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Integrated control of root-feeding fly larvae infesting vegetable crops (FlyIPM)

C-IPM Coordinated Integrated Pest Management in Europe

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C-IPM

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Short description on the elaboration of the proposal (earlier projects this project is based on, involvement of end users/farmers/other stakeholders in the design of the project)

The species of root fly on which this project focuses (*Delia radicum, D. floralis, D. antiqua, D. platura* and *Chamaepsila rosae*) have been researched in Europe and North America where they are economically important pests. There is a good understanding of their basic biology and ecology. A number of potential components of IPM strategies have been investigated for one or more species, but control in Europe still relies mainly on the use of insecticides. Components of IPM that have been investigated for one or more species include host plant resistance, cultural control methods, sterile insect release, inundative and conservation biological control with arthropods, entomopathogenic nematodes and fungi, companion planting, intercropping, undersowing, trap crops, physical barriers and decision support (monitoring and forecasting). There is scope for refining and combining some of these approaches and for evaluating them collaboratively in different locations and cropping systems.

The phenology of all species is relatively well understood. Monitoring systems have been developed for all species. Forecasting systems using weather data have been developed in the UK and Germany for *P.rosae* and *D. radicum* and have been used by the respective industries for more than 10 years. In the UK, information on pest activity is disseminated through a web site hosted by Syngenta UK and in Norway through the VIPS program developed by NIBIO and the Agricultural Extension Service.

The University of Rennes (IGEPP) has been investigating the use of volatile organic compounds to manage *D. radicum*. They have shown that it is possible to modify oviposition behaviour under field conditions by using dispensers to release volatile chemicals that significantly decrease the numbers of eggs laid on plants. The aim is to develop a push-pull strategy combining the use of synthetic volatile compounds and attractive *Brassica* cultivars (used as trap crops) to control infestations. The potential for trap cropping has been demonstrated in experimental plots and this approach needs to be tested on a larger scale. This approach requires further development but there may be the potential to combine it with other components of an IPM strategy.

Recent developments in molecular tools mean that the potential for identifying and studying the root-colonizing/endophytic capacity of entomopathogenic fungi (EPF) strains isolated from host-plants and understanding plant-EPF-insect interactions is improved. Several studies have demonstrated promising results by infecting *D. radicum* larvae with EPF under controlled conditions, particularly with *Metarhizium* spp. However, it remains a challenge to target the soil-dwelling larvae in the field. Many EPFs also associate with plant roots, where *Metarhizium* can persist and proliferate in the rhizosphere, and some fungi become endophytic in the root system. Soil drenching of EPF inoculums showed promise in greenhouse and field experiments, but such methods will be challenging to implement in an IPM strategy. Roots grown from seeds inoculated with *Metarhizium* remained infective to root-feeding larvae in greenhouse conditions, indicating that the roots can deliver EPF inoculum in the soil. EPFs appear to be compatible with other natural enemies e.g. parasitoids, suggesting that EPF have limited non-target effects. Furthermore, EPF inoculation may bolster the crop by promoting plant growth.

While entomopathogenic nematodes (EPN) are potentially useful field-applied biocontrol agents for soil dwelling pest insects, their control potential is limited, in the main by ambient temperatures. EPN species have narrow temperature ranges over which they can effectively control pests and these vary between EPN species and strains. Currently, EPN useful for control of *D. radicum* are applied to coincide with oviposition in the field, which invariably is at ambient temperatures unsuitable for optimal efficacy of these agents. Research has shown that the infectivity of key nematode groups, such as the Heterorhabditidae and Steinernematidae, can be enhanced; giving potential for enhanced performance, at both optimal and sub-optimal temperatures. Enhancement can occur following low-temperature storage of EPN in water with particular combinations of temperature and duration. Improving the field performance of these agents could contribute to making them a more robust alternative to current chemical control strategies.

Approaches to IPM of root flies in Europe have been considered on several occasions (e.g. paper by Finch & Collier, 2000; EPPO workshop on *C. rosae* 2009; EIP-AGRI Focus Group 'Integrated Pest Management – focus on *Brassica* species' 2014-2016). Key requirements identified included: reliable, cost-effective and simple monitoring and decision support systems; alternative control strategies with fewer side effects on beneficials; knowledge about alternative ways of applying treatments; better ways of presenting information to growers. Unfortunately, with the exception of some changes in the insecticide treatments applied, and greater use of physical barriers, IPM strategies used commercially to control root flies have not been enhanced in the 16 years since the paper by Finch & Collier was published and, although decision support systems have been available for a number of years, there is scope for improvement. It is also timely to consider the impact of climate change on pest life-cycles in future.

Reference: Finch, S. & Collier, R.H. (2000). Integrated pest management in field vegetable crops in northern Europe – with focus on two key pests. Crop Protection (19), 817-824

Outputs - results of the activities undertaken in the project

Several important vegetable crops grown outdoors in temperate climates can be damaged by the root-feeding larvae of Diptera; the larvae of *Delia radicum* (L.) (cabbage root fly), *D. platura* (Meigen) (bean seed fly), *D. florilega* (Zetterstedt) (root fly), *D. antiqua* (Meigen) (onion fly), *D. floralis* (Fallén) (turnip fly) and *Chamaepsila rosae* (Fabricius) (carrot fly). All species damage the root systems of host plants, and some occasionally attack above-ground plant parts as well. This can lead to considerable losses in crop quality and overall yield. Root-feeding fly larvae themselves are difficult targets for insecticidal control because they are in the soil or inside the plant tissue, and non-systemic insecticides applied as sprays do not readily penetrate to reach the target. Adult flies are also difficult targets because there need to be opportunities for them to acquire a sufficient dose of insecticide, either through direct contact or through contact with treated surfaces. Due to environmental and human health considerations, some formerly effective insecticidal active ingredients have been banned in several European countries, making crop protection more challenging for the growers. Overall, there is a European ambition to reduce pesticide use, articulated in the new EU Biodiversity and Farm to Fork Strategies.

The project has focused on the tools and approaches that might be part of an IPM package to manage root-feeding fly larvae on vegetables and this is particularly 1) biocontrol with entomopathogens and nematodes, 2) physical barriers, 3) combinations of attractants and repellents and 4) the development of a push-pull strategy using trap crops. Underlying all of this is a need to know when pests are present, through crop monitoring and weather-based forecasts. With the exception of monitoring and forecasting, very few of the tools are used by growers currently. The research focus was particularly on the cabbage root fly (*Delia radicum*).

The consortium considered the phenology of the target pests and methods of monitoring and forecasting them. A collaborative study led from Norway showed that most populations of *D. radicum* tested were of the early-emerging biotype. Methods of monitoring all species are available and similar monitoring approaches are used in all countries. Day-degree and more complicated forecasting models are available or being developed for all species. The more complicated tools require updating and this is underway for the German SWAT models, but not for the UK models, which need a software upgrade. The likely impacts of climate change have been explored for both *C. rosae* and *D. radicum*. The effects, or possible effects, of climate change on *C. rosae* are already apparent in Switzerland and the UK, where the life-cycle appears to be getting closer to the situation in south-western France.

Research in France identified the best varieties of Chinese cabbage to be used as a trap crop in a push-pull design against the cabbage root fly, *D. radicum,* together with a spatial design that could optimize the effect of this trap crop on the colonisation of broccoli plants by this pest. Volatiles that could be used to manipulate this colonisation behaviour in such a design were unreliable in their effects in the field, but other non-volatile compounds were identified that show good potential. The most effective compound was tested in a large-scale push-pull trial. In this experiment the compound was sprayed onto young broccoli plants (i.e. target crop) surrounded by Chinese cabbage strips (i.e. trap crop). This product displayed a very promising potential to reduce *D. radicum* oviposition but further experiments on product formulation, quantity used, persistence etc. need to be conducted before use in commercial fields.

The activities in WP3 focused on interactions between the plants, biological control agents such as entomopathogenic fungi (EPF) (Denmark) and entomopathogenic nematodes (EPN) (Ireland), and the target pest *D. radicum*. Research produced new insights about practical application methods for entomopathogenic fungi (EPF) and nematodes (EPN), and the effects on control of *D. radicum* larvae under realistic cultivation regimes were evaluated. New knowledge was obtained about the stimuli that influence host-plant fining by *D. radicum* when plants are, or are not, inoculated with EPF, and the application methods showed promise as a "kill" component in combination with a trap crop strategy. Research in the UK showed that the broad range of temperature regimes under which EPF are active demonstrates their versatility independent of origin. Temperature conditioning of EPN did not seem to improve mortality and crop damage, but adjustments of application rates and EPN concentrations may enhance control efficacy against *D. radium* larvae in the field.

Other control methods were investigated, both as individual practices and in combination. The tactics investigated included a large field experiment in Norway with cauliflower as the main crop and the following methods to reduce attack by *D. radicum*: trap cropping (Chinese cabbage as trap), repellent+trap crop, exclusion fences, trap crop+exclusion fences. There was a clear reduction in attack rate in the treatments with exclusion fences with or without trap crop, compared to all other treatments. Greenhouse and field experiments in Switzerland investigated the repellent effects of sage extracts in different formulations and in combination with other IPM tools. Sage extracts were tested in different combinations with an attractant (rutabaga juice), fungal biocontrol agents and insect netting. The sage extracts greatly reduced the number of *D. radicum* eggs laid and the number of larvae that developed on the plants in the greenhouse experiments. The fungal biocontrol agent also reduced the number of larvae and pupae in the greenhouse experiments, as well as the amount of damage in the field experiments. Insect netting was the most beneficial control method in the Swiss field experiments. In an experiment in the UK several biological insecticides were compared either as pre-planting or at planting applications for control of *D. radicum*. Root and foliage weight were greater and root and stem damage was reduced by pre-planting treatment with spinosad (produced from metabolites of soil bacteria) or azadirachtin (from extracts of the neem tree). The combination of a reduced dose of spinosad and a fungal control agent gave slightly less effect and the fungal treatment alone showed little difference from the control. Field trials in Germany in 2018 and 2019 investigated fungi and nematodes as biological control agents for *D. radicum*. The 2019 trials added a trap crop and a repellent to combine the elements of push-pull. The timing of the trials was according to the SWAT forecasting model, in order to test the benefits of using this model in an IPM strategy. The 2018 trial showed a significant reduction in *D. radicum* survival in the plots treated with the fungal biocontrol. Overall, the applied biocontrol agents were not very effective in controlling *D. radicum*. The 2019 trial showed that the different methods or "IPM tools" could easily be combined to develop a push-pull strategy. However, more research is needed to optimise conditions to favour the biological control agents.

Of the tools that have been evaluated, there seems to be real potential for improved forecasting systems for several species. In addition to the current use of crop covers to exclude certain pests, vertical barriers seem to be a good option for management of *D. radicum* in certain situations. Whilst the push-pull technique requires further work before it is commercially-viable, there is real potential to use it as part of an IPM strategy for *D. radicum* in future. Interestingly, although this research has confirmed that the mortality of *D. radicum* larvae achieved by the fungal pathogens tested is 'too late' to protect the current crop, it could be applied to a trap crop to improve its function as a 'dead end'.

The consortium members have engaged with stakeholders in Europe through publications and events and papers have been prepared for a wider audience, some of which are published, some under review or in press, and some in preparation. Engagement with stakeholders and knowledge exchange will continue after the end of the project. A number of Masters students have been involved in the research. In conclusion, whilst few of the approaches considered will be taken

immediately into commercial practice the project has identified routes that individual countries might pursue to develop effective strategies and increase the uptake of IPM.

Main results, conclusions and fulfilment of objectives by Work Package

WP1	**Phenology, monitoring and forecasting**
WPL: Rosemary Collier (UK) Responsible partners: FR; DE; IE; NIBIO NO; SL; CH; UK	
Overall summary of main results and conclusions WP1 Each partner has identified the data sets that they hold on root fly phenology and accompanying weather data. Raw data sets are not so freely available as anticipated. Some of the information from partner countries is in press or already published. For the brassica root flies, previous work has shown that different 'diapause' phenotypes exist in some countries. Different populations have varying temperature requirements for diapause completion/fly emergence, which is a challenge for accurate prediction of activity. Such phenotypes have been identified in the UK (*D. radicum*) and Norway (*D. floralis*), while the status in other countries is less clear. Led by NIBIO NO the consortium collected samples of pupae from *D. radicum* populations from various locations around Europe. After winter storage and diapause development, the uniformity of emergence at controlled conditions in the laboratory was tested (NIBIO, Tromsø, Norway). Our results showed that the flies from the Norwegian, French and Irish populations (collected 2018) clearly fall into the definition of early-emerging flies as all flies emerged within 16 days at 18°C (Johansen *et al*., 2019). The flies from the English population, however, had a much more protracted emergence, although the majority of the emerged flies (82 and 59 percent in 2018 and 2019, respectively) fell into the group of early emergers. The distribution patterns obviously have an impact on fly pressure during the season, and monitoring and forecasting systems need to take this into account. European and other approaches to monitoring and forecasting root fly activity and disseminating information have been reviewed and compared. The main monitoring systems are trapping adult flies (water traps or sticky traps) or sampling eggs (directly from soil or with felt 'egg traps'). Egg sampling has been used only for *D. radicum* although it is also feasible to do this for *D. floralis*, *C. rosae* and possibly *D. antiqua*. Treatment thresholds are used in some countries – mostly for *C. rosae* and based on trap captures. Within Europe two forecasting systems are based on simulation models. These are the UK models (*D. radicum*, *C. rosae*) (outputs currently published on the AHDB Pest Bulletin website https://www.syngenta.co.uk/ahdb-pest-bulletin) and the SWAT models from Germany (*D. radicum*, *C. rosae*, *D. antiqua*). The forecasting models for *D. radicum* and *C. rosae* in the UK were validated with recent monitoring data from the UK. The software (MORPH) that runs the models is now outdated and there is little opportunity to obtain funding to update it. With separate funding the algorithms have been extracted and summarised and this information has been used by one company, Agrii, to build the model for *C. rosae* into their bespoke modelling software. The SWAT model has not been formally validated to date because appropriate monitoring data have not been collected, however reports of false predictions are numerous. Germany started to collect and digitize long term monitoring data for *C. rosae* and *D. radicum* from the JKI experimental station in Brunswick, Germany. Furthermore, JKI has started to develop a new software version of the SWAT model, which is compatible with modern operating systems. The new version will be amended with an optimization algorithm to improve the model parameters. However, it will be necessary to feed the model with a large amount of data that are not available yet. There are day-degree models for *C. rosae* and *D. radicum* in Norway and a day-degree model to estimate the development of *C. rosae* damage which originated in Sweden. There are also day-degree models of North American origin for *D. radicum*, *D. antiqua* and *D. platura*. Work is ongoing to establish a day-degree model for emergence of *D. antiqua* in Norway (Thöming et., 2019). The	

potential to forecast infestations of *D. platura* started in this project and is being investigated further in the UK within a new PhD project as this is a high priority for UK growers.

The potential impact of climate change was investigated in Switzerland for *C. rosae* and has been considered in the UK for *D. radicum* and *C. rosae. Chamaepsila rosae* is the most serious pest in Swiss carrot production. Since the early 1990s *C. rosae* has been able to complete three generations in years with a fully humid and warm summer (e.g. 2007, 2014) under conditions in north and central Switzerland, whereas in 2006, 2013, 2015 and 2017 only weak flight activity of the third *C. rosae* generation was observed (Sauer, 2018). During the summers of these years heat waves caused an increase of soil temperature (-10cm) approximately to or above 23°C. These findings are in line with earlier reports that larval and pupal survival or pupal development of *C. rosae* are affected by temperatures within that range. The risk of *C. rosae* developing a third generation is expected to be more unlikely in north and central Switzerland during the following decades. Global warming includes potential shifts in population dynamics of pests. Peak activity might vary more pronouncedly between years. Therefore, monitoring and forecasting systems are of increasing importance for sustainable farming systems. For *C. rosae* in the UK it seems likely that climate change will reduce the size of the second and possibly third generations. Although there is some evidence that this may be happening, the mechanism – aestivation or an effect of high temperatures and drought on survival of eggs/larvae - is not clear. For *D. radicum* in the UK a study in 1991 indicated what the effects of climate change on phenology might be (Collier et al, 1991). Since then research for AHDB (Collier et al., 2015) showed that eggs/larvae will survive the winter if it is relatively mild. Although this is not surprising, at present it is thought that most *D. radicum* overwinter as pupae in diapause. Also, at present, egg-laying ceases relatively early in the autumn once temperatures decline, but a warmer autumn may prolong egg-laying.

The potential for decision support systems to improve the management of root-feeding fly pests of vegetables in Europe has been reviewed by the consortium and submitted as a paper to 'Insects' where it is under review.

Publication

Collier, R., Mazzi, D., Folkedal Schjøll, A., Schorpp, Q., Thöming, G., Johansen, T.J., Meadow,R., Meyling, N.V., Cortesero, A., Vogler, U., Gaffney, M.T., Hommes, M. (2020) The potential for decision support systems to improve the management of root-feeding fly pests of vegetables in Europe. *Insects*. Under review.

