selective areas if deemed necessary as introduced in (Garcerá *et al.*, 2018 and Berger *et al.*, 2019), following the precision AG system deployment view in **Figure 5**.

In general, reducing pesticides goes hand in hand with using less water to dissolve and transport these pesticides plus potential adjuvants. Further, a fine grain adaptation to the TRV means that the air to transport pesticide and water to the plant is reduced, which has a direct effect on fuel consumed by the tractor.

Moreover, a key element for the roll-out of precision AG solutions is farmers trust. Hence, in the EU LIFE project *Life-F_3* [6] a practical in-field approach is taken to demonstrate savings by running FEDE's *Smartomizer H_3O* and comparing results against existing baseline tracer sprayers at *Herdade do Outeiro*.

To demonstrate that *Smartomizers H_3O* actually achieve the objectives of pesticide, water, and fuel consumption, *Herdade do Outeiro* staff monitored consumptions, as well as the quality of spray distribution in the canopy over the growing seasons 2020 and 2021 for an on farm baseline sprayer and the respective *Smartomizer H_3O*.

At *Herdade do Outeiro* the *Smartomizer H_3O* of type *M120 M2.0* as shown in **Figure 7** (a) is tested with a sprayer configuration that allows a sufficient spray droplet distribution as shown in **Figure 7** (b).

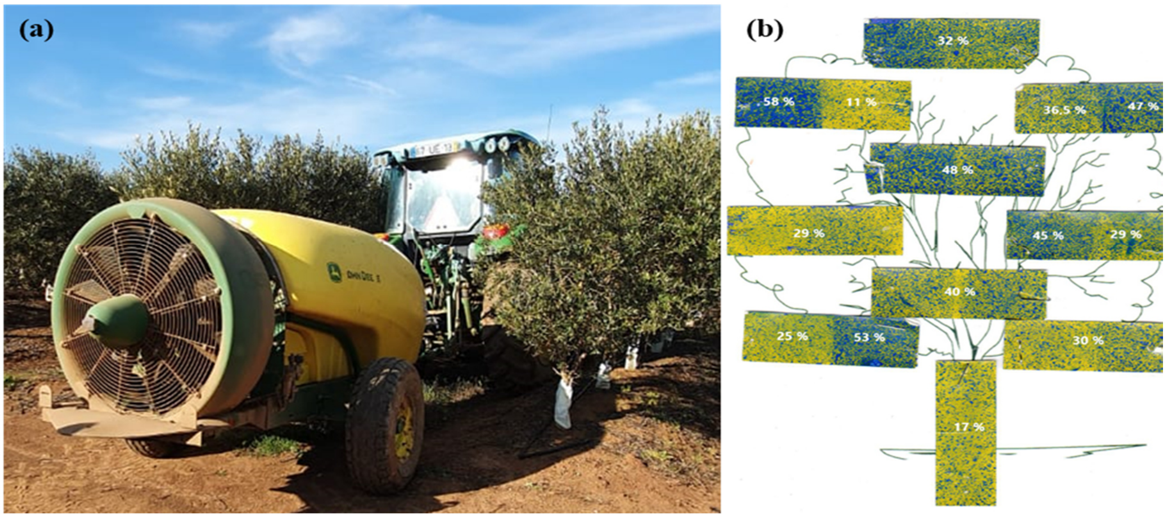

Figure 7. (a) Smartomizer H3O (produced by Fede under John Deere brand) during tests in farm Herdade do Outeiro. (b) Coverage measurement achieved with Smartomizer H3O, source (Berger *et al.* 2022b).

Tests results achieved showed a reduction of spray volume by 17.65% (from 850 L/ha to 700 L/ha), maintaining a coverage higher than 10% in all sample points as shown in Figure 7(b), where the App *SnapCard*[7] is used to determine the coverage on the water-sensitive paper.

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[5] The material in this case study is based on the material in the original publication (Berger *et al.*, 2022b)

[6] *Life **F**arm , **F**resh **F**ruit* (Life-F_3), Grant Agreement number ENV/ES/00349, https://www.fedepulverizadores.com/en/life-f3/

[7] Government of Western Australia, 2013. *SnapCard* (Version 2.1.1). Online: https://agspsrap31.agric.wa.gov.au/snapcard/

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In addition to the 17.65% PPP and spray water reduction achieved, work performance, measured in *ha* treated per hour, improved by around 26% (from 2.25ha/h to 3ha/h) thanks to a tractor forward speed increment from 7.5km/h to 9km/h that becomes possible due to the fact that the *Smartomizer* H_3O requires less tractor power for the actual spraying action albeit at a comparable fuel consumption as compared to the reference sprayer working at 7.5km/h. Thus, *Herdade do Outeiro* staff not only spent less time spraying (with the associated labour cost savings) but also spent approximately 26% less fuel (recalling that tractor fuel consumption while spraying is measured as L/h).

