OPTIMA - OPTIMISED INTEGRATED PEST MANAGEMENT FOR PRECISE DETECTION AND CONTROL OF PLANT DISEASES IN PERENNIAL CROPS AND OPEN-FIELD VEGETABLES

Athanasios Balafoutis[1], Nikos Mylonas[2], Spyros Fountas[2], Dimitris Tsitsigiannis[2], Paolo Balsari[3], Massimo Pugliese[3], Emilio Gil[4], David Nuyttens[5], Gerrit Polder[6], Fausto Freire[7], Jose Paulo Sousa[7], Mathilde Briande[8], Valerie Le Clerc[8], Jean-Paul Douzals[9], Amedeo Caffini[10], Lars Berger[11], Zisis Tsiropoulos[12], Daniele Eberle[13], Sarah Bellalou[14], Andreas Thierfelder[15]

[1]Institute for Bio-economy and Agri-technology, Center for Research and Technology Hellas, Volos, Greece

[2]Agricultural University of Athens, Athens, Greece

[3]University of Torino, Torino, Italy

[4]Universidad Politecnica de Cataluna, Barcelona, Spain

[5]Instituut voor Landbouw-, Visserij- en Voedingsonderzoek, Merelbeke, Belgium

[6]Wageningen University & Research, Wageningen, the Netherlands

[7]Universidade de Coimbra, Coimbra, Portugal

[8]Institute for life, food and horticultural sciences and landscaping – AGROCAMPUS OUEST, Rennes, France

[9]National Research Institute of Science and Technology for Environment and Agriculture - IRSTEA, France

[10]CAFFINI, Verona, Italy

[11]Pulverizadores FEDE, Valencia, Spain

[12]AGENSO, Athens, Greece

[13]Terre da Vino, Barolo, Italy

[14]INVENIO, France

[15]European Crop Protection Association - ECPA, Brussels, Belgium

a.balafoutis@certh.gr, nmylonas@aua.gr, paolo.balsari@unito.it, david.nuyttens@ilvo.vlaanderen.be, emilio.gil@upc.edu, gerrit.polder@wur.nl, fausto.freire@del.uc.pt, valerie.leclerc@agrocampus-ouest.fr, jean-paul.douzals@irstea.fr, amedeo.caffini@caffini.com, lberger@fedepulverizadores.com, tsiropoulos@agenso.gr, eberle@terredavino.it, s.bellalou@invenio-fl.fr, andreas.thierfelder@ecpa.eu

ABSTRACT

OPTIMA is an H2020 research project that will develop an environmentally friendly IPM framework for vineyards, apple orchards and carrots by providing a holistic integrated approach which includes all critical aspects related to integrated disease management, such as i) use of novel biological Plant Protection Products, ii) disease prediction models, iii) spectral early disease detection systems and iv) precision spraying techniques. It will contribute significantly to the reduction of the European agriculture reliance on chemical Plant Protection Products resulting in reduced use of agrochemicals, lower residues and reduced impacts on human health.

Keywords: IPM, biological plant protection products, disease prediction models, spectral disease detection, precision spraying

1. INTRODUCTION

As the global population approaches 9 billion by 2050 (UN, 2015), the UN Food and Agriculture Organization (FAO) expects that demand for agricultural outputs will increase by 60% compared with the annual average from 2005 through 2007, representing an increase of approximately 1% per year. Furthermore, the total crop yield reduction caused by all crop pest species (estimated to be around 67,000 —including plant pathogens, weeds, invertebrates and some vertebrate species) reaches 40% (Oerke et al., 1994). Therefore, global food security is undermined by pests alongside other constraints, such as inclement weather, poor soils and farmers' limited access to technical knowledge (Chandler et al., 2011). Ways to make crop protection more sustainable are required and Integrated Pest Management **(**IPM) is promoted as the best way forward, shown also by its central position in the 2009/128/EC Sustainable Use Directive on Plant Protection Products (PPPs) (EU, 2009).