References

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- Collier, R.H.; Finch, S.; Phelps, K.; Thompson, A.R. Possible impact of global warming on cabbage root fly (*Delia radicum*) activity in the uk. *Annals of Applied Biology* **1991**, *118*, 261-271, doi:10.1111/j.1744-7348.1991.tb05627.x.
- Johansen, T.J., Cortesero, A.-M., Gaffney, M., Meadow, R., Schorpp, Q., Collier, R. (2020) Phenology of brassica root flies (*Delia radicum* and *D. floralis*) in northern Europe. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Stratford-upon-Avon (UK), 13-16 October, 2019. Edited by R. Meadow. In press.
- Sauer, C. (2019) Possible impacts of climate change on carrot fly's population dynamics in Switzerland. IOBC-WPRS Bulletin: Proceedings of the Meeting at Wädenswil/Arneberg (Switzerland) 02-06 October, 2017. 142:31-41.
- Thöming, G. Folkedal Schjøll, A., Johansen, T.J. (2019). Developing tools for monitoring and forecasting of onion fly *Delia antiqua* in Norway. *IOBC-WPRS Bulletin*, **2019**. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Wädenswil/Arenenberg (Switzerland), 02-06 October, 2017. Edited by R. Meadow. 142, 42-49.

Report on the results obtained (A) and changes to the original plan/ WP objectives (B) by tasks and partners:

WP1- Task 1: Acquire and summarise current and historical data on root fly phenology and accompanying weather data (M1-6)

Each partner identified and summarized the data sets that they hold (if any) on root fly phenology and accompanying weather data. Raw data sets of insect counts with accompanying weather data were not so freely available as anticipated. Some of the information from partner countries is in press or already published.

Partner: CH Agroscope
Results obtained:
Data sets available on *D. radicum* for 15 years from 2 locations – flies and eggs – no accompanying weather data is readily available.

Chamaepsila rosae - Recent data are presented in this paper:
Sauer, C. (2019). Possible impacts of climate change on carrot fly's population dynamics in Switzerland. *IOBC-WPRS Bulletin*, **2019**. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Wädenswil/Arenenberg (Switzerland), 02-06 October, 2017. Edited by R. Meadow. 142, 31-41.

Comments on deviations from original plan:
No deviations from original plan.

Partner: DE JKI
Results obtained:

Data sets are available for *D. radicum* and *C. rosae*. A limited data set is available for *D. antiqua*. Monitoring and climatic data of the last 10 years were sent to UK, University of Warwick for model validation purposes. Pupae were provided for the collaborative study on emergence of adult *D. radicum* from overwintered pupae coordinated by NIBIO NO.

Comments on deviations from original plan:
No deviations from original plan.

Partner: FR IGEPP
Results obtained:

Data sets on egg laying on felt traps set on broccoli and Chinese cabbage plants are available for *D. radicum* for 5 years from 1 location with accompanying weather data. More data, on longer periods of times, are also available from the "Chambres d'agriculture" in western France. However, accompanying weather data are not always available.

For *C. rosae*, interesting information was published by Villeneuve & Latour (2017):

Villeneuve, F. & Latour, F. (2017). A few biological specificities of the carrot root fly (Psila rosae Fabre) for a more accurate forecasting in carrot (Daucus carota L.) production. In: Proceedings of the International Symposium on carrot and other Apiaceae, Angers, France September 17-19, 2014. Acta Horticulturae 1153, 193-199.

Pupae were provided for the collaborative study on emergence of adult *D. radicum* from overwintered pupae coordinated by NIBIO NO.

Comments on deviations from original plan:
No deviations from original plan.

Partner: IE Teagasc
Results obtained:

Data sets available for *D. radicum and C. rosae* collected over the three years of the project at 2 locations. Climatic data corresponding to monitoring data was also collected and available. A review of previous collections of Irish pest trapping was conducted, including published and institutional data, however no substantive data sets were available.

Pupae were provided for the collaborative study on emergence of adult *D. radicum* from overwintered pupae coordinated by NIBIO NO.

Comments on deviations from original plan:

No deviations from original plan.

Partner: NO NIBIO
Results obtained:

First described observations of larval damage to brassica roots in Norway are from 1817 in Northern Norway. Until about 1930, the larvae of brassica root flies (*Delia radicum)* were assumed the cause of the symptoms. Today, it is a well-established fact that the turnip root fly (*Delia floralis)*, belonging to the northern part of Europe, is the dominating species in the northern-most parts of Europe.

In Norway, *D. radicum* seem to have uniform and only early emerging populations. *D. floralis*, however, have a wide range of emergence biotypes, making predictions of emergence and egg-laying difficult. *Delia radicum* have 1-2 generations while *D. floralis* is univoltine (one generation). Other well-established root flies are onion flies (*D. antiqua*, 1-2 generations) and carrot flies (*Chamaepsila rosae, 1-2* generations).

Previous systematic phenological observations and weather data (various projects)

Delia radicum and D. floralis

1975-1980. Emergence cages at six locations in northern Norway, water traps and egg-counting at one location (Tromsø),– including climate data (Johansen & Hals 1990)

1990 -1995. Collection of pupae (1990-Tromsø and Manndalen, 1994-Tromsø). Trials for calculation of base temperature for pupal development. Conclusion: 4 °C for *D. radicum* based on extrapolation of linear relationship between temperatures and developmental rate. For *D. floralis* there was no such linear relationship (more work needed on diapause) (unpublished material).

Delia radicum

Field collection of pupae, several locations around Norway (1999-2000) – emergence in lab. in controlled climate conditions (Johansen and Meadow 2006).

Records of start of egg-laying at about 10-20 locations (2001-2004) – observations of first egg laying and climate data are not complete. Identification to species also lacking, but with assumption of *D. radicum* being the earliest (unpublished data).

Delia floralis

Field collection of pupae (2004-2006). One early and one late emerging phenotype. Emergence data from lab. (Johansen & Meadow 2013).

Delia antiqua

Some old data (1960-ies from emergence cages, and some data for developmental time for larvae and pupae). Limited amount of climate data.

Water trap/sticky trap catches of adults, 2-3 locations (2015-2017) – ongoing ID/counts (weather data from weather stations in the area, not on site)

Field collection of pupae, 4 locations (2016). Emergence data from lab. (limited material, unpublished).

Chamaepsila rosae

Limited material from temperature logging in field together with sticky trap catches (2011-2013, unpublished).

Validating work (Finnish model) with sticky trap catches together with climate data (2008-2014).

Additional work

Delia radicum and *D. floralis*

Much data on egg-laying (species not identified) on many locations over the years are available in VIPS database.

Chamaepsila rosae

Some data for sticky trap catches (2011-2013 on Jæren, South-West Norway) accompanied with temperature logging (Tinytag) are available.

Delia antiqua

Older work by T. Rygg (1960) present the biology of *D. antiqua* based on data from emergence cages. However, results are related to calendar data rather than accumulated temperatures. Climate data are probably unavailable. Some studies at fixed temperatures of development of larvae and pupae are included.

Related publications where climate data are included:

Johansen TJ & A Hals 1990. The biology of *Delia radicum* L. and *D. floralis* Fallèn (Diptera: Anthomyiidae) in northern Norway. Norsk Landbruksforskning 4: 337-350 (In Norwegian with English summary.

Johansen TJ & R Meadow 2006. Population differences in emergence of brassica root flies (Diptera: Anthomyiidae). Environ. Entomol. 35 (5): 1161-1165.

Johansen TJ & Meadow R 2014. Diapause development in early and late emerging phenotypes of *Delia floralis*. Insect Science 21: 103–113. DOI 10.1111/1744-7917.12013.

Rygg T 1960. The onion fly. Investigations on its biology and control in Norway. Bulletin No. 18, The Norwegian Plant Protection Institute (In Norwegian with English summary).

Collaborative study

The two first objectives in WP.1 are: 1) 'confirmation of phenology of root flies in Europe' and 2) 'identification of climate/weather on number and timing of fly generations'. Knowledge on these topics are necessary to develop robust forecasting systems for practical use.

Brassica root flies (*Delia radicum* and *D. floralis*)

For the brassica root flies, previous work has shown that different 'diapause' phenotypes exist in some countries. Different populations have varying temperature requirements for diapause completion/fly emergence, which is a challenge for accurate prediction of activity. Such phenotypes have been identified in the UK (*D. radicum*) and Norway (*D. floralis*), while the status in other countries has not been investigated for many years (Finch *et al.*, 1988). Led by NIBIO NO the consortium collected samples of pupae from *D. radicum* populations from various locations around Europe. The work has been summarised and submitted for publication:

Johansen, T.J., Cortesero, A., Gaffney, M.T., Meadow, R., Schorpp, Q., Collier, R. (2020). Phenology of brassica root flies (*Delia radicum* and *D. floralis*) in northern Europe. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Stratford-upon-Avon (UK), 13-16 October, 2020. Edited by R. Meadow. In press.

Methods

In the autumn of 2017 and 2018, colleagues were asked to dig for at least 100 CRF pupae, and forward them to NIBIO Tromsø, Norway, for emergence studies. Only samples which arrived before the end of January the year after collection, were included in the studies, due to possible post-diapause temperature accumulation during later transport. The samples received were stored at 3-4 °C in moist sand or vermiculite, until the end of February. Then the pupae were washed, and by a quick visual check, samples were sorted for damaged and parasitized pupae and irrelevant species were removed. The remaining pupae were counted and placed in Petri dishes in moist vermiculite and put back to cold storage. For emergence, starting in March, the pupae were kept in a controlled temperature day-light chamber (18°C). The number of emerged flies were recordd every second or third day. The results are presented as cumulative emergence curves showing the percentage of flies from the total number of flies emerged. After emergence, sub-samples of male flies were checked for correct identification based on hair structure on hind femur.

Results

A total of nine samples of pupae from five different countries were received in Tromsø. Unfortunately, the first request for pupae collection, in late autumn 2017, made it difficult for some of our colleagues to dig pupae. This explains the low sample number that year. In addition, the emergence results from four of the samples could not be used in the final result presentation. For Norway 2017 this was due to a late arrival of pupae and possible post-diapause development during transport. Another problem was the very low numbers of flies that emerged in samples from Germany (2017 and 2018) and England (2) in 2018 (Table 1.1). A second sample from England was sent because the first consignment did not arrive within a reasonable time. The low percentage of emergence was obviously caused by heavy parasitism of the pupae, as numerous Hymenopteran and Coleopteran parasitoids emerged from the pupae. Species identification of these parasitoids were not carried out, but a mixed sample were stored.

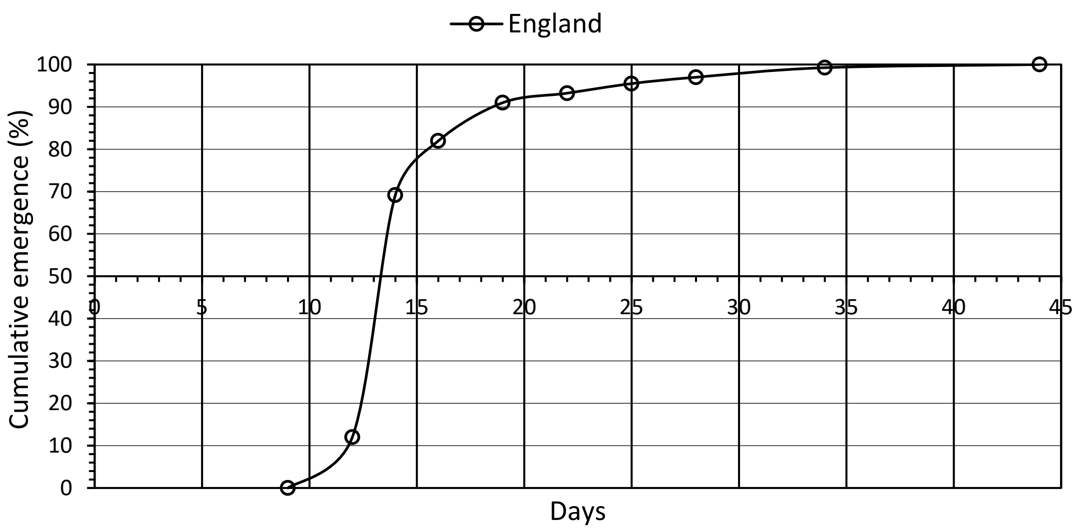
For the five remaining samples, the cumulative emergence curve (based on the percentage of the total number of emerged flies) at 18°C is shown in Fig. 1.1a, b. According to Finch *et al*. (1988), all flies that emerged within 14 days at 20°C were classified as “early emergers”. In our case, at 18°C, this will equal 16 days (224 day-degrees accumulated with 4°C as the developmental zero). Our results show that the flies from the Norwegian, French and Irish populations (collected 2018) clearly fall into this definition of early emerging flies as all flies emerged within 16 days. The flies from the English population, however, had a much more protracted emergence, although the majority of the emerged flies (82 and 59 percent in 2018 and 2019, respectively) flies fell into the group of early emergers (Fig. 1.1 a, b).

Due to the relatively limited number of populations included in this study, general conclusions about differences in emergence patterns is hard to make. Nevertheless, based on our and previous studies (see above), the existence of early, intermediate and late emerging flies, as well as protracted emergence in the spring may occur. The emergence characteristics of *D. radicum* in various European regions should therefore be further investigated and differences be accounted for in forecasting models.

Table 1.1. Emergence of adult Delia radicum from pupae collected from European countries 2017-2018.

Country	Year	No. pupae in exp.	No. flies emerged	% flies emerged	Remarks
Germany	2017	92	15	16	Numerous parasitoids
England	2017	162	133	82	
Norway	2017	132	114	86	
France	2018	860	81	9	Numerous parasitoids
Germany	2018	163	3	2	Numerous parasitoids
Norway	2018	222	185	83	
Ireland	2018	168	148	88	
England (1)	2018	271	64	24	Parasitoids
England (2)	2018	201	19	9	Numerous parasitoids

a) 2018



b) 2019

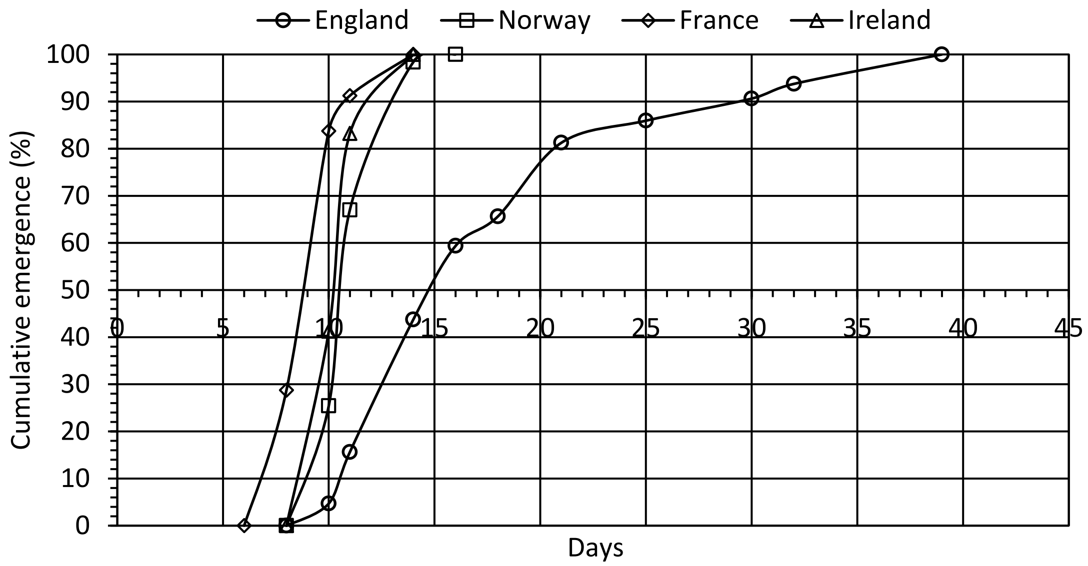


Figure 1.1. Emergence of post-diapausing European populations of cabbage root flies (Delia radicum) at controlled temperature (18 ℃).

Publication

Johansen, T.J., Cortesero, A., Gaffney, M.T., Meadow, R., Schorpp, Q., Collier, R. (2020). Phenology of brassica root flies (*Delia radicum* and *D. floralis*) in northern Europe. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Stratford-upon-Avon (UK), 13-16 October, 2020. Edited by R. Meadow. Submitted.

Reference

- Finch, S., Bromand, B, Brunel, E., Bues, M., Collier, R. H., Dunne, R., Foster, G., Freuler, J., Hommes, M., Keymeulen, M. van, Mowat, D. J., Pelerents, C., Skinner, G., Städler, E. & Theunissen, J. 1988: Emergence of cabbage root flies from puparia collected througout northern Europe. In: Progress on Pest Management in Field Vegetables, eds. Cavalloro and Pelerents: 33-36.

Comments on deviations from original plan:

No deviations from original plan.

Partner: UK University of Warwick
Results obtained:

Data sets on *D. radicum* (egg and fly counts), *D. platura/florilega* and *C. rosae* (fly counts) are available since at least 1999 for Wellesbourne, Warwickshire. Associated weather data are also available – but hourly soil temperatures are only available from 2014. There are 3 generations of *D. radicum* and *C. rosae*. The data on *D. platura* show that there is always one large 'peak' of activity in early spring but after that it is hard to distinguish the subsequent generations (e.g. Figure 1.2).