Concluding, while significant positive impacts are achieved for the environment (17.65% PPP, and 26% GHG), there are also important economic savings from moving from the reference sprayer with a cost of 332 €/ha and year to the *Smartomizer* H_3O with a cost of 271.35 €/ha and year.

Case – Codling Moth control in a group of farms in Northern Ireland

In Northern Ireland, Codling Moth (*Cydia pomonella*) is a relatively new pest seen in some orchards over the last 5 years, possibly due to climate change environmental warming.

To monitor presence of Codling Moth in orchards in 2021, plant pheromone traps were placed out in the orchards at the start of June. Pheromone traps give off the scent of female Codling Moths which attracts adult male moths. An economic threshold of 5 moths per week in 2 out of 4 weeks determines when treatment is necessary. This should coincide with egg hatch of the larvae.

The results of placing pheromone traps, with an example shown in Figure 8, in ten orchards throughout the top fruit growing region of Northern Ireland which is located in an area of only approximately a 20 km radius showed traps in 4 orchards for Codling Moth exceeded the threshold of 5 moths per week over a 2 week time period. 2 traps in orchards had below the economic threshold of 5 moths/week/2 weeks with the remaining 4 traps catching no male codling moth in 2021.

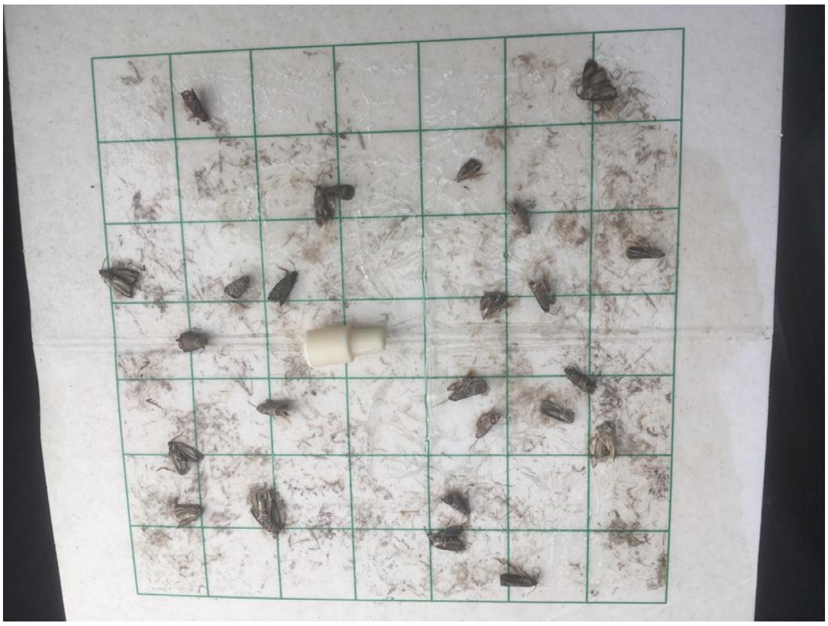

Figure 8. Codling Moth pheromone trap 19 June 2021.

The outcome of this work was that four growers with 102 *ha* of orchards needed to spray to control Codling Moths using Coragen (*200g/l chlorantraniliprole*). The remaining six growers with 88 *ha* who were monitoring their orchards for Codling Moth did not need to spray for the pest. This resulted in those six growers saving in excess of 15 liters of *Coragen*.

Clearly, the checking of traps is labour intensive and the setting of the right thresholds requires specialist knowledge. Precision agriculture, with remote trap monitoring, as offered, for example, by companies like *Trap View*, in combination with a *decision support system* (DSS) that helps to indicate the need for spraying under consideration of the different thresholds, can significantly simplify operations. Going a step further, linking DSS indications directly with the configuration of spray job orders in the cloud, that can afterwards be download to the sprays as in the deployment view of the *Fede* system in Figure 5, would be an additional relive for growers and advisors.

Concluding, using simple off the shelf precision AG technology for the treatment of Codling Moths scaled over the total orchard area for Northern Ireland, pesticide reduction could sum up to about 107 litres of pesticides on a yearly basis for this specific pest alone.