IPM could make a difference in this effort, as it emphasizes on the growth of a healthy crop with the least possible disruption to agro-ecosystems, and encourages natural mechanisms for pest management (Lamichhane et al., 2016). IPM is a systems approach that combines different crop protection practices and subsequent integration of appropriate measures that discourage the development of populations of harmful organisms and keep the use of plant protection products and other forms of intervention to levels that are economically and ecologically justified and reduce or minimize risks to human health and the environment (Flint and van den Bosch, 1981).

Synthetic PPPs have been common practice in industrialised countries for pest management since the Green Revolution and together with optimised crop varieties, intensive mechanization, irrigation and crop nutrition through rigorous fertilization, they increased agricultural yields significantly (70% in Europe and 100% in the USA (Lamichhane et al., 2016)). Ideally, PPPs are used to exterminate the targeted pests. Unfortunately, the application of PPPs worldwide is being executed with limited consideration to the dosage rate, optimum number of applications, timing and frequency resulting in rampant use of these agrochemicals, under the axiom: "if little is good, much more will be better" (Wasim Aktar et al., 2009), having as result the contamination of natural resources by PPPs, including soil, water, turf and all vegetation types. On the contrary, Bio-PPPs are a particular group of crop protection tools that can substitute or support synthetic PPPs and are ideal for IPM schemes. Bio-PPPs are defined as a mass-produced agent manufactured from a living microorganism or a natural product and sold for the control of plant pests (EU, 2009). That said, Bio-PPPs show attractive properties, such as their selectivity, their little or no toxic residue production, and the significantly lower development costs in comparison to synthetic PPPs (Hajek, 2004).

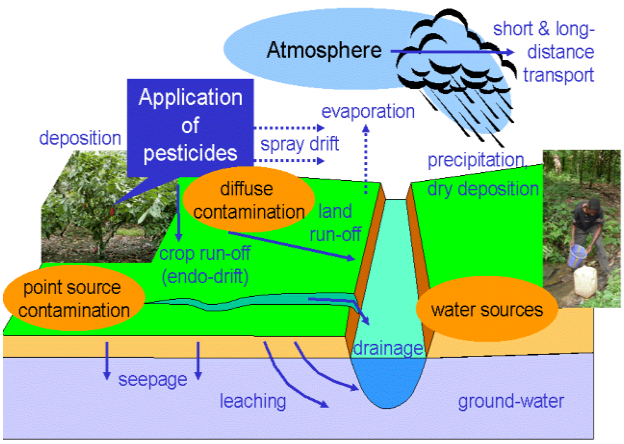

Figure 1: Routes of environmental contamination from PPPs. Source: Wikipedia

PPPs are mainly applied, especially in conventional agriculture, using hydraulic and hydro-pneumatic sprayers. The principle of operation is to convert a PPP formulation that in most cases is diluted in water (or another liquid carrier) into droplets that will be sprayed upon the canopy of the selected crop to spread the chemical compound. Unfortunately, dose-transfer to the biological target (i.e. the pest) through PPP spraying has high inefficiencies and significant amounts of the active ingredient end up elsewhere in the environment (Graham-Bryce, 1977) contaminating natural resources (water, soil, air). There are numerous routes of environmental contamination from PPPs (Figure 1). Contamination can be either point source which is mainly related to the handling of PPPs on a farm during cleaning, filling, remnant liquid management, transport and storage (TOPPS, 2008a) or diffuse source which is mainly related to run-off from field after application, discharge from drainage and off target deposition of spray due to wind (spray drift) (TOPPS, 2008b). Therefore, diffuse sources can be mainly reduced through optimization of spraying technology. Novel spraying equipment targeting to a precise application spraying process uses only the approved and advised amount of PPPs reducing therewith both wastes – such as remnants in the sprayer - and risks, yet ensuring optimised biological efficacy with the greatest input cost effectiveness.