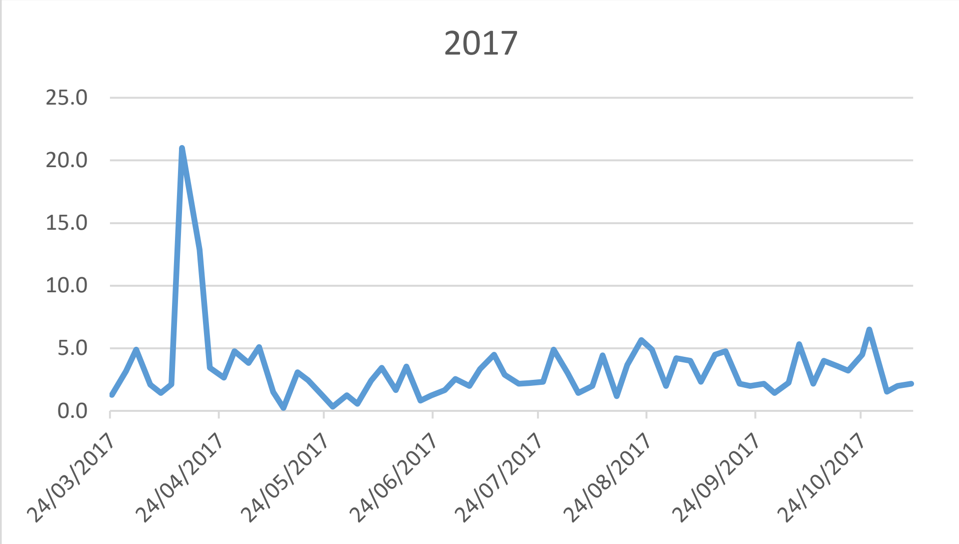


Figure 1.2. Mean number of bean seed flies trapped per day at Wellesbourne, Warwick, UK in 2017.

In southern England, both *D. radicum* and *C. rosae* have 3 generations a year, although it is not clear how much 'damage' is caused by the third generations. In Scotland, both species usually have two generations. In recent hot summers emergence of the second generation of *C. rosae* appears to have been 'reduced' which may be as a result of pupal aestivation.

Pupae were provided for the collaborative study on emergence of adult *D. radicum* from overwintered pupae coordinated by NIBIO NO.

Comments on deviations from original plan:
No deviations from original plan.

WP1- Task 2: Review and compare European and other approaches to monitoring and forecasting root fly activity and disseminating information. Validate forecasting systems for a range of locations using T1.1 data (M6-18)

The main monitoring systems are trapping adult flies (water traps or sticky traps) or sampling eggs (directly from soil or with felt 'egg traps'). Egg sampling has been used only for *D. radicum* although it is also feasible to do this for turnip fly, *C. rosae* and possibly *D. antiqua*. Treatment thresholds are used in some countries – mostly for *C. rosae* and based on trap captures. Within Europe two forecasting systems are based on simulation models. These are the UK models (*D. radicum*, *C. rosae*) (outputs currently published on the AHDB Pest Bulletin website https://www.syngenta.co.uk/ahdb-pest-bulletin) and the SWAT models from Germany ((*D. radicum*, *C. rosae*, *D. antiqua*). There are day-degree models for *C. rosae* and *D. radicum* in Norway and a day-degree model to estimate the development of *C. rosae* damage which originated in Sweden. There are also day-degree models of North American origin for *D. radicum*, *D. antiqua* and *D. platura*. Work is ongoing to establish a day-degree model for emergence of *D. antiqua* in Norway. The potential to forecast infestations of *D. platura* is being investigated in the UK. Validation depends on formatting the available weather data in the appropriate way for each of the models.

Publication

Collier, R., Mazzi, D., Folkedal Schjøll, A., Schorpp, Q., Thöming, G., Johansen, T.J., Meadow,R., Meyling, N.V., Cortesero, A., Vogler, U., Gaffney, M.T., Hommes, M. (2020) The potential for decision support systems to improve the management of root-feeding fly pests of vegetables in Europe. Insects. Under review.

Partner: CH Agroscope
Results obtained:
The group contributed to the work summarised in Collier *et al.* (under review). The SWAT forecasting model for *C. rosae* has been evaluated in Switzerland (published):

Sauer, C. (2019). Possible impacts of climate change on carrot fly's population dynamics in Switzerland. IOBC-WPRS Bulletin, **2019**. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Wädenswil/Arenenberg (Switzerland), 02-06 October, 2017. Edited by R. Meadow. 142, 31-41.

Comments on deviations from original plan:
There were no deviations from the original plan.

Partner: DE JKI
Results obtained:
The group contributed to the work summarised in Collier *et al.* (under review).

The SWAT system has forecasting models for *D. radicum*, *C. rosae* and *D. antiqua* was available to the FlyIPM consortium. The SWAT model is hosted on the ISIP platform for consultants only, not for farmers. The usage of the SWAT model by consultants is not a standard procedure, because the model has not been validated so far. The most frequent use is to forecast the beginning of the flight of the first generation; however reports of false predictions are numerous. Validation for *D. radicum* and *C. rosae* was not possible, due to a lack of data from different locations in Germany. The JKI has collected monitoring data for the last 25 years. But a substantial amount of that data is not in digital form. Monitoring data and climatic data for the last 10 years was sent to the UK for model validation.

Comments on deviations from original plan:
There were no deviations from the original plan.

Partner: FR IGEPP
Results obtained:
Forecasting is mainly based on egg laying activity monitored on felt traps for *D. radicum*. Forecasting of *C. rosae* is mainly based on adult monitoring (sticky traps). Evaluation of the SWAT system was done by Villeneuve & Latour:
Villeneuve, F. & Latour, F. (2017). A few biological specificities of the carrot root fly (*Psila rosae* Fabre) for a more accurate forecasting in carrot (*Daucus carota* L.) production. In: Proceedings of the International Symposium on carrot and other Apiaceae, Angers, France September 17-19, 2014. Acta Horticulturae 1153, 193-199.

Comments on deviations from original plan:
There were no deviations from the original plan.

Partner: NO *NIBIO*
Results obtained:
<u>Forecasting and models in Norway (VIPS)</u>

D. radicum/D. floralis

Model based on accumulated temperatures (day-degrees above 4 °C) for *D. radicum.*

Model based on observations (first egg-laying).

Chamaepsila rosae

Model based on accumulated temperatures (Finnish model).

Model based on observations (trap-catches, sticky traps).

Work going on to validate a Swedish day-degree model for the time of harvest to prevent economical damage by the 2nd generation.

Delia antiqua

Work is ongoing to establish a day-degree model for emergence (Thöming *et al.,* 2019). Some problems with temperature-driven models in Norway are due to a strongly varying climate and too long a distance to weather stations.

<u>Publication</u>

Thöming, G., Folkedal Schjøll, A., Johansen, T.J. (2019). Developing tools for monitoring and forecasting of onion fly *Delia antiqua* in Norway. *IOBC-WPRS Bulletin*, **2019**. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Wädenswil/Arenenberg (Switzerland), 02-06 October, 2017. Edited by R. Meadow. 142, 42-49.

Comments on deviations from original plan:
There were no deviations from the original plan.

Partner: UK University of Warwick
Results obtained:

<u>*Chamaepsila rosae*</u>

Forecasts for *C. rosae* were validated against monitoring data collected at Wellesbourne, Warwick since 2015 (using Rebell^{R} sticky traps) and using weather data from an in-field weather station that records temperatures hourly. Forecasts were run previously using Met Office weather data and hourly temperatures were estimated by interpolation (Phelps *et al.*, 1993). Forecasts of emergence and egg-laying were compared with the monitoring data. An example of the output of the model is shown in Figure 1.3 for 2019. Each year, traps were first placed in the plot of carrots that has been overwintered and contained the population that will emerge (blue). The traps were then moved to a newly-sown plot of carrots (orange). First generation emergence is often quite well-predicted by trap captures in the overwintered plot and egg-laying by the trap captures in the new plot, suggesting that the flies move to the new plot of carrots to lay eggs.

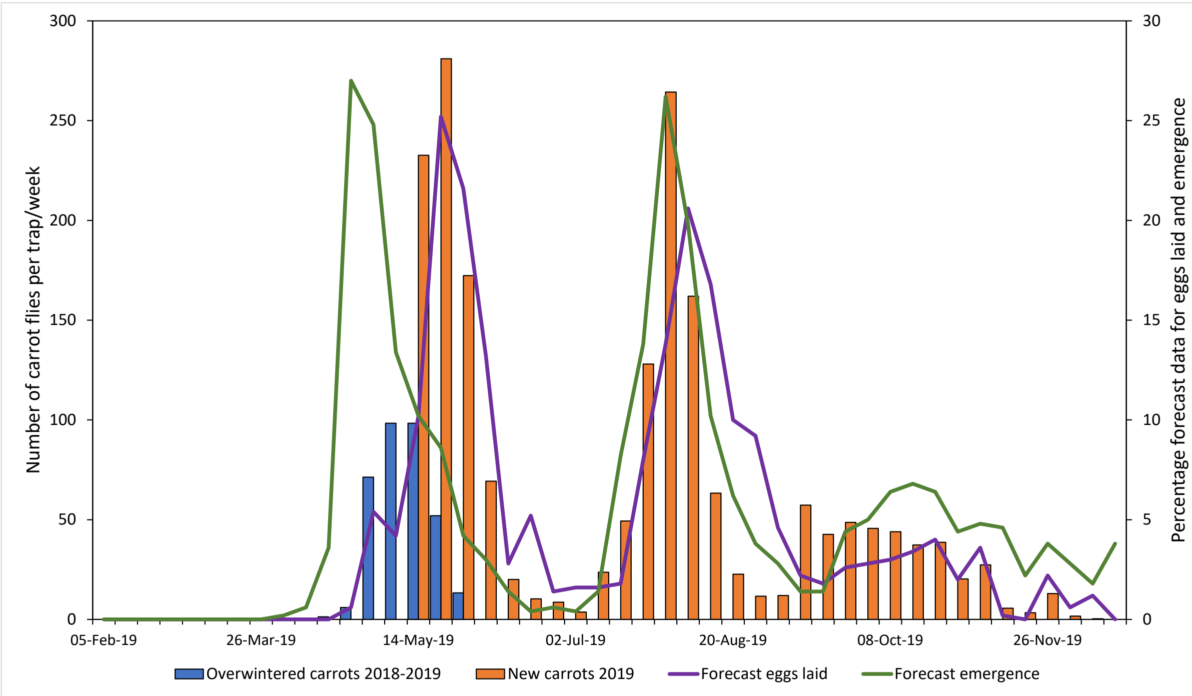


Figure 1.3. Comparison of observed and forecast carrot fly activity at Wellesbourne, Warwickshire, UK in 2019.

For a more formal validation, the dates of observed and forecast 10% and 50% 'activity' were estimated for each generation by interpolation and are presented in Table 1.2. Table 1.2 shows that forecasts of egg-laying provided the best 'fit' for the first generation trap captures, where there is quite a long period between emergence and egg-laying. This period is much shorter at the time of the second generation because temperatures are higher and development is more rapid. The third generation was the least well-predicted.

A paper on phenology of *C. rosae* in the UK and use and accuracy of the UK forecasts is in preparation.

Table 1.2 Comparison of dates of observed and forecast 10% and 50% 'activity' of Chamaepsila rosae at Wellesbourne, Warwickshire, UK, estimated for each generation by interpolation.

	Observed – sticky trap captures			Forecast emergence		Forecast egg-laying	
	Date 10%	Date 50%		10% Observed – expected (days)	50% Observed – expected (days)	10% Observed – expected (days)	50% Observed – expected (days)
1st generation	05-May-14	17-May-14		14	12	-5	-4
1st generation	07-May-15	26-May-15		24	18	5	-2
1st generation	06-May-16	19-May-16		26	14	5	-1
1st generation	05-May-17	16-May-17		22	25	0	4
1st generation	07-May-18	19-May-18			14		0
1st generation	05-May-19	28-May-19			20		-10
Earliest	**05-May**	**16-May**	**Mean**	**21.5**	**17.2**	**1.3**	**-2.2**
Latest	**07-May**	**28-May**	**Mean absolute difference**	**21.5**	**17.2**	**3.75**	**2**
2nd generation	20-Jul-14	06-Aug-14		4	18	0	10
2nd generation	30-Jul-15	18-Aug-15		-4	-4	-10	-12
2nd generation	26-Jul-16	10-Aug-16		-1	0	-7	-9
2nd generation	20-Jul-17	01-Aug-17		-1	2	-8	-6
2nd generation	16-Jul-18	01-Aug-18		6	19	1	12
2nd generation	20-Jul-19	05-Aug-19		1	-1	-4	-8
Earliest	**16-Jul**	**01-Aug**	**Mean**	**0.8**	**5.7**	**-4.7**	**-2.2**
Latest	**30-Jul**	**18-Aug**	**Mean absolute difference**	**2.8**	**7.3**	**5**	**9.5**
3rd generation	01-Oct-14	23-Oct-14		10	2	6	-4
3rd generation							
3rd generation	13-Oct-16	27-Oct-16		-1	-8	-15	-10
3rd generation	01-Oct-17	21-Oct-17		-14	-15	-13	-18
3rd generation	01-Oct-18	14-Oct-18		26	10	15	9
3rd generation	20-Sep-19	15-Oct-19		-17	-19	-14	-15
Earliest	**20-Sep**	**14-Oct**	**Mean**	**0.8**	**-6**	**-4.2**	**-7.6**
Latest	**13-Oct**	**27-Oct**	**Mean absolute difference**	**13.6**	**3.2**	**12.6**	**11.2**

Delia radicum

At the University of Warwick, data are collected annually on the numbers of flies captured in yellow water traps and the numbers of eggs laid around the base of monitoring plants (cauliflower). A typical set of data would look like Figure 1.4. In some years the second and third generations appear to merge or the third generation is not very apparent. Figure 1.5 compares the pattern of egg-laying in 2016 with forecasts of emergence and egg-laying. Female flies need about 80 day-degrees above 6°C to feed and mature their eggs so there is quite a long period between emergence and egg-laying at the time of the first generation. Forecasts were run as for *C. rosae.* For a more formal validation, the dates of observed and forecast 10% and 50% 'activity' were estimated for each generation of *D. radicum* by interpolation and Table 1.3 compares the timing of observed and forecast egg-laying for four years from 2014 to 2017 inclusive. The mid-point of the second generation is the least easy event to predict.

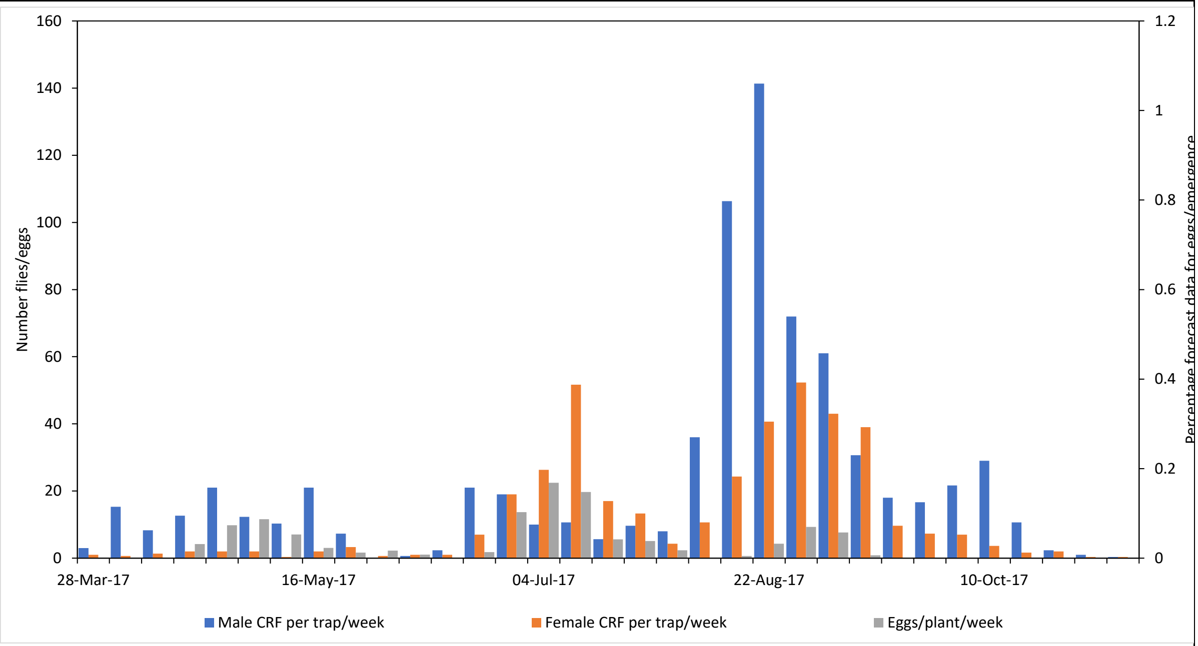


Figure 1.4. Numbers of flies captured in yellow water traps (3) and numbers of eggs laid around cauliflower plants (15) per week at Wellesbourne, Warwickshire, UK in 2017.