Case – Apple farm in Spain

The Case Study was conducted on a 0.56 ha plot of a commercial Apple orchard located in Épila (Zaragoza, Spain). This is a region where 11% of the Spanish national apple harvest is produced and where *apple scab* is one of the most common diseases in spring and can significantly reduce harvest quality and quantity. Two commercial varieties are planted in the test plot, *Golden Smoothee* and *Galaxy Gala*. Trees are trained in a central leader system with mechanical pruning conducted by rotatory cutting discs. Drip irrigation is available during the whole season.

The *Agricultural Mechanization Unit of the Polytechnical University of Catalunya* (UMA-UPC)[8] coordinated the Case Study in the framework of the EU Horizon 2020 OPTIMA research project[9,10,11]. In terms of precision agriculture technology, the Case Study made use of a pest *early detection system* (EDS)[12] integrated with a Decision Support System (DSS)[13], as well as of a smart sprayer. The sprayer base chosen was an air-assisted *Fede* orchard sprayer (model *Fede Inverter Qi* 9.0)[14] with a tank capacity of 2000 L as shown in **Figure 9**.

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[8] Case Study partner contact details: http://optima-h2020.eu/partners/polytechnic-university-of-catalonia-upc/

[9] OPTIMA - Optimised Pest Integrated Management to precisely detect and control plant diseases in perennial crops and open-field vegetables, project webpage: http://optima-h2020.eu/

[10] EIP-AGRI OPTIMA project page with links to “Practice Abstracts” in the EIP-AGRI Common Format: https://ec.europa.eu/eip/agriculture/en/find-connect/projects/optimised-pest-integrated-management-precisely

[11] Case study related EIP-AGRI Practice Abstract of the OPTIMA Apple case: *Field evaluation of the OPTIMA IPM system: Apple case*, https://optima-h2020.eu/wp-content/uploads/2022/07/pa26_en.pdf

[12] mainly developed by Wageningen Research, Case Study partner contact details: http://optima-h2020.eu/partners/wageningen-research-wr/

[13] mainly developed by AGENSO, Case Study partner contact details: http://optima-h2020.eu/partners/agricultural-environmental-solutions-agenso/

[14] Case Study partner contact details: http://optima-h2020.eu/partners/pulverizadorees-fede-s-l-fede/

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Figure 9. OPTIMA Smart Sprayer during Épila field trials, source (Berger *et al.* 2022a).

In order to carry out a high-precision spray application, UMA-UPC[8] customised the sprayer base with several ultrasonic sensors as well as controller and spray nozzle actuators. The ultrasonic sensors characterized the canopy and provided information that was interpreted to apply different flows through the spray nozzles. The sprayer was equipped with eleven nozzles per side, although only ten nozzles were used in response to the crop height requirements on site. Three sections were defined per side, with an ultrasonic sensor, a motor valve, and a pressure sensor per section. Upon scanning the vegetation with the ultrasonic sensors, the spray controller calculated the flow-rate per section, obtaining the forward speed from a *Global Navigation Satellite System* (GNSS) and acted on the spray nozzles in real time as described in detail in (Salas *et al.*, 2022). The working pressure was always within the range of 4 to 14 bar and the driving speed was 5 km/h. The sprayer was able to modulate the amount of plant protection product based on canopy structure making use of a newly developed software based on the *tree row volume* (TRV) method (Xun *et al.*, 2022).

Moreover, the cloud-connected sprayer was designed to act in an on/off mode depending on pest maps generated on the basis of EDS information in combination with climate data in the DSS as described in (Berger *et al.* 2022a).

Results from the trial showed that the OPTIMA smart sprayer was able to read the prescription maps and allowed the flow of liquid only when its geo-location was within the defined treatment zone. Outside the map-defined treatment zones, the flow-rate was zero and consequently, the OPTIMA smart sprayer did not operate. It can be concluded, that with respect to on/off zone spraying, the savings potential is significant, as long as the EDS/DSS reliably indicates the areas that do not have to be sprayed.

Moreover, real time variable rate spraying based on canopy structure achieved 23% pesticide savings in comparison to conventional spraying.

Taking both precision AG technologies together it can be seen that pesticide savings can be significant and are readily realizable with existing high-end spraying equipment.

Case – Apple farm in Poland

In Poland, farm PAWLAK has 40 ha dedicated to apple farming and around 1 ha is occupied by buildings, hedges and wildflowers to host pollinators and to contribute to biodiversity. Moreover, the exploitation is run by a passionate early adopter and influencer very active in researching and implementing new technologies and techniques in apple production. As such, PAWLAK is an ideal small hold end user case for studying the usage of precision agriculture technology with the aim of pesticide use reduction.