The overall objective of OPTIMA is to develop an environmentally friendly Integrated Pest Management (IPM) framework for use-cases in orchards, vineyards and open-field vegetables by providing a holistic approach which includes the major elements related to integrated disease management: (i) combined use of bio-PPPs and synthetic PPPs, (ii) DSS for disease prediction, (iii) spectral disease detection systems and (iv) precision spraying techniques.

OPTIMA advanced IPM framework will consist of 4 main pillars (Prediction, Detection, Selection and Application), and will focus on plant diseases that annually damage high-value crops (fruits and vegetables) and demand high amounts of fungicides to be applied in numerous spraying applications. OPTIMA will work on apple scab, grape downy mildew and Alternaria leaf blight of carrot, based on the importance of the aforementioned diseases and crops for the European agriculture.

To accomplish OPTIMA's vision, the specific project objectives are:

- Objective 1: Optimize plant disease prediction models and develop advanced early disease detection methods
- Objective 2: Evaluate and screen biological and synthetic PPPs and assess plant and pathogen resistance mechanisms for successful disease control
- Objective 3: Enhance and develop innovative precision spraying technologies
- Objective 4: Test and evaluate the proposed new IPM elements under field conditions
- Objective 5: Assess health, environmental and socioeconomic impacts and risks of the proposed IPM system

2. Methodology

To achieve all specific objectives of OPTIMA and deliver a fully functional IPM system, eight Work Packages (WP) will undertake the required actions, as shown in Figure 2:

1. **WP1** focuses on assessing end-users' requirements following the co-creation approach, while participating in the design and evaluation of the developed products, tools and strategies throughout the project life-time. End-users will also evaluate the features of the demonstrated IPM system in the pilot areas.
2. **WP2** focuses on the development of a DSS for the prediction of grape downy mildew, apple scab and Alternaria leaf blight of carrots based on agro-climatic, pathogen biological cycle algorithms and users' testimonies and on the development of a portable advanced detection system for in-field localization and monitoring of the selected diseases using state of the art machine learning;
3. **WP3** deals with the development of novel sustainable IPM strategies, to be applied as preventive or therapeutic control methods for the selected plant diseases both at experimental and commercial scale. Several biological and chemical intervention strategies will be tested experimentally to expand the range of available tools and the best performing options will be optimised for the optimum application strategy to be pilot testing. The focused diseases will be

Alternaria leaf blight in carrots, grape downy mildew in vineyards and apple scab in apple orchards.

4. **WP4** brings together technological advancement to primarily define optimal spray configuration and parameters for the different crop-disease combinations and reduce spray drift while applying PPPs. These findings together with different variable rate application technologies will be used to develop three smart sprayers for each disease/crop combination.
5. **WP5** is the phase of OPTIMA project that will receive all the components of the IPM system and evaluate them separately and as a whole. The DSS and the disease detection system will be tested in three selected pilot areas, while the efficacy of selected synthetic and bio-PPPs will be evaluated as well. The smart sprayers for each crop will be tested to quantify the improvements on deposition, coverage and drift reduction in comparison to conventional sprayers, at commercial fields. Finally, all components of the IPM system as a whole will be tested in-field and compared with conventional crop protection methods.
6. **WP6** focuses on performing an extended Life-Cycle Assessment (LCA) combined with Human and Environmental Risk Assessment (HERA) using a Multi-Criteria Decision Analysis (MCDA) to identify and quantify the human health, environmental and socio-economic impacts and risks of treatments of the selected crops, comparing the conventional with the proposed IPM crop protection system
7. **WP7** covers the dissemination, communication and exploitation strategy for achieving high visibility of the OPTIMA project results and enable fast exploitation of the developed products.
8. Finally, **WP8** is the project management aiming to achieve smooth evolution of the project regarding technical coordination and monitoring, efficient communication, financial and administrative issues, and appropriate data management.