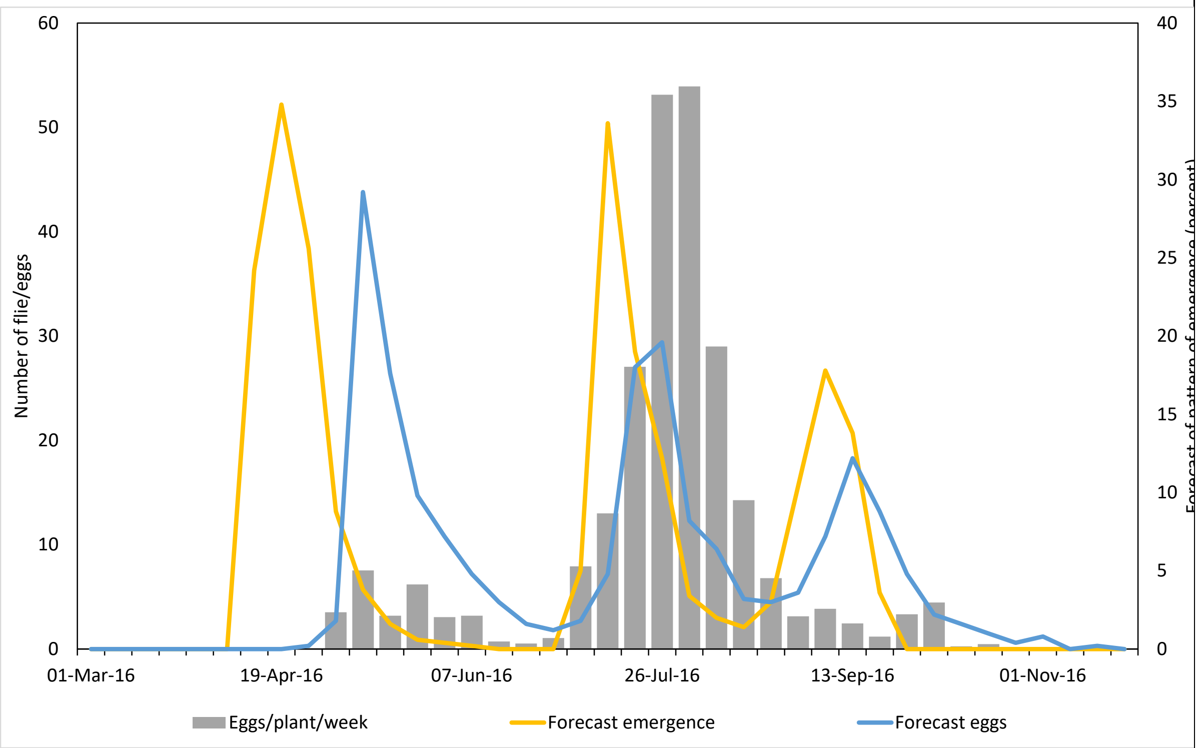


Figure 1.5. Numbers of eggs laid around cauliflower plants (15) per week at Wellesbourne, Warwickshire, UK in 2016 compared with the forecast pattern of fly emergence and egg-laying activity.

Table 1.3. Comparison of the observed and forecast timing of egg-laying activity at Wellesbourne, Warwickshire, UK in 2014-2017.

		Date of 10% egg-laying	Date of 50% egg-laying	10% Observed - forecast	50% Observed - forecast
2014	1st Gen	2-May-14	15-May-14	9	8
2015	1st Gen	6-May-15	21-May-15	2	0
2016	1st Gen	1-May-16	16-May-16	-3	3
2017	1st Gen	18-Apr-17	29-Apr-17	8	-6
Mean				4	1.25
Mean absolute difference				5.5	4.25
2014	2nd Gen	3-Jul-14	19-Jul-14	-2	1
2015	2nd Gen	27-Jun-15	14-Jul-15	5	-23
2016	2nd Gen	12-Jul-16	27-Jul-16	0	5
2017	2nd Gen	23-Jun-17	3-Jul-17	-5	-23
Mean				-0.5	-10
Mean absolute difference				3	13

A paper on phenology of *D. radicum* in the UK and use and accuracy of the UK forecasts is in preparation.

Delia platura/florilega

The University of Warwick has also been working on the development of a day-degree forecast for *D. platura/florilega* and on validating/refining existing forecasting models using the UK data set. The first work was done within the FlyIPM project and this has been taken forward subsequently in a PhD project funded by the University of Warwick and two grower-funded organisations (AHDB and PGRO). Table 1.4 shows accumulated day-degrees above a base of 3.9^{o}C from 1 February to the estimated first peak of activity each year (Sanborn *et al.*, 1982: Anon. 1969). This 'model' is being tested more widely in 2020 by working with several growers and using trap data from commercial crops. This includes testing a system of monitoring fly captures on sticky traps using the Trapview^{R} system. A sticky trap is placed in front of a camera which photographs the trap at least once a day and sends the image to a web site where the trap can be viewed remotely by subscribers to the system. The camera is powered by a solar cell (Figures 1.6 and 1.7). One of the challenges is to identify the *D. platura/florilega* correctly and there is no 'algorithm' at present.

Figure 1.6 Trapview[R] set-up for monitoring D. platura/florilega.

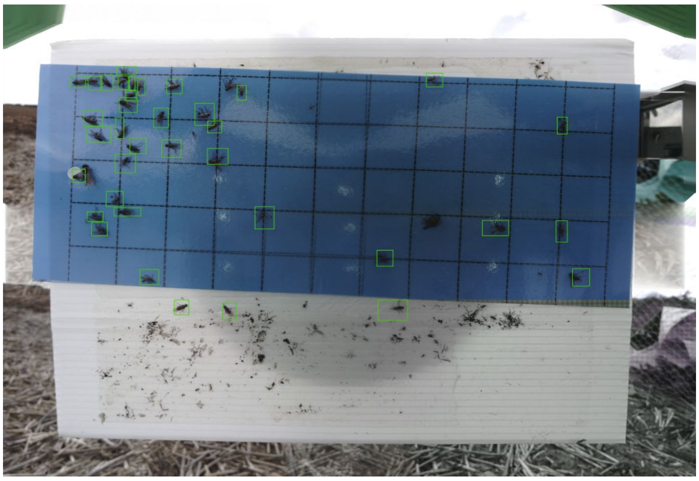


Figure 1.7 Image of sticky trap D. platura/florilega on Trapview[R] web site.

Table 1.4. Accumulated day-degrees for the beginning and peak of the first generation of for D. platura/florilega each year (1999-2019). Daily day-degree sums were estimated from maximum and minimum air temperatures.

Year	Start	Mid-point
1999		450.50
2000	241.15	396.25
2001	252.65	405.30
2002		404.85
2003	302.45	375.20
2004		386.95
2005	286.2	467.55
2006		343.00
2007	498.1	557.75

2008		322.05
2009	333.8	409.00
2010		311.85
2011		360.35
2012		336.90
2013	111.015	250.62
2014	400.08	560.72
2015		355.75
2016	296.8	392.60
2017	321.3	377.20
2018	320.03	398.83
2019	287.05	361.28
Mean	293.49	380.86
SD	31.02	40.68
CV	11%	11%

Delia antiqua

Attempts were also made to start to develop a day-degree forecast using *D. antiqua* from a laboratory culture. Two batches of diapause pupae were used; 1) newly-formed on 16 March 2018 and put into cold storage at 4°C to complete diapause development; 2) newly-formed on 5 February 2019. There were 3 replicates of 50 pupae for each treatment and the pupae were buried at a depth of 10 cm close to the weather station at Wellesbourne. There were also 3 control replicates for each treatment which were kept in an incubator in the laboratory at 15°C. The experiment started on 7 February 2019. The cumulative emergence curves for the total numbers of pupae that emerged per treatment are shown in Figure 1.8 (maximum would be 150). Unfortunately, emergence was very poor in the field, particularly for the oldest batch of pupae. In addition, as would be expected, the newer pupae did not emerge as synchronously as the older pupae, as they did not have time to complete diapause development before the experiment started. In the laboratory, the older batch started to emerge on 27th February (after 20 days) and 50% had emerged by 1st March (after 22 days). In the field 50% of this batch of pupae had emerged by 20th May. Using the threshold temperature determined by Eckenrode et al. (1975) of 4.4°C the pupae in the laboratory required 212 (10%) and 233 (50%) day-degrees to emerge. Using weather data recorded at the nearby weather station, the pupae that emerged by 20th May had required approximately 450 day-degrees above a base temperature of 4.4°C. This result and the poor emergence in the field indicate that further work is required.

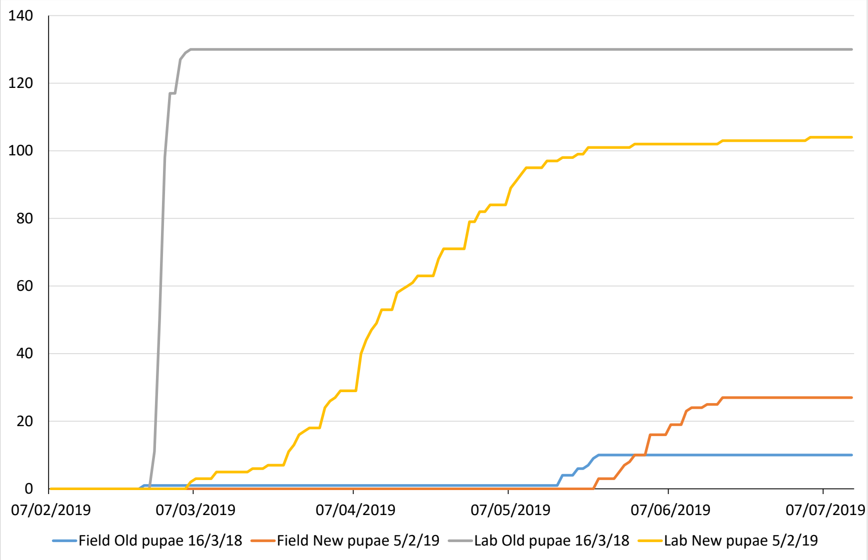


Figure 1.8. Cumulative emergence of adult Delia antiqua from diapause pupae buried in the field or kept in the laboratory at 15°C. Experiment started on 7 February 2019.

Chamaepsila rosae and *Delia radicum*

The University of Warwick attempted to test the SWAT models for *D. radicum* and *C. rosae* using UK weather and monitoring data. However, comparing forecast and actual phenology was very difficult as there is no numerical output from the SWAT model, only graphs. Similarly, it might have been possible to test the UK models with data from overseas but the form of the weather data from overseas was not appropriate for the models.

The software (MORPH) that runs the UK models for *D. radicum* and *C. rosae* is now outdated and there is little opportunity to obtain funding to update it. With separate funding the algorithms have been extracted ad summarised and this information has been used by one company, Agrii, to build the model for *C. rosae* into their bespoke modelling software.

References

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Sanborn, S. M., J. A. Wyman, and R. K. Chapman. 1982. Threshold temperature and heat unit summations for seedcorn maggot development under controlled conditions. Ann. Ent. Soc. Amer. 75: 103-106.

Comments on deviations from original plan:

It had been envisaged that more monitoring and appropriate associated weather data would be available in partner countries than was actually available and so opportunities for forecast validation were very limited indeed.

WP1- Task 3: T1.3 Identify best practice for monitoring/forecasting (M12-30)

Due to differences between 'local' situations and systems, each country identified its own 'best practice' for monitoring/forecasting. Adult *D. radicum* can be captured in water traps or on sticky traps, although it can be more difficult to identify them on sticky traps. Monitoring systems depend mainly on the flies' attraction to particular wavelengths of light (yellow traps are used usually) although some also exploit the flies' responsiveness to host plant volatiles. It is also possible to monitor changes in the numbers of eggs laid around selected host plants either by direct sampling of the substrate (soil or sand) or by using 'egg traps'. Since *D. floralis* infests the same host plants as *D. radicum*, monitoring methods are broadly similar.

Two earlier studies indicated that blue and white traps are more effective than yellow traps for capturing *D. platura*. More recently a synthetic lure has been developed which can be used in conjunction with these traps and this is being tested in the UK in 2020. Most countries do not monitor numbers of *D. platura* and *D. florilega* routinely, while routine monitoring is undertaken at one site (Wellesbourne, Warwickshire) in the UK using yellow traps.

Adult *Delia antiqua* can be captured in water traps or on sticky traps. Research has been undertaken to determine the most effective colour for these traps (blue or white are effective). *Delia antiqua* is not monitored routinely in any northern European country, although in Norway there is a demand for such monitoring.

Adult *C. rosae* can be captured in water traps or on sticky traps but sticky traps are used in most instances. Again trap colour (usually orange) is important. Inclining traps at 45° to the vertical makes them more attractive to, and selective for, *C. rosae*, which prefers to land on the lower surface of the trap.

Most of the information gathered and disseminated about these species relates to their phenology (timing) rather than abundance. One exception is the use of information on numbers of *C. rosae* to deploy treatment thresholds. The use of thresholds for *C. rosae* in northern Europe was reviewed in 2009 following a European workshop on management of this species. Treatment thresholds based on egg counts are used for the *D. radicum*/*D. floralis* complex in Norway. In Germany thresholds have been investigated for *D. radicum*, but are not in use any more due to changes and reductions in the availability of insecticides. The thresholds are only valid for head cabbage, broccoli and cauliflower and are related to the development of the crop.

Forecasting systems have been developed for five species: *D. radicum*, *D. floralis*, *D. platura*, *C. rosae* and *D. antiqua*. All but one of the systems forecast phenology rather than abundance; a Norwegian forecast for *D. floralis* is based on a damage threshold. Day-degree forecasts have been developed in North America for *D. radicum, D. platura*, and *D. antiqua* and are presented on several advisory web sites in North America and are obviously available for use in Europe. In the UK, simulation models have been developed for *D. radicum* and *C. rosae* and in Germany there are simulation models for these species (SWAT) together with a preliminary model *D. antiqua.* In Norway a day-degree model for *D. radicum* has been developed based on spring emergence and the oviposition period. A comparable forecasting model based on day-degrees for *D. radicum* is also available in Denmark based on local soil temperatures for individual postal code areas. All models require current weather data. The day-degree models use air temperature records. Air and soil temperatures are used in the UK, Norwegian and German simulation models.

Table 1.5 summarises the approaches used overall for the target pest species.

Table 1.5 Main root-feeding fly pests of vegetable crops and the types of decision-support tool Available in Europe (see text for further details).

Pest insect	Common name	Plant family affected	Monitoring systems	Forecasting systems	Thresholds Available
Delia radicum	Cabbage root fly	Brassicaceae	Traps using vision and olfaction, egg sampling	Day-degree models, simulation models	Norway, France
Delia floralis	Turnip fly	Brassicaceae	Traps using vision, egg sampling	Warnings are disseminated based on egg counts which are related to damage thresholds	Norway
Delia platura	Bean seed fly	Various	Traps using vision and olfaction	Day-degree models	No
Delia florilega	Root fly	Various	Traps using vision and olfaction	No	No
Delia antiqua	Onion fly	Alliaceae	Traps using vision	Day-degree models, simulation model	No
Chamaepsila rosae	Carrot fly	Asteraceae	Traps using vision	Day-degree models, simulation models	Several countries

Partner: CH Agroscope
Results obtained:

Yellow water traps are used to monitor *D. radicum* and orange sticky traps to monitor *C. rosae.* The SWAT model has been evaluated for *C. rosae* in Switzerland. The SWAT model is used for both species with adaptation to Swiss conditions

Comments on deviations from original plan:
There were no deviations from the original plan.

Partner: DE JKI
Results obtained: In Germany thresholds have been investigated for *D. radicum*, but are not in use any more due to changes and reductions in the availability of insecticides. The thresholds are only valid for head cabbage, broccoli and cauliflower and are related to the development of the crop.

Germany has started to collect and digitize long term monitoring data for *Chamaepsila rosae* and *Delia radicum* from the JKI experimental station in Brunswick, Germany. Furthermore, the JKI started to develop a new software version of the SWAT model, which is compatible with modern operating systems. The new version will be amended with an optimization algorithm to improve the model parameters. However, it will be necessary to feed the model with a large amount of data that are not available yet.

Although a vast amount of parameters can be set in the SWAT model, several of them cannot be used. The main reason for the omission of certain parameters is lack of knowledge about their spatio-temporal dynamics. Even the accuracy for the preferred parameter air-temperature might be inaccurate, due to wrong parameterization and impact of climate change. Soil temperature should only be used until June. Soil temperature is measured by the German Meteorological Service in Grassland where it can be very different to field conditions and vary a lot at small spatial scales. Unless a farmer does not measure soil temperature at his own fields at several locations it gets difficult to use it for reliable forecasts in the SWAT models. The same holds for wind, and soil moisture. Another confounding factor of unpredictable impact is the amount of other brassicaceous crops in the vicinity of a field, such as oil seed rape. Management actions in such crops can cause migration events which elevate flies and egg counts to unpredictable numbers in the fields of interest. More research and innovative approaches are needed to integrate such factors in the SWAT model.

Comments on deviations from original plan:
There were no deviations from the original plan.

Partner: FR IGEPP
Results obtained:

Delia radicum – Use of SWAT model to predict beginning of flight and egg monitoring on sentinel plants with felt traps during the risk period

Chamaepsila rosae – Use of SWAT model to predict the beginning of flight and coloured traps for adults during the risk period.

Comments on deviations from original plan:
There were no deviations from the original plan.

Partner: NO NIBIO
Results obtained: In Norway, a Finnish temperature-based model for day-degree accumulation is used in the VIPS system for forecasting the flight activity period for the first generation of carrot flies. In addition, growers are recommended to use yellow sticky traps to monitor activity. The growers are recommended to spray when the first flies occur but, based on field history and due to the lack of effective insecticides, some growers tend to wait a bit longer before applying the first insecticide spray. After the first insecticide application has been applied, growers are advised to spray when trap catches are four or more flies per trap per week. Damage thresholds are also being used for the *D. radicum/D. floralis* complex in Norway, even though most producers use crop covers. The damage thresholds are related to the plants' developmental stage and indicate the number of eggs per plant that can be tolerated before a reduction in growth and yield exceeding the costs of treatment is expected. There is one threshold for newly-planted cabbage (i.e. head cabbage, broccoli and cauliflower), and another threshold for cabbage that has been in the field for more than 4 weeks. The VIPS system produces warnings based on weekly observations of oviposition related to damage thresholds for the different development stages.