With the aim to quantify pesticide savings through the use of high-end precision agriculture sprayers with crop sensing capabilities (branded by *Fede* as *AIs*), the high-end *Fede* sprayer as shown in **Figure 10** was tested on

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an apple field of 2,5 hectares in the location of Pniewy (51.899922, 20.789639), Poland, with a 3 m by 1 m planting system and with a 3 m tree height.

Figure 10: *Fede* precision agriculture sprayer with *AIs* crop sensing technology during field trials at 40 ha apple farm PAWLAK in Poland.

Field test analysis was carried out comparing performance and agronomic inputs savings against PAWLAK´s reference sprayer model *Slaze Duet* from manufacturer *Unia*.

Measuring absolute agronomic inputs consumed while keeping pesticide coverage higher than 10 % in all sample points set up via uniformly distributing water-sensitive paper in the canopy and posterior evaluation of paper samples with the App *SnapCard*[7] delivered:

Table 1: Pesticide and other savings at *Case – PAWLAK* due to the use of precision agriculture sprayer with Fede's *AIs* crop sensing technology.

	Reduction	%
Water consumption reduction (L)	-11197.20	-25.0%
Hectares worked each hour (ha/h)	0.49	37.1%
Hours of spraying operation reduction (h)	-30.02	-29.3%
Fuel consumption reduction (L)	-144.11	-29.3%
PPP consumption reduction (units of pesticides)	-84.82	-25.0%
Fuel cost reduction (€)	-187.34	-29.3%
Water cost reduction (€)	-11.20	-25.0%
PPP cost reduction (€)	-9306.32	-25.0%
Operator cost reduction (€)	-150.11	-29.3%
Cost of treatment reduction (€)	-9654.97	-25.1%
Cost of treatment reduction per hectare (€/ha y	-724.30	-25.1%
CO_2 reduction per sprayer - year (kg)	-373.15	-29.3%
CH_4 reduction per sprayer - year (kg)	-0.06	-29.3%
NO_2 reduction per sprayer - year (kg)	-5.36	-29.3%

Table 1 shows in the case of *PAWLAK* with crop sensing technology *AIs*, that it is possible to save 25% water and *plant protection products* (PPP). Further, a fuel consumption reduction of 29% is achieved, implying a 29%

reduction in greenhouse gas emissions. Also, work efficiency increased thanks to the spraying-hours reduction of 29%. Summing up all savings, the overall cost of treatment was reduced by over 25%.

Although precision agriculture sprayers with automatic canopy sensing can bring a plurality of benefits (as little defects on the fruit have huge impact on its market price), the easiest to see cost-benefit is when looking at the amount of diesel fuel and phytosanitary product saved. This heavily depends on farm size (*ha* treated with one sprayer), crop homogeneity, tractor fuel efficiency, the baseline reference sprayer, number of treatments and the cost of phytosanitary products used.

Performing a cost-benefit analysis for the specific situation at *PAWLAK* shows financial savings on agricultural inputs (*i.e.* on pesticides, spray water, tractor fuel and labour hours) of around 760 € per hectare and year. Multiplied by the 40 hectares of PAWLAK's apple farm, gives a total saving of over 30 000 €. Here it has to be mentioned that the amount of savings at PAWLAK is so considerable as PAWLAK handles a significant number of treatments during the year, around 14-15 treatments. In consequence, investments into precision AG spraying equipment pays back for this specific 40 ha apple farm in much less than a year.

Case – Almond farm in Portugal

With disease management, large farm operations struggle to identify means to significantly reduce pesticide usage. This has a lot to do with the fruit conditions required to meet market demand. Additionally, integration of model data as part of DSS has up till now had limited success and is sometimes difficult to manage on a large scale due to the short time requirement to make the spray. To manage pests, many operations instead utilize scheduled cover sprays to reduce disease risk associated with variable weather. Refined disease models are critical for fungicide reductions since fungicides must be applied before the plant is infected as fungicides work best as plant protectants and there are very few (if any) curative fungicides.

Thus, irrespective of fine-tuning challenges, technology has a major role in assisting farms with reducing pesticide. Strategies may range from small non-technological steps to more advanced integration of modern technology. For example, on farm *Rota Unica*, with more than 2000 ha of almonds under management in the region of Evora, Portugal, it was found that providing accurate measuring tools at the fill stations and training pesticide applicators on how to properly use the measuring tools has led to an average 5% reduction in pesticide use. Hence, *Rota Unica* has begun to integrate "nurse tanks" which provide pre-mixed pesticide solutions to the spray rigs within the field. This job is often performed by two or three people, with specialist training in and high command of pesticide handling. Apart from the already mentioned 5% pesticide savings, this has reduced the time required to spray the orchard by 8%.