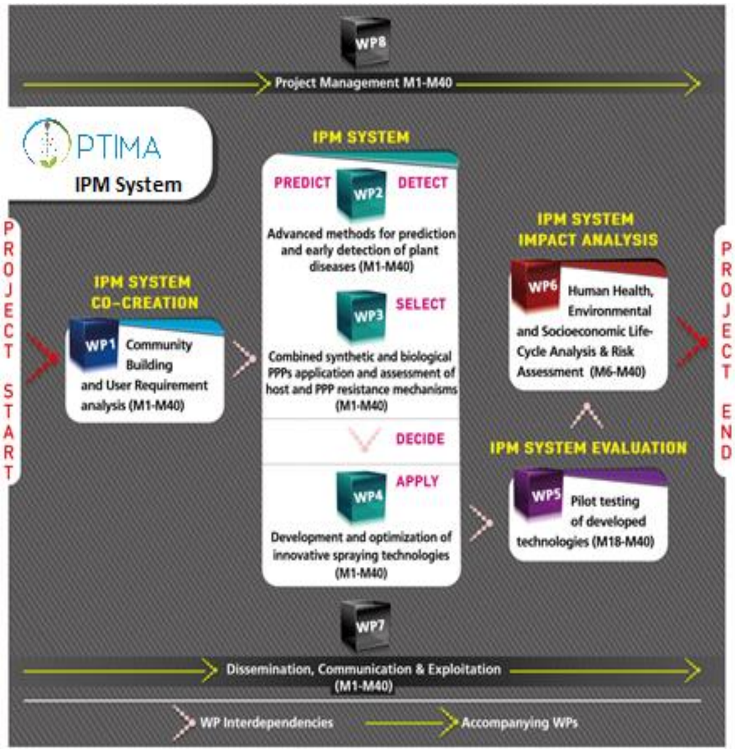

Figure 2: Overall structure of the OPTIMA project

3. Expected Results

OPTIMA will:

1. **optimise already existing disease prediction models** using agro-climatic and biological algorithms; users' testimonies; and geostatistical methods, which will be used for the development of a Decision Support System (DSS).
2. **develop advanced spectral detection systems** for in-field localisation and monitoring of the selected diseases in the use-case crops. OPTIMA's detection system will be used as standalone system providing information at site-specific level that can be used to export the variable rate spraying prescription maps; or as embedded to the three developed in the course of the project smart sprayers for the three crop types, where the image detection results will be transferred directly to the control unit of the sprayer in real-time to adjust the spraying quantity on site.
3. **evaluate a collection of 10 different bio-PPP agents** per host of commercial (market-ready) and under development bio-PPPs (from partner's culture collections) together with selected new generation synthetic fungicides against apple scab, downy mildew in vineyards and Alternaria leaf blight in carrots to identify the most efficient combinations to efficiently control the diseases.
4. **develop three smart prototype sprayers** for carrots, vineyards and apple orchards actuating different nozzle types, sprayer settings and adopting variable rate application control based on optimal selection of spray parameters, canopy and disease characteristics, together with the integration of innovative drift reducing technologies in order to minimize losses to the environment.
5. **follow the co-creation process** to take advantage of the end-users' experience in its functions. After the technical validation and evaluation of the proposed IPM system and according to the numeric assessment of the benefits that will be obtained from the system evaluation in terms of farm economics, environmental and human health protection and social aspects, the pragmatic depiction of the impacts of such system will become clear.
6. **pilot test the OPTIMA developed IPM approach** in three selected use case areas. Trials of the OPTIMA IPM system and its individual components (DSS, disease detection system, combinations of PPPs and smart sprayers) will be carried out to evaluate the improvements and benefits when compared with the normal practices applied in the specific areas. Field experiments will be conducted in close collaboration with the three farmers' cooperatives that participate in the project and will follow the field experiments on a daily basis. Primarily, the developed standalone early disease detection system will be evaluated and optimised in field assessment by correlation with conventional field scouting techniques. At the same time, a data collection procedure will be arranged to quantify the savings on PPPs, water and time. The prediction model will be evaluated in two growing seasons (year 1 and 2) and tested with the other IPM system components in year 3.
7. **field-evaluate the selected synthetic and bio-PPPs combination** using the developed three smart sprayers for each crop. Depending on the crop characteristics, and following the EPPO guidelines for every single crop, a complete evaluation strategy of disease control will be conducted. Good spraying practices and the most accurate working parameters developed by OPTIMA will be demonstrated and compared with conventional practices. Benefits in terms of less PPP amount and less contamination will be measured and explained to the end-users for the purposes of system evaluation.
8. **test and evaluate the three smart sprayers** developed in field conditions to define their ability to generate a safe, efficient and improved spray application process. Over the established experimental plots, field trials will be conducted in order to evaluate the spray quality distribution (deposition on leaves, coverage, penetration, etc.), the risk of drift, the potential reduction of PPP loses, and the capability of the three developed sprayers to adapt the spray distribution to the canopy characteristics. During the field trials a complete canopy characterization using different electronic sensors (ultrasonic, LiDAR, etc.) will be performed to collect the necessary information about the intended target. Once the canopy will be characterized, the smart sprayers will be ready to arrange the Variable Rate Application process