Comments on deviations from original plan:
There were no deviations from the original plan.

Partner: SL University of Ljubljana
Results obtained: No information obtained.

Comments on deviations from original plan:
There were no deviations from the original plan.

Partner: UK University of Warwick
Results obtained:

In the UK, best practice for monitoring and forecasting is as follows:

Delia radicum – yellow water traps, egg-sampling from around the base of a sample of susceptible plants, use of the AHDB cabbage root fly forecast outputs. Attempts are being made currently to determine whether this species can be identified from images of sticky traps or water traps. This is to determine whether monitoring can be simplified.

Chamaepsila rosae – orange sticky traps and use of the AHDB carrot fly forecast outputs.

Delia platura/florilega – current thinking is that growers need to be much more aware of the phenology of these flies. This is because insecticidal control options are very limited on some crops, and not available on organic crops, and cultural approaches are likely to need accurate timing. This might include cover application/removal or delaying sowing if flies are very abundant. There are two aspects 1) more regular monitoring of fly abundance and 2) development of forecasts described above.

As with *D. radicum*, attempts are being made currently to determine whether this species can be identified from images of sticky traps or water traps (blue, white or yellow). This is to determine whether monitoring can be simplified. With a commercial grower this year, a Trapview (http://www.trapview.com/v2/en/) system has been set up to test the feasibility of such an approach (Figures 1.6 and 1.7). In this system, a trap is set up (sticky trap in this instance) and is photographed once or more times a day with a camera *in situ* that is solar-powered. The image is displayed on a web site that is accessible via login details. In this case it is possible to view the trap remotely at frequent intervals. It can be challenging to separate *D. platura/florilega* from closely-related species.

Delia antiqua – this is a localised pest and can be monitored with water or sticky traps but has to be separated from other species using a microscope. A day-degree forecast may be feasible – see above.

Comments on deviations from original plan:
There were no deviations from the original plan.

WP1- Task 4: Use existing forecasting systems to predict the impact of climate change on root flies (M12-24)

It was not possible for all partners to undertake this task, depending on access to forecasting systems and appropriate monitoring data.

Partner: CH Agroscope
Results obtained:

Chamaepsila rosae is the most serious pest in Swiss carrot production. Since the early 1990s *C. rosae* has been able to complete three generations in years with a fully humid and warm summer (e.g. 2007, 2014) under conditions in north and central Switzerland, whereas in 2006, 2013, 2015 and 2017 only weak flight activity of the third *C. rosae* generation was observed. During the summers of these years heat waves caused an increase of soil temperature (-10cm) approximately to or above 23°C. These findings are in line with earlier reports that larval and pupal survival or pupal development of *C. rosae* are affected by temperatures within that range. The risk of *C. rosae* developing a third generation is expected to be more unlikely in north and central Switzerland during the following decades. Global warming includes potential shifts in population dynamics of pests. Peak activity might vary more pronouncedly between years. Therefore, monitoring and forecasting systems are of increasing importance for sustainable farming systems. This work was published:

Sauer, C. (2019) Possible impacts of climate change on carrot fly's population dynamics in Switzerland. IOBC-WPRS Bulletin: Proceedings of the Meeting at Wädenswil/Arneberg (Switzerland) 02-06 October, 2017. 142:31-41.

Comments on deviations from original plan:

There were no deviations from the original plan.

Partner: DE JKI
Results obtained: No work undertaken on this task.

Comments on deviations from original plan:
There were no deviations from the original plan.

Partner: FR IGEPP
Results obtained: No work undertaken on this task. A previous study on *C. rosae* (Villeneuve & Latour, 2014) has shown that the second generation does not 'occur' in very hot years, probably due to pupal aestivation but there is a 'third' generation.

Villeneuve, F.; Latour, F. A few biological specificities of the carrot root fly (*Psila rosae* Fabre) for a more accurate forecasting in carrot (*Daucus carota* L.) production. In: Proceedings of the International Symposium on carrot and other Apiaceae, Angers, France, 17-19 September, 2014. Acta Hortic. 1153, 193-199.

Comments on deviations from original plan:
There were no deviations from the original plan.

Partner: NO NIBIO
Results obtained: No work undertaken on this task.

Comments on deviations from original plan:
There were no deviations from the original plan.

Partner: SL University of Ljubljana
Results obtained: No work undertaken on this task.

Comments on deviations from original plan:
There were no deviations from the original plan.

Partner: UK University of Warwick
Results obtained:

Chamaepsila rosae
As is the case in Switzerland from time to time (Sauer, 2019) and also in France (Villeneuve & Latour, 2017), the pattern of fly activity appears to deviate from the 'normal' three generations and numbers of flies during the second generation and sometimes third generations appear to be very low (Figure 1.9).

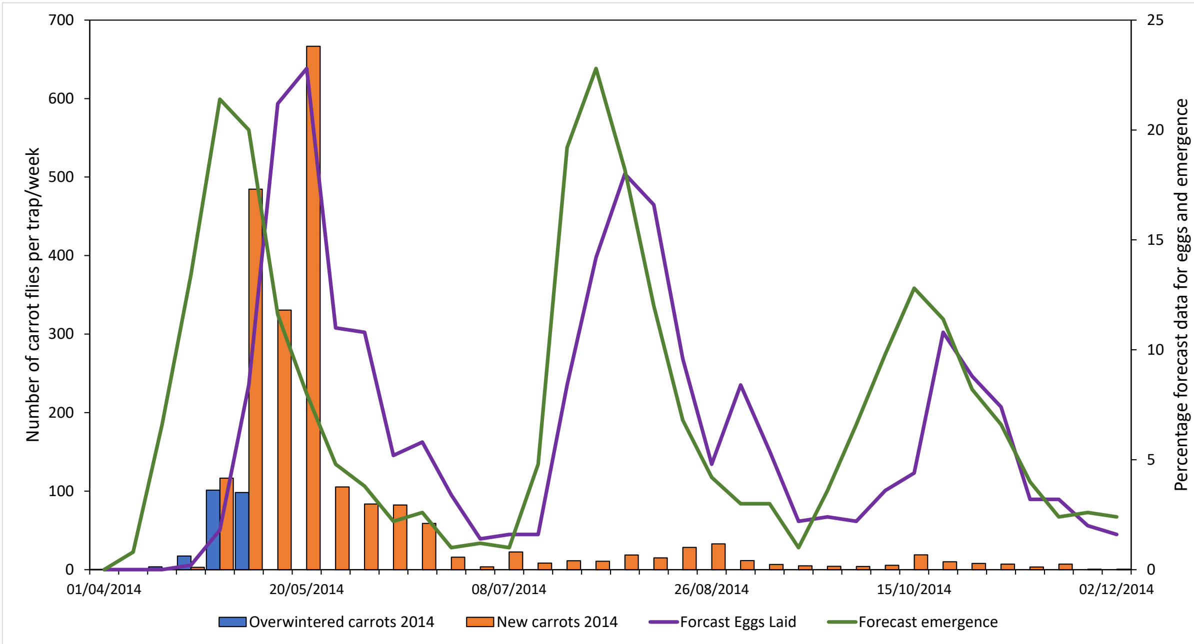


Figure 1.9. Comparison of observed and forecast carrot fly activity at Wellesbourne, Warwickshire, UK in 2014.

A simple 'summary analysis' was undertaken on the data set described in Table 1.2 to see whether the 'effect' on fly numbers could be related to temperature or rainfall during June and July when the immature stages leading to the second generation are developing. In all years the second generation was 'smaller' than the first generation; the greatest difference was in 2014 and the least in 2019 (Table 1.6). Although the greatest difference between the first and second generations was in 2014, this was neither the warmest nor driest year (warmest and driest years highlighted in orange). The smallest difference was in 2019, which was the wettest year (highlighted in blue) but not the coolest (which was 2015 – highlighted in blue).

The UK carrot fly model does have 'aestivation' built into it using data from a study at Wellesbourne, where an increasing proportion of carrot fly pupae were induced into aestivation as the rearing temperature was increased from 24 to 30°C (Collier & Finch, 1996). However, pupae only responded to high temperatures for a relatively short period, soon after their formation. Once they had passed this sensitive stage, they merely developed faster in response to the high temperatures. Aestivation ended and development resumed as soon as temperatures fell. In the model, aestivation is induced when temperatures rise above 24°C and persists as long as the high temperatures persist. For 2014 (Figure 1.9), and indeed for 2018 (Figure 1.10; the warmest year) the forecast did not predict an effect of aestivation. The data for 2019 can be used for comparison (Figure 1.3) and are more 'typical'. Thus, although there is some evidence that climate change may be reducing the relative size of the second and possibly third generations of *C. rosae* in the UK, the mechanism – aestivation or an effect of high temperatures and drought on survival of eggs/larvae - is not clear.

Table 1.6. Fly captures at Wellesbourne in 2014-19 ranked by the numbers captured during the second generation as a percentage of the first generation and compared with total numbers captured during the second generation, the mean soil temperature during June-July and the total rainfall during the same period.

	2014	2018	2016	2017	2015	2019
Rank	**1**	**2**	**3**	**4**	**5**	**6**
Second generation as percentage of first generation	8	18	21	29	45	91
Number	471	186	291	547	506	2175
Average soil temperature	17.60	22.02	17.51	19.05	16.09	18.44
Total rainfall (mm)	4.79	0.81	4.59	3.90	0.98	6.88

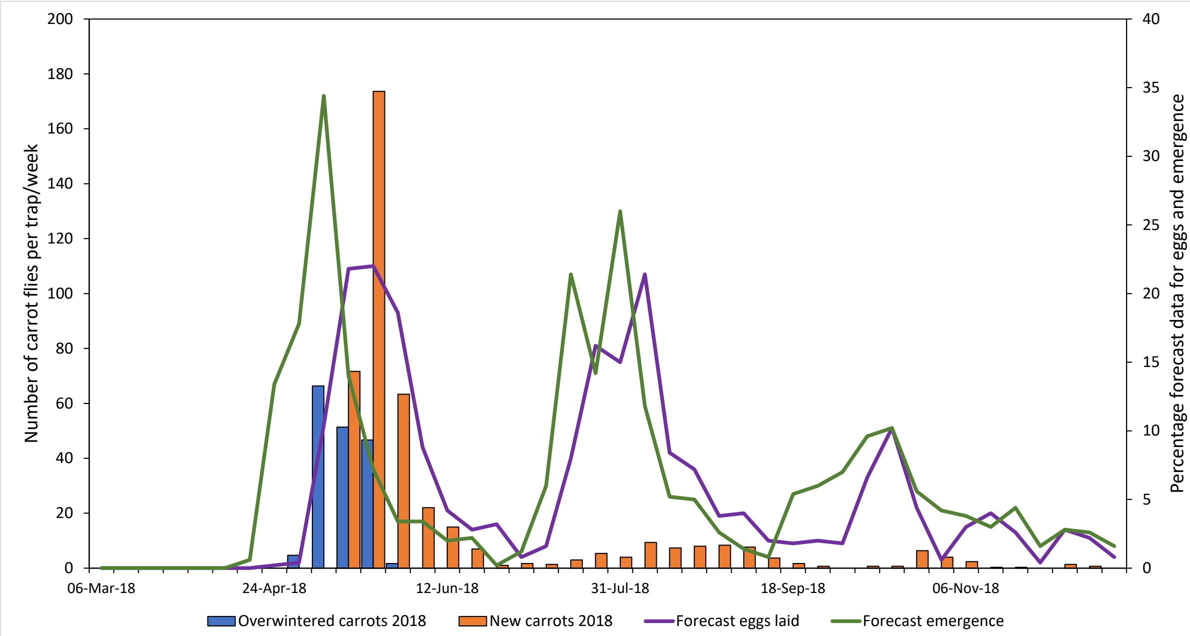


Figure 1.10. Comparison of observed and forecast carrot fly activity at Wellesbourne, Warwickshire, UK in 2018.

In recent years, the carrot fly traps at Wellesbourne have been in place all winter and occasionally a small number of flies have been captured in early spring before the main period of emergence. The carrot fly forecast model also suggests that this will happen.

<u>*Delia radicum*</u>

For *D. radicum* a study in 1991 indicated what the effects of climate change on phenology might be (Collier et al, 1991). Since then research for AHDB (Collier et al., 2016) showed that eggs/larvae will survive the winter if it is relatively mild. Although this is not surprising, at present it is thought that most *D. radicum* overwinter as pupae in diapause. Also, at present, egg-laying ceases relatively early in the autumn once temperatures decline but a warmer autumn may prolong egg-laying.

References:

Collier, R.H.; Finch, S.; Phelps, K.; Thompson, A.R. Possible impact of global warming on cabbage root fly (*Delia radicum*) activity in the uk. *Annals of Applied Biology* **1991**, *118*, 261-271, doi:10.1111/j.1744-7348.1991.tb05627.x.
Collier et al (2015). Brassicas: comparison of treatments to control cabbage root fly. AHDB Project FV 416a. Final Report.
Sauer, C. (2019) Possible impacts of climate change on carrot fly's population dynamics in Switzerland. IOBC-WPRS Bulletin: Proceedings of the Meeting at Wädenswil/Arneberg (Switzerland) 02-06 October, 2017. 142:31-41.

Villeneuve, F. & Latour, F. (2017). A few biological specificities of the carrot root fly (Psila rosae Fabre) for a more accurate forecasting in carrot (Daucus carota L.) production. In: Proceedings of the International Symposium on carrot and other Apiaceae, Angers, France September 17-19, 2014. Acta Horticulturae 1153, 193-199.

Comments on deviations from original plan:
There were no deviations from the original plan.

WP1- Task 5: Disseminate information on best practice for monitoring/forecasting (M30-36)

The mechanisms used to disseminate information in partner countries are listed below.

Partner: CH Agroscope
Results obtained: In Switzerland, information is provided via the "Gemüsebau Info", an electronic bulletin coordinated by the competence centre for agricultural research Agroscope, covering all growing regions and the three official languages.

Comments on deviations from original plan:
There were no deviations from the original plan.

Partner: DE JKI
Results obtained: In Germany ISIP (Information System for Integrated Plant Production) provides advisors with relevant information on request.

Comments on deviations from original plan:
There were no deviations from the original plan.

Partner: FR IGEPP
Results obtained: In France, information is given through the "Bulletins de Santé du Végétal (BSV)" coordinated by the regional agricultural chambers and available online.

Comments on deviations from original plan:
There were no deviations from the original plan.

Partner: NO NIBIO
Results obtained: in Norway, VIPS is an online open source forecast and information service for decision support in integrated management of pests, diseases and weeds.

Comments on deviations from original plan:
There were no deviations from the original plan.

Partner: SL University of Ljubljana
Results obtained: no information received.

Comments on deviations from original plan:
There were no deviations from the original plan.

Partner: UK University of Warwick
Results obtained:

In the UK, information about best practice with regard to monitoring and forecasting is disseminated through AHDB Factsheets for carrot pests and brassica pests and through the AHDB Pest Bulletin https://www.syngenta.co.uk/ahdb-pest-bulletin. The AHDB Factsheet for carrot pests has been updated recently but is not published yet. The Factsheet for brassica pests will be updated. Information about best practice is also disseminated by direct contact with a number of growers. Work to define what is 'best practice' for *D. platura/florilega* is still underway.

A presentation about 'best practice' with regard to decision support in the UK for all pests of vegetable and salad crops was made at the Working Group "Integrated Protection in Field Vegetables Meeting at Stratford-upon-Avon (UK), 13-16 October, 2019 and a paper has been submitted:

Publication
Collier, R.; Elliott, M.; Wilson, D.; Teverson, D.; Cowgill, S. Phenology and abundance of pest insects of vegetable and salad crops in Britain: decision support for growers. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Stratford-upon-Avon (UK), 13-16 October, 2019. Edited by R. Meadow. In press.

Comments on deviations from original plan:
There were no deviations from the original plan.

Publications during the project that are relevant to WP1:

Collier, R., Mazzi, D., Folkedal Schjøll, A., Schorpp, Q., Thöming, G., Johansen, T.J., Meadow,R., Meyling, N.V., Cortesero, A., Vogler, U., Gaffney, M.T., Hommes, M. (2020) The potential for decision support systems to improve the management of root-feeding fly pests of vegetables in Europe. *Insects*. Under review.

Collier, R.; Elliott, M.; Wilson, D.; Teverson, D.; Cowgill, S. Phenology and abundance of pest insects of vegetable and salad crops in Britain: decision support for growers. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Stratford-upon-Avon (UK), 13-16 October, 2019. Edited by R. Meadow. Submitted.

Collier, R.H. & Villeneuve, F. (2019). 'Pests of carrot' in 'Carrot and other vegetable Apiaceae' CABI. In press.

Johansen, T.J., Cortesero, A., Gaffney, M.T., Meadow, R., Schorpp, Q., Collier, R. (2020). Phenology of brassica root flies (*Delia radicum* and *D. floralis*) in northern Europe. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Stratford-upon-Avon (UK), 13-16 October, 2020. Edited by R. Meadow. Submitted.

Sauer, C. (2019). Possible impacts of climate change on carrot fly's population dynamics in Switzerland. *IOBC-WPRS Bulletin*, **2019**. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Wädenswil/Arenenberg (Switzerland), 02-06 October, 2017. Edited by R. Meadow. 142, 31-41.