In a more advanced technological setting, the use of "electronic eyes" on spray rigs to spot vegetation reduces the amount of material sprayed per hectare, while also reducing off-site movement of pesticide. Using "electronic eyes" in the one and two year old orchards at *Rota Unica* has led to a 20% to 30% reduction of pesticide in these first few growing seasons. These savings often provide a payback for the "electronic eyes" technology within 3 to 4 years, especially if planting of new orchard blocks occurs over multiple years. However, it is important to note that these savings are not realized as the orchard canopy increases in size which means that the amount of gaps between trees are diminishing.

Accurate and effective spray coverage is a major barrier for all farm operations, and can lead to poor performance or fungicide/insecticide resistance formation. Spray rigs must be operated at the appropriate speed, applying the appropriate volume at the correct pressures to maximize coverage. This often occurs at very low speeds (3.5-5 km/hr), and when wind speeds are not too high. However, many operations fail to follow these guidelines due to the short timeline to apply pesticides (3-5 days). This timeliness will become increasingly critical if reduced risk, biological pesticides are integrated into the system since they tend to target specific stages of the pest or disease. To manage, operations will need to either purchase additional equipment, and hire additional operators or rely on contract services. However, increasing work force or outsourcing can bring in increased risk of human pesticide application errors (if not kept at bay for example with proactive spray rigs and cloud traceability of spray parameters). Thus, within *Rota Unica* the use of autonomous herbicide and canopy spray rigs is investigated. The ability to integrate remote sensing tools into the equipment will allow the pesticide to be applied only to the tree or targeted weeds. Although the rigs will cost substantially more (*e.g.*

GUSS systems from USA are priced over 100,000 euros) and have limited functionality since they can only be used for spraying, they do have a reasonable payback. As an example, we have demonstrated that a 10% reduction in pesticide use due to more accurate spray targeting can save 2-4 euros/ha per spray application, depending on the product used. Additionally, there will be a reduction in labour hours as one person would be able to manage multiple rigs. Considering that it often takes 0.5-1.0 hour to spray a ha, depending on the crop, this could have additional savings. It is also important to note that the rig supervisor position will require a more specific skillset and most likely higher salary.

Turning to pest management systems and other technologies, integrations at *Rota Unica* have proven more difficult. Often hardware purchased is not truly automated and requires weekly maintenance that takes as much time as traditional products. Within the USA, there have been several successful integrations of mating disruption into peach, apple, and almond orchards. These orchards utilize aerosol dispensers to emit pheromone, confusing the male moths, preventing them from mating with females. This strategy works well on larger farm areas due to the increased efficiency of aerosol distribution along the edge of the orchards. This edge effect is due to the movement of the pheromone from the point of dispersal. The use of aerosol dispensers with the ability to time release the pheromone has been shown to reduce 1-2 insecticide applications, depending on the crop. Although at *Rota Unica* these tools have finally not been integrated, the use of aerosol dispensers has shown to reduce damage by Navel Orangeworm (*Amyelois transitella)* by 2-3% within California almond operations, while not increasing or even reducing pesticide applications.

Concluding on the experiences at *Rota Unica*, unless consumer sentiment changes, and consumers learn to accept disease or insect infested fruit, pome and stone fruits will be reliant on some type of pesticide. Improved communication of new, low active ingredient, reduced-risk pesticides on the market to farm operators will lead to less pesticide applied. These products will then need to be properly mixed, applied at the appropriate time, and applied to the correct area. Improvement of on-farm pesticide selection and mixing is a reasonable short-term goal and could provide a 5-40% reduction in pesticide use, depending on the farm and specific crop. For example, using the target-specific *chlorantraniliprole* at 280 ml/ha provides the same control of *Anarsia lineatella* as 480 ml/ha of the broad spectrum insecticide *acetamprid*. Improving spray application methods can provide medium term reductions, reducing pesticide use by an additional 10%. Furthermore, these goals will also be useful when utilizing reduced risk pesticides and have been demonstrated on larger farms to provide operational savings, which can offset the investment. In the longer term, improved insect and disease models and sensing equipment can lead to improved timing of pesticide products, potentially reducing the need for some applications. Removing a single spray from the operation will reduce pesticide usage by 5-15%, depending on the cropping system.

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