that will be executed either based on previously generated canopy and risk maps, or on the on-going measurements provided by the on-board sensors.

9. **Evaluate and quantify the disease incidence severity** of the three selected diseases at the end of the experimental session
10. **Conduct an extended Life-Cycle Assessment** (LCA) of the complete OPTIMA IPM framework, and a full Human and Environmental Risk Assessment (HERA), together with Social LCA and the economic viability to address life-cycle costs together with scenario and sensitivity analysis.
11. **Conduct a Multi-Criteria Decision Analysis** (MCDA) to fully assess the proposed crop protection systems for apple scab, grape downy mildew and Alternaria leaf blight in carrots based on the complementary use of LCA and HERA.

REFERENCES

UN. (2015) http://www.un.org/en/development/desa/news/ population /2015-report.html, accessed on April 25th, 2019

Oerke E.C., Dehne H-W., Schonbeck F., Weber A. (1994). Crop production and crop protection: estimated losses in major food and cash crops. Elsevier doi: 10.1016/C2009-0-00683-7

Chandler, D., Bailey A.S., Tatchell G.M., Davidson G., Greaves J., Grant W.P. (2011). The development, regulation and use of biopesticides for integrated pest management, Phil. Trans. R. Soc. B, 366 (1573):1987-1998. doi: 10.1098/rstb.2010.0390

EU. (2009) http://eur-lex.europa.eu/LexUriServ/ LexUriServ do?uri=OJ:L:2009:309:0071:0086:en:PDF

Lamichhane J.R., Dachbrodt-Saaydeh S., Kudsk P., Messéan A. (2016). Toward a Reduced Reliance on Conventional Pesticides in European Agriculture, Plant Disease, 100 (1), 10-24. doi: 10.1094/PDIS-05-15-0574-FE

Flint, M.L. & van den Bosch, R. (1981). Introduction to integrated pest management. New York: Plenum Press. doi: 10.1017/S0014479700013715

Wasim Aktar, Dwaipayan Sengupta, Ashim Chowdhury (2009). Impact of pesticides use in agriculture: their benefits and hazards, Interdiscip Toxicol. 2(1): 1–12. doi: 10.2478/v10102-009-0001-7

Hajek, A. (2004). Natural enemies: an introduction to biological control. Cornell University, New York Cambridge University Press, doi: 10.1017/CBO9780511811838

Graham-Bryce, I.J. (1977) Crop Protection: A Consideration of the Effectiveness and Disadvantages of Current Methods and of the Scope for Improvement, Philosophical Transactions Royal Society London, Series B, Biological Sciences, 281 (980): 163-179. doi: 10.1098/rstb.1977.0131

TOPPS. (2008a) http://www.topps-life.org/uploads/8/0/0/3/8003583/_topps_best_management_practices_findoc_070613.pdf

TOPPS (2008b) http://www.topps-life.org/uploads/8/0/0/3/8003583/ansicht_drift_book_englisch.pdf