Thöming, G., Folkedal Schjøll, A., Johansen, T.J. (2019). Developing tools for monitoring and forecasting of onion fly *Delia antiqua* in Norway. *IOBC-WPRS Bulletin*, **2019**. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Wädenswil/Arenenberg (Switzerland), 02-06 October, 2017. Edited by R. Meadow. 142, 42-49.

WP2	Potential for management by manipulating pest behaviour

WPL: **Anne-Marie Cortesero**, FR
Responsible partners: FR, NO NMBU, NO NIBIO.

Overall summary of main results and conclusions WP2

We have conducted laboratory and field experiments to identify best trap crop varieties to be used in a push-pull design against the cabbage root fly, *D. radicum*. Promising varieties have been identified by FR as well as a spatial design that could optimize the effect of this trap crop on the colonisation of broccoli plants by this pest. Volatiles that could be used to manipulate this colonisation behaviour in such a design showed some unreliability in their effects in the field, but we have tested other non-volatile compounds that show very encouraging potential. The first steps of this WP were conducted mainly by FR. NO and CH have used the identified varieties and compounds for further testing in their experiments (See WP4 section).

Several candidates from the carboxylic acid family that could reduce *D. radicum* oviposition were tested in different experiments. Of the six compounds tested, only three could significantly reduce oviposition both in laboratory and field trials. The most effective one (i.e. trans-ferulic acid) was chosen to be tested in a large-scale push-pull trial. In this experiment trans-ferulic acid was sprayed on young broccoli plants (i.e. target crop) surrounded by Chinese cabbage strips (i.e. trap crop). This product displayed a very promising potential to reduce *D. radicum* oviposition but further experiments on product formulation, quantity used, persistence etc. need to be conducted before use in commercial fields.

Report on the results obtained (A) and changes to the original plan/ WP objectives (B) by tasks and partners:

WP2- Task 1: IGEPP (FR) has identified one promising brassicaceous species which appears to have very good potential as a trap crop in a push-pull. We will explore variability in this species to identify attractive varieties compatible with cultural methods and planting time (M4-21)

Partner: FR IGEPP
Results obtained:

We have explored the variability of Chinese cabbage varieties in both laboratory and field experiments in order to identify the most promising varieties to be used as a trap crop (i.e. pull component) in a push-pull strategy against *D. radicum*.

Fifteen Chinese cabbage varieties were compared in a multiple choice experiment with caged females. One broccoli variety was included as a control.

Figure 2.1 shows the number of eggs laid on the different varieties tested in this experiment:

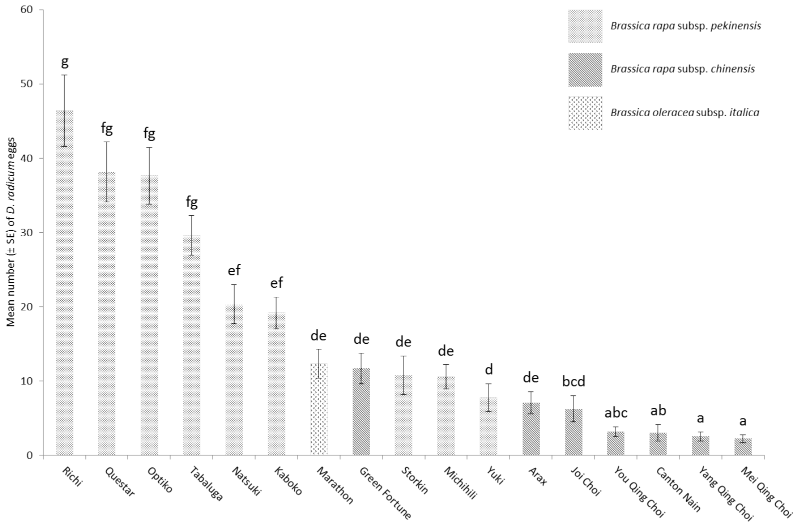


Figure 2.1. Chinese cabbage varieties compared in a multiple choice experiment with caged females. One broccoli variety (cv Marathon) was included as a control.

These varieties were also tested in the field with natural infestations of *D. radicum* and the results obtained are shown in Figure 2.2.

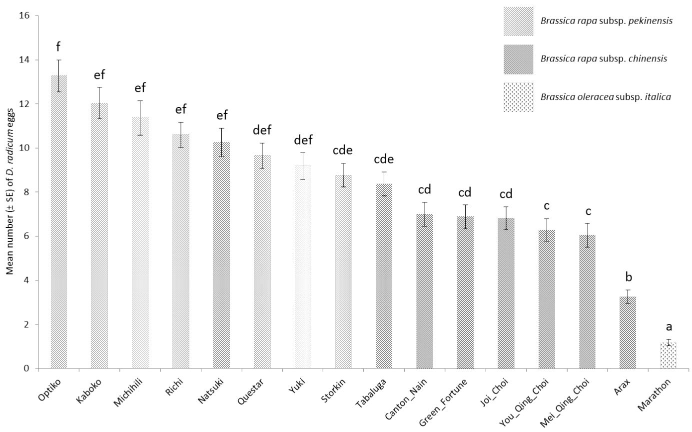


Figure 2.2. Chinese cabbage varieties tested in the field with natural infestations of D. radicum. One broccoli variety (cv Marathon) was also included as a control.

Both experiments show that a large difference exists between varieties in the attractiveness of Chinese cabbage for *D. radicum.* Results from the lab and the field experiments are globally congruent and show that several varieties could be interesting for future use in push-pull designs. Their compatibility with local conditions in different countries were tested though experiments conducted in WP4 by NO and CH. Results of this task were published recently (see Lamy *et al.*, 2020).

<u>Publication:</u>

Lamy, F., Bellec, L., Rusu-Stievenard, A., Clin, P., Ricono, C., Olivier, D., Mauger, S., Poinsot, D., Faloya, V., Daniel, L., et al. Oviposition preference of the cabbage root fly towards some chinese cabbage cultivars: A search for future trap crop candidates. *Insects* 2020, *11*, doi:10.3390/insects11020127

Comments on deviations from original plan:

There were no deviations from the original plan.

WP2- Task 2: We will determine the optimal spatial arrangement of suitable trap crop varieties in experimental and commercial fields using *in situ* and *in silico* experiments (M16-33)

Partner: FR IGEPP
Results obtained:

The influence of several spatial arrangements of the trap crop on egg infestations on broccoli plants by *D. radicum* were tested in an experimental field trial (Figure 2.3).

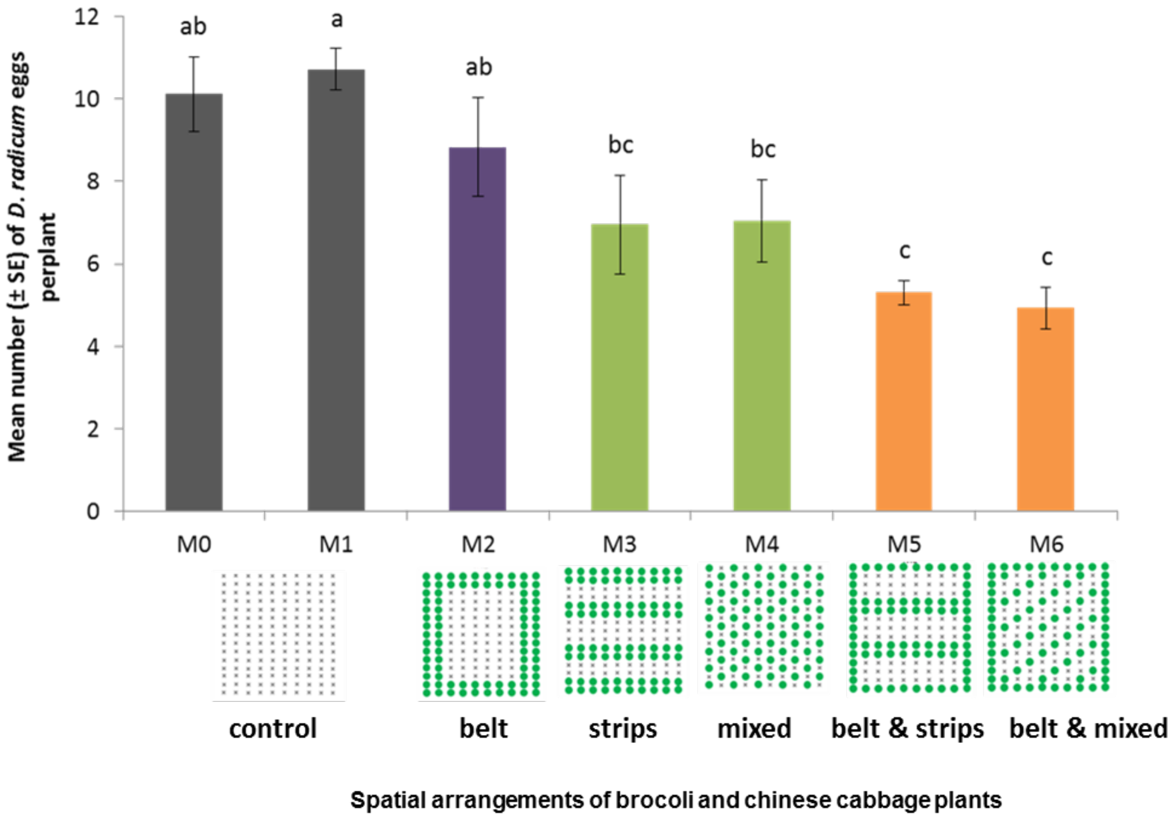


Figure 2.3. Influence of several spatial arrangements of the trap crop on egg infestations on broccoli plants by D. radicum when tested in an experimental field trial.

Results indicate that arrangement of the Chinese cabbage has a strong influence on its potential as a trap crop. The best designs seem to be obtained when it is placed both around the target crop and inside it (i.e. belt & strip and belt & mixed).

Comments on deviations from original plan:

There were no deviations from the original plan.

WP2- Task 3: T2.3 In a push-pull design, the trap crop will be combined with repellent plants or volatiles that are placed in the part of the field to be protected. We will explore the potential for such a design and determine how both components are best positioned in the field (M16-33)

Partner: FR IGEPP

Results obtained:

The influence of a complete push-pull design on crop infestation by *Delia radicum* was tested at a large scale in a vegetable production area with a very high infestation level. This push-pull design aimed at protecting a broccoli crop (i.e. target crop) by combining a pull component made of Chinese cabbage strips (i.e. trap crop) and a push component (consisting in a solution of 10mM trans-ferulic acid sprayed on broccoli leaves once a week). Two modalities (control and push-pull) were tested with nine repetitions of each (Figure 2.4).

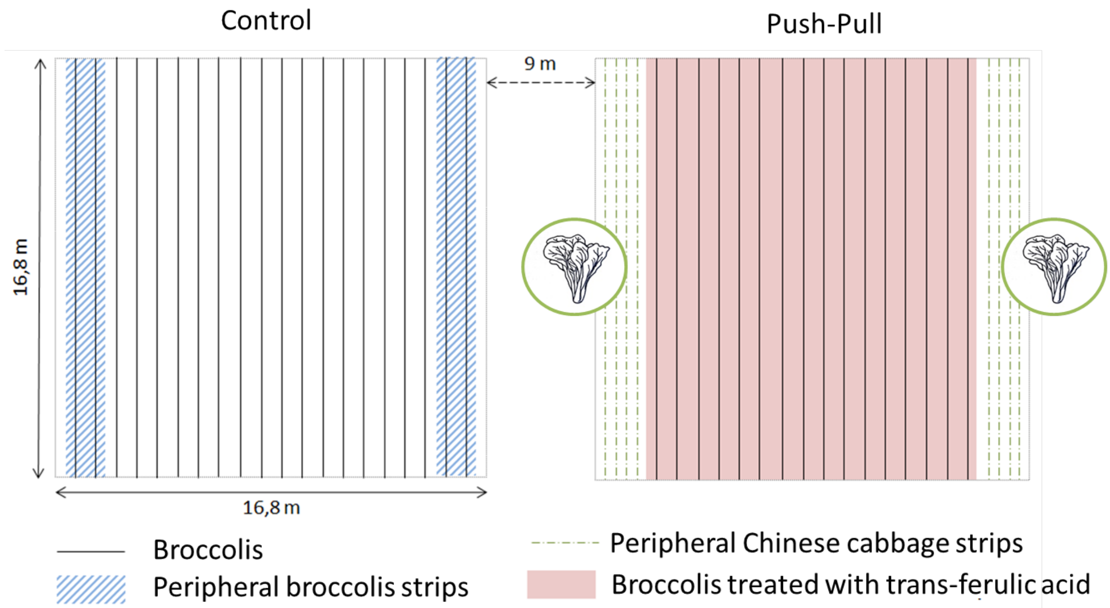


Figure 2.4. Details on control and push-pull plots. The control modality is only composed of untreated broccolis while in the push-pull one, broccolis were sprayed with trans-ferulic acid and surrounded by two trips of Chinese cabbages. Both modalities have the same surface (282m²).

The oviposition of *D. radicum* was recorded during the first three weeks of the experiment and despite a very large infestation level (up to 100 eggs per plant on the second and third weeks), the push-pull system significantly reduced the number of eggs laid on broccoli plants (Figure 2.5):

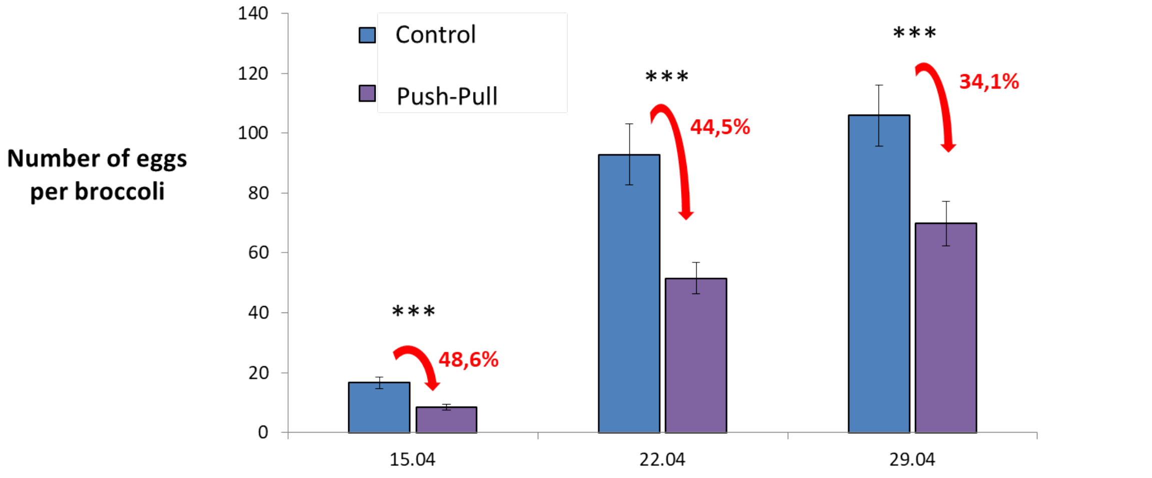


Figure 2.5. Mean number (± SE) of D. radicum eggs laid per broccoli during the three first weeks of the field trial.

The next weeks, we recorded the number of larvae and then the number of pupae developing in the root system of broccoli plants (Figure 2.6). The push-pull system had a significant effect on the number of larvae, but the number of pupae was not reduced. This result could be explained by the large infestation level and the insufficient resource provided by the young broccoli plants even when the oviposition was reduced by 40%.

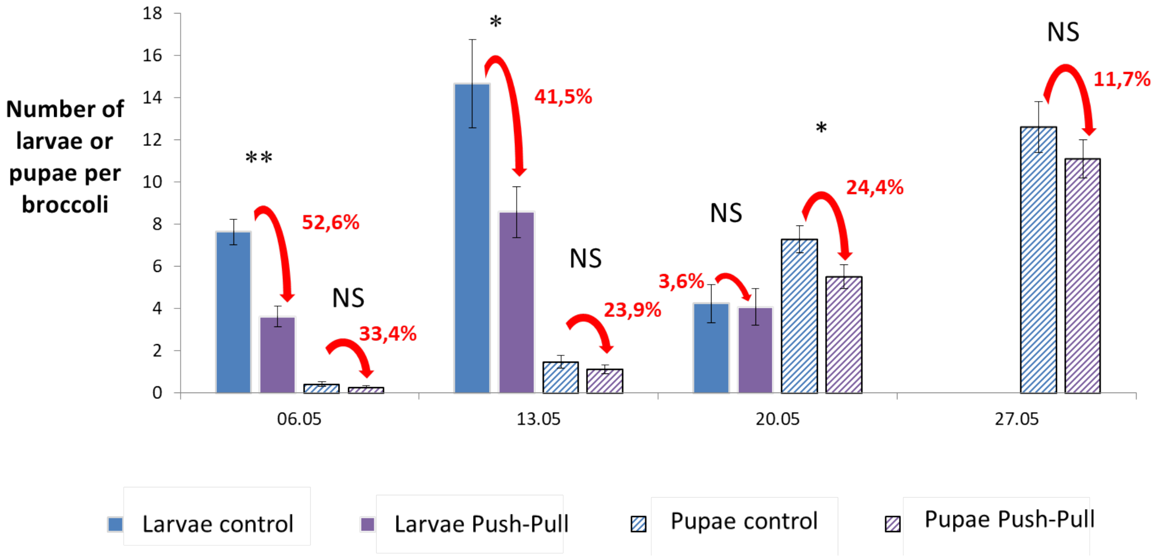


Figure 2.6. Mean number (± SE) of D. radicum larvae and pupae per broccoli during the four next weeks of the field trial.

Comments on deviations from original plan:

The only deviation in this task was the use of trans-ferulic acid as push component, which is not a VOC (see below).

WP2- Task 4: T2.4 Volatiles that decrease plant infestations have been identified but their use in the field has not been optimized yet. We will determine the optimal spacing for odour dispensers, the best release rate to be used and the most efficient timing for volatile release in the field (M16-33)

Partner: FR IGEPP
Results obtained:

Results obtained in successive field experiments on candidate volatiles identified by FR prior to the project (i.e. Eucalyptol) appeared to show that they are quite unstable. Infestation levels of broccoli plants were decreased by more than half on some assays while they were not influenced by volatiles in others. The interference of volatiles with other factors may be responsible for this lack of effect and questions the reliability of their use.

Due to the irregular results we obtained with volatiles in the field, we decided to test non-volatile compounds before moving on with Task 4. Non-volatile compounds decreasing the oviposition of *D. radicum* were identified in previous laboratory experiments (see Cole et al 1989: Deterrent effect of carboxylic acids on *D. radicum* oviposition). The effect of such compounds was pre-tested in the lab and confirmed previous results obtained (Figure 2.7).

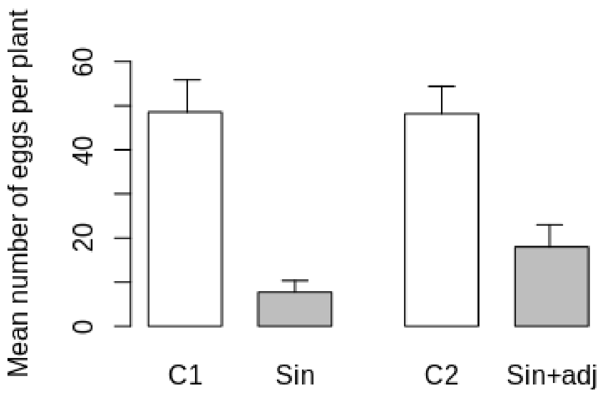


Figure 2.7. Mean number (± SE) of eggs laid per plant by caged D. radicum females. C1 and C2: untreated controls; Sin: plants sprayed with sinapic acid; Sin+adj: plants sprayed with sinapic acid and adjuvant.

Another laboratory experiment on carboxylic acids revealed three promising candidates to be used as oviposition inhibitor in a push-pull strategy against the CRF (trans-ferulic acid, trans-cinnamic acid and sinapic acid) (Figure 2.8).

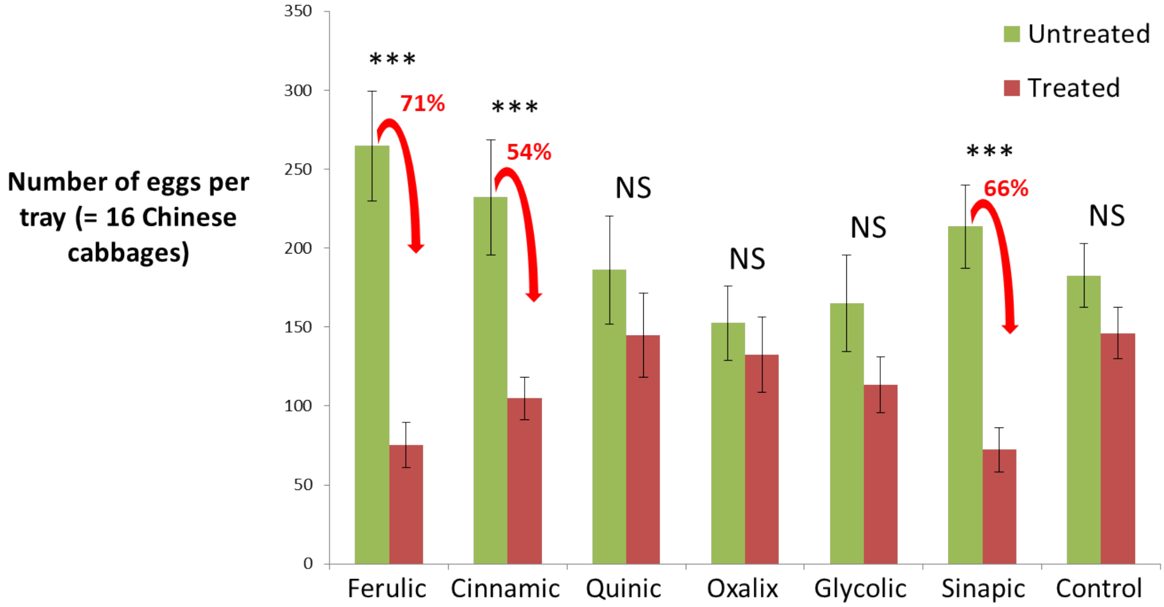


Figure 2.8. Mean number (± SE) of D. radicum eggs laid on Chinese cabbages trays treated or not with 6 different carboxylic acids in laboratory conditions.

These results were confirmed in a natural infestation experiment (Figure 2.9) and ferulic acid was identified as the most efficient and less hazardous compound. It was selected to be tested in the full push-pull experiment (see task 3 above).

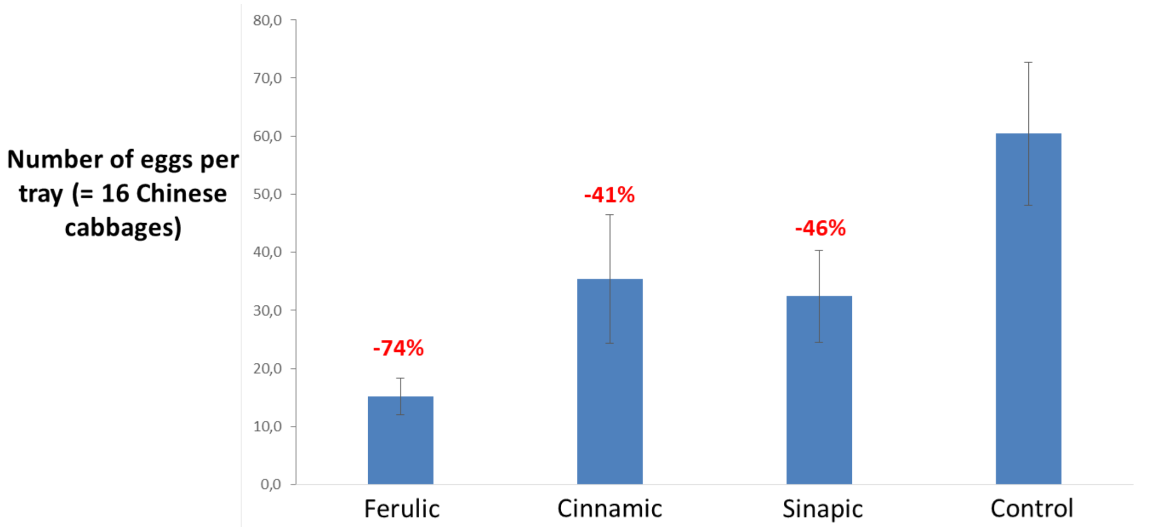


Figure 2.9. Mean number (± SE) of D. radicum eggs laid on Chinese cabbage plants in trays treated or not with 3 different carboxylic acids on natural infestation conditions.

Comments on deviations from original plan:

The only deviation in this task was the use of compounds that were not a VOCs.

WP2- Task 5: T2.5 In collaboration with a company developing volatile dispensers we will determine the most suitable dispensers and identify variations in volatile release depending on climatic conditions (M4-21)

Partner: FR IGEPP
Results obtained:

Based on our results (see above), volatiles may not be the best solution for a push-pull design.

Comments on deviations from original plan:
As we decided not to use VOCs any more in this project, this task could not be conducted. However, at the end of the project we initiated a new task with the same objectives on the ferulic acid in order to optimize its use in the field.

WP2- Task 6: T2.6 The impact of the proposed push-pull strategy on natural enemies of *D. radicum,* and other potential pests of brassicaceous vegetable crops will be determined (M16-33)

Partner: FR IGEPP, NO NIBIO/NMBU
Results obtained:
The Chinese cabbage used as pull component in our push-pull strategy seems to be very attractive for some other brassicaceous pest like the turnip sawfly (*Athalia rosa*e) (Figure 2.10) or flea beetles (*Alticidae*).

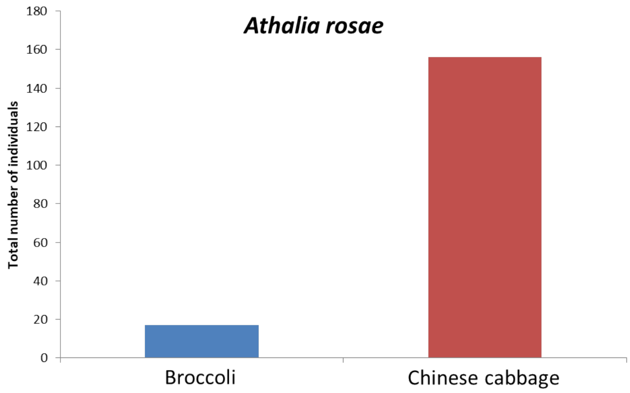


Figure 2.10. Total number of Athalia rosae adults counted on the broccoli crop and on the Chinese cabbage strips of a push-pull experiment (quadrats method).

The presence of Chinese cabbage allows habitat diversification which is beneficial for some natural enemies like Staphylinidae (Figure 2.11).

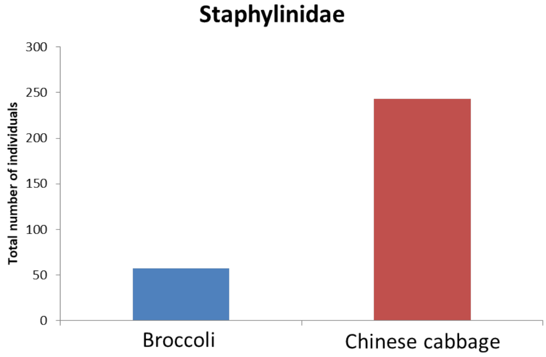


Figure 2.11. Total number of Staphylinidae collected in pit-fall traps present inside the broccolis crop and the Chinese cabbage strips of a push-pull experiment.

These results confirmed many field observations concerning the attractivity of Chinese cabbages to other insects, including natural enemies.

Comments on deviations from original plan:
Due to time constraints (the large-scale field experiment was extremely time consuming), we could not further document the effects of our full push pull design on other brassicaceous pests nor *D. radicum* natural enemies.

WP2- Task 7: T2.7 The best trap crop and volatile options will be combined and tested at a commercial field scale (M28-33)

Partner: FR IGEPP, NO NIBIO/NMBU
Results obtained:

See above (Task 2.3).

Comments on deviations from original plan:
Push pull experiments with Chinese cabbage and trans ferulic acid presented in Task 3 were conducted in a producer field that was rented by INRA for this project but conducted as producers would. However, using non-homologated compounds in actual commercial fields is not possible in France. The promising results obtained with the trans ferulic acid calls for further experimentations that could lead to future homologation.

WP3	**Interactions between plants, biological control agents and *Delia radicum***
WPL: Nicolai Vitt Meyling, DK Responsible partners: DK, FR, NO NMBU and NIBIO, UK, IE	
Overall summary of main results and conclusions WP3 The activities in WP3 focused on interactions between the plants, biological control agents such as entomopathogenic fungi (EPF) and entomopathogenic nematodes (EPN), and the target pest *D. radicum*. Interactions were considered below ground (egg/larval/pupal stages) and above ground (adult flies). Isolates of EPF were selected and tested for their ability to establish in cauliflower rhizospheres, infect *D. radicum* larvae, and cause behavioural responses of adult female flies. Rhizosphere establishment depended on fungal isolate and inoculation method; two isolates (KVL16-36 and NCRI 250-02) were selected for further trials using the inoculation method by placing colonized rice grains in the potting media. Cauliflower plants were tested for their ability to cause infections in *D. radicum* larvae through fungal colonized roots in both sterile sand and in field soil under semi-field conditions; infection occurred in larvae, but mortality occurred mostly after pupation and fungal inoculation did therefore not reduce the number of developed larvae	

although fungal isolates established well in the rhizosphere. The application method of EPF does not have much potential in reducing the direct damage to the crop, but the EPF can affect the number of flies emerging from the inoculated plant.

Behavioural studies were conducted in wind-tunnel experiments to evaluate if EPF inoculated plants were more attractive for the flies than non-inoculated plants and whether flies oriented by odour and/or visual cues. EPF inoculated plants were more attractive to *D. radicum* females than were non-inoculated plants when the flies were exposed to both odour and visual cues. However, when flies only responded to odour, the non-inoculated plants were more attractive than the EPF inoculated plants. Visual appearance of the EPF inoculated plants may thus lead to increased attraction and hence oviposition by *D. radicum*. This potential attraction was evaluated in field trials together with a trap crop, Chinese cabbage developed under WP2, as well as in broccoli. No difference in numbers of larvae and pupae was observed between EPF inoculated and non-inoculated Chinese cabbage or broccoli, but a relatively large proportion of the pupae became infected by EPF in the inoculated treatments, which contributed to a significant reduction in adult flies emerging from the inoculated plants. The EPF application may therefore be a tool within an IPM strategy using trap crops to reduce the *D. radicum* population of the following generation.

To evaluate the likely performance of the two EPF isolates under realistic soil temperature conditions in Northern Europe, germination and mycelial (= colony) extension rates were quantified at a range of temperatures between 5-35°C. The data were fitted to a model to predict optimum temperature conditions. The isolates showed similar responses in germination of conidia and mycelial growth. Maximum germination occurred between 20 to 30°C. Neither isolate germinated at 5 or 10°C. The estimated optimum temperatures for growth were 28.3°C (KVL16-36) and 27.9°C (NCRI250/02), while the optimum temperatures for germination were 29.8°C (KVL16-36) and 30.1°C (NCRI250/02). The temperature profiles matched well with the predicted optimum temperatures of larval development.

Temperature conditioning of EPN species were evaluated in both lab and field trials in comparison to non-conditioned nematodes, with a focus on the species *Steinernema feltiae*. Initial laboratory trials on method development using dried sand in petri dishes showed that the performance of the non-conditioned EPN was comparable to the conditioned EPN indicating that *S. feltiae* had good ability to cause mortality in *D. radicum* larvae. Field experiments (using commercial nematodes, *S. feltiae* and *H. bacteriophora*, testing different application methods and concentrations of Infective Juveniles (IJs) per plant) were challenged by adverse climatic conditions in 2018, but were replicated later. The non-conditioned EPN resulted in lower crop damage scores and the conditioned EPN resulted in a higher level of root damage, with no influence of application rate (35k IJs vs. 70k IJs). In additional laboratory experiments, there was a noticeable trend that higher numbers of mature *S. feltiae* were recovered from *Galleria melonella* larvae exposed to the non-conditioned nematodes, particularly those applied at 70K IJ. Overall, the experiments indicated no benefit in subjecting the EPN *Steinernema feltiae* to a temperature conditioning regime pre application, from an agronomic perspective. However, the experiments did indicate that a high application rate of *S. feltiae* (70K IJ as a drench) had some benefit in terms of enhanced plant performance. The results indicate that delaying nematode application to coincide with the later larval instars of *D. radicum* may be required to enhance efficacy, but also potentially to reduce the required application rate below 70K IJ, which may not be economically feasible for commercial growers. Therefore, a strategy of frequent applications of EPN may be required for adequate management of *D. radicum.*

In conclusion, the research conducted in WP3 has produced new insights in practical application methods for EPF and EPN, and the effects on control of *D. radicum* larvae under realistic cultivation regimes were evaluated. New knowledge was obtained on *D. radicum* host-plant finding when plants are inoculated with EPF, and the application methods showed promise as a "kill" component in combination with a trap crop strategy. The broad range of temperature regimes under which EPF are active demonstrates their versatility independent of origin. Temperature conditioning of EPN did not indicate to improve mortality and crop damage, but adjustments of application rates and EPN concentrations may enhance control efficacy against *D. radium* larvae in the field.

Report on the results obtained (A) and changes to the original plan/ WP objectives (B) by tasks and partners:

WP3- Task 1: T3.1 Selection of root-colonizing EPF strains of *Metarhizium*, including one commercial strain and strains isolated in Northern Europe (M1-3)

Partner: DK University of Copenhagen, NO NIBIO,NMBU, UK University of Warwick
Results obtained:

Four EPF isolates with known root colonization ability and/or efficiency against belowground insect larvae were selected for initial experiments (Table 1.1).

Table 1.1. EPF isolates selected for initial experiments.

Isolate-accession	Species	Notes/comments
KVL 04-57	*Metarhizium brunneum*	Infects D. radicum (Rännbäck et al. 2015); same origin as commercial product Met52; known root colonizer (Klingen et al. 2015).
KVL 12-35	*Metarhizium robertsii*	Known to colonize roots and infect insects feeding on roots (Keyser et al. 2014); Danish origin.
NCRI 250/02	*Metarhizium brunneum*	Root colonizer and infective against insect larvae at relatively low temperature (Klingen et al. 2015); Norwegian origin (NIBIO).
KVL 16-36	*Metarhizium brunneum*	Obtained as pure culture directly from the commercial product Met52.

References:

Keyser CA, Thorup-Kristensen K & Meyling NV (2014) *Metarhizium* seed treatment mediates fungal dispersal *via* roots and induces infections in insects. *Fungal Ecology*, 11, 122-131

Klingen I, Westrum K & Meyling NV (2015) Effect of Norwegian entomopathogenic fungal isolates against *Otiorhynchus sulcatus* larvae at low temperatures and their persistence in strawberry rhizospheres. *Biological Control*, 81, 1-7

Rännbäck L-M, Cotes B, Anderson P, Rämert B & Meyling NV (2015) Mortality risk from entomopathogenic fungi affects oviposition behavior in the parasitoid wasp *Trybliographa rapae*. *Journal of Invertebrate Pathology*, 124, 78-86

Comments on deviations from original plan:

No deviations from original plan

WP3- Task 2: T3.2 Implement cultivation-dependent and -independent (PCR-based) protocols to detect EPF qualitatively and quantitatively in soil and root samples (M3-7)

Partner: DK University of Copenhagen
Results obtained:

Cultivation-dependent methods included plating suspensions of root homogenate on selective agar media which had low detection level and generated quantitative data (CFU/root sample).

Also a cultivation-independent qPCR protocol was implemented with *Metarhizium*-specific primers on DNA extracted from roots in fungal inoculated plants. Both methods had a low detection level for EPF and were used in the following experiments, but the CFU data also informed on biological activity of the EPF and was therefore preferred.

Comments on deviations from original plan:

No deviations from original plan.

WP3- Task 3: T3.3 Evaluate relative root-colonizing/endophytic capacity of selected EPF strains on host plants of *D. radicum* (M7-13)

Partner: DK University of Copenhagen

A- Results obtained:

Initially, 3 strains were tested for root-colonization ability using two inoculation methods, seed coating and fungal colonized rice grains. The latter represents granular inoculum comparable to commercial product Met52. However, the strain KVL04-57 could not sporulate on rice so this treatment was not evaluated. Overall, coated seeds gave low colonization although fungus was detected, while rice grains gave much higher fungus levels in the rhizosphere both after 20 days (transplanting) and 40 days (see Figure 3.1). The Norwegian strain NCRI 250-02 gave highest CFU levels and was selected for further experiments.

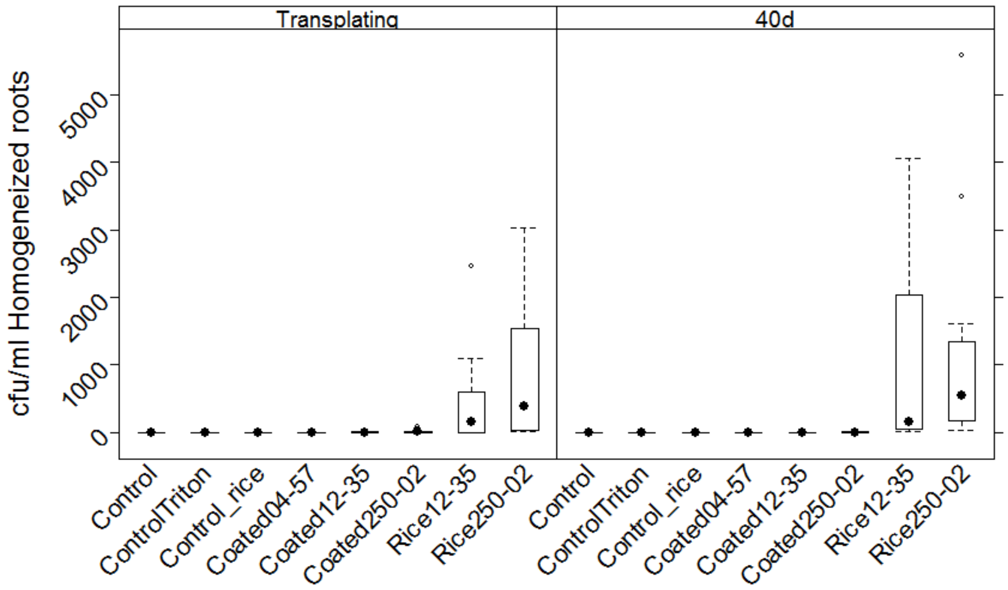


Figure 3.1. Root-colonization ability using two inoculation methods, seed coating and fungal colonized rice grains.

Comments on deviations from original plan:

No deviation from original plan; however, since strain KVL04-57 did not sporulate on rice, it was replaced for further experiments by KVL16-36 as a representative commercial strain.

WP3-Task 4: T3.4 Evaluate different inoculation methods to target larvae below ground in laboratory and greenhouse experiments (M7-12, 16-24)

Partner: DK University of Copenhagen
Results obtained:

In lab experiments, larvae of *Tenebrio molitor* (model insect) were exposed to washed roots of fungus-inoculated cauliflower, which resulted in infections. To target *D. radicum* larvae with the two selected strains, NCRI 250-02 and KVL 16-36, larvae were directly exposed in lab assays to fungal suspensions at two doses expected to represent LC50; larval mortality occurred in a dose dependent manner and more larvae pupated at the low than at the high dose. However, at the end, an equal proportion of individuals died from fungal infections as pupae died later.

Larvae were also exposed indirectly by inoculating cauliflower plants as in T3.3; plants were uprooted and washed and transplanted into sterile sand and incubated in a climate-controlled room. Twenty *D. radicum* eggs were added to each plant and incubated for 2 weeks. Equal numbers of larvae were recovered from the control and fungal-treated plants, but some larvae and pupae in the fungal treatments succumbed to infection during incubation. Thus, larval survival was not significantly affected, but individuals died from fungal treatments during the pupal stage leading to lower successful fly emergence.

Reference:

Thapa, S., Cotes, B., Uslu, H., Meyling, N.V. (2020). Inolucation of the entomopathogenic fungus *Metarhizium brunneum* to target the larvae of the cabbage root fly *Delia radicum*. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Stratford-upon-Avon (UK), 13-16 October, 2020. Edited by R. Meadow. Submitted.

Comments on deviations from original plan:
No deviations from original plan.

WP3- Task 5: T3.5 Evaluate *D. radicum* survival after infestation of EPF inoculated plants in climate chamber and semi-field conditions (M14-24)

Partner: DK University of Copenhagen
Results obtained:

The experiments reported under T3.4 were upscaled to be tested under semi-field conditions in a protected outdoor area. Plants were inoculated with fungal colonized rice and grown for 20 days in a greenhouse, then transplanted into 6 L of field soil and grown for 20 more days before transfer to outdoor conditions. After 3-4 days adaptation, 40 *D. radicum* eggs were placed at the base of each plant and incubated outside for 28 days; then larvae and pupae were extracted from the roots/soil, counted and incubated for infections. The experiment included 4 treatments (2 controls, 2 fungal inoculations) each with 10 replicate plants. The level of fungal colonization of root samples was evaluated on selective agar media. The experiment was conducted twice, mid-June until mid-August and mid-July until mid-September.

The numbers of larvae and pupae recovered from each plant did not differ between treatments (Fig. 3.2). However, during incubation more larvae died in the fungal treatments and most of these showed signs of fungal infections (Fig. 3.3). Only in fungal treatments were *Metarhizium* CFUs detected on root samples using the cultivation-dependent method.

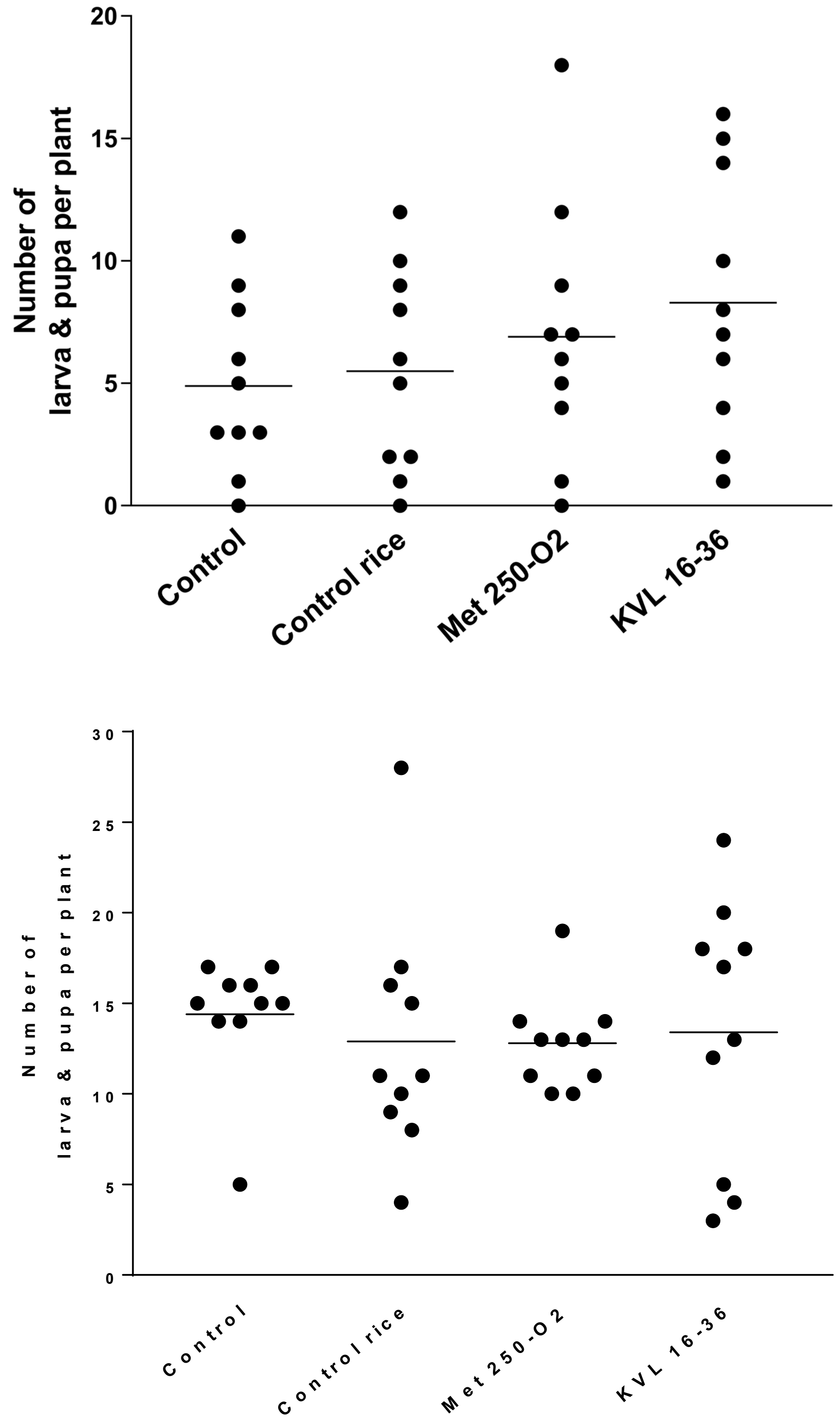


Figure 3.2. Numbers of D. radicum larvae and pupae recovered per plant after semi-field experiments with fungal inoculations on rice (two M. brunneum isolates 250/02 and KVL16-35). Data representing the first (top) and second experimental (bottom) experimental repetitions (n=10 per repetition). Each dot represents an observation, the horizontal lines are mean values.

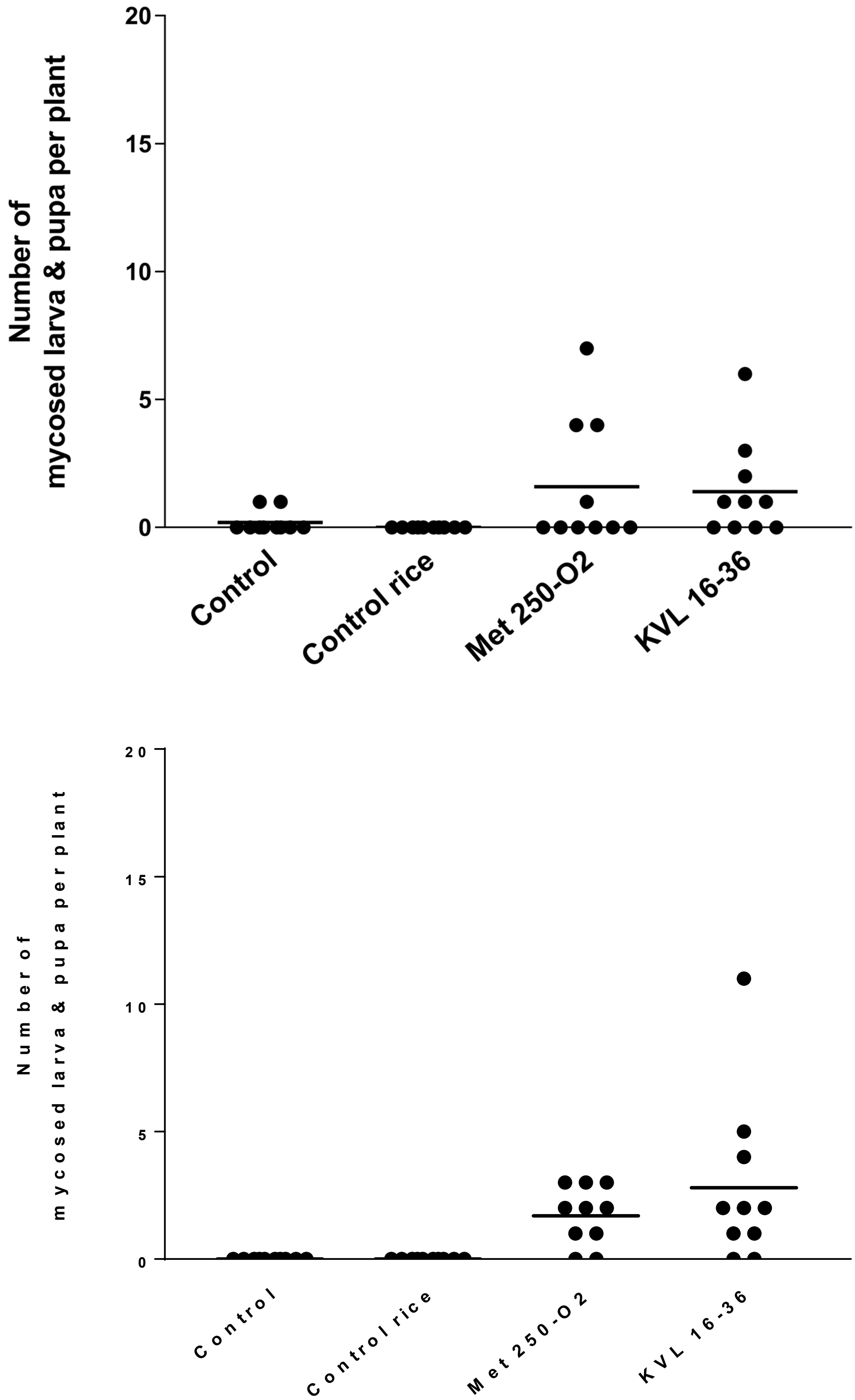


Figure 3.3. Fungal infections (mycosis) in D. radicum larvae and pupae recovered per plant after semi-field experiments with fungal inoculations on rice (two M. brunneum isolates 250/02 and KVL16-35). Data representing the first (top) and second (bottom) experimental repetitions (n=10 per repetition). Each dot represents an observation, the horizontal lines are mean values.

In addition, in both the fungal treatments *Metarhizium* colonies were observed on culture plates after spreading root homogenate from the root systems of the experimental plants. No comparable fungal growth was observed from either of the two control treatments. The inoculation method therefore was able to establish *M. brunneum* of both isolates in the rhizosphere of the plants grown in field soil even after >70 days post inoculation, and the inoculum ensured infections in *D. radicum* larvae feeding on the inoculated plants. However, the mortality induced by the infecting fungi appeared to occur predominantly after pupation and the inoculation method will therefore be unlikely to significantly reduce the feeding damage caused by *D. radicum*. The application of *M. brunneum* should rather be considered as part of an IPM programme for reduction of the population size of the next generation of *D. radicum*, or as a kill-component of trap crops, as described under WP2.

Comments on deviations from original plan:

No deviations from original plan. Attacks to experimental plants by *Plutella xyllostella* during the first experimental repetition meant that all treatments were sprayed with Dipel which is not expected to affect Dipteran species. The summer and early autumn of 2018 were unusually hot in Denmark, thus the temperatures in the semi-field setting were higher than would be expected in a standard field situation.

WP3- Task 6: T3.6 Assess impact of different conditioning regimes on EPN species in incubator studies (M4-9, 16-21)

Partner: IE

Results obtained:

Initial studies were conducted, attempting to repeat the bioassay methods utilised in Guy et al. (2012), and initially used successfully against *D. radicum,* using *S. feltiae* within this study (Figure 3.4). This method involved adding nematodes to a column (Eppendorf) where the insect was packed with a substrate, in this instance sand. This method was chosen initially as it best mimicked field application methodology for cabbage root fly control. However, inconsistent mortality within the untreated controls and a poor rate of infective juvenile recovery from cadavers required a modification in the method. Initially, experiments were conducted by altering the substrate used (sand was replaced with both a peat-based growing medium or sterilised field soil) and by also altering the total amount of water the nematodes were loaded into the sample with. Ultimately, no combination returned experimental results sufficiently consistent to move forward.

Figure 3.4. Larva of Delia radicum infected with Steinernema feltiae. Nematodes are visible through the cadaver surface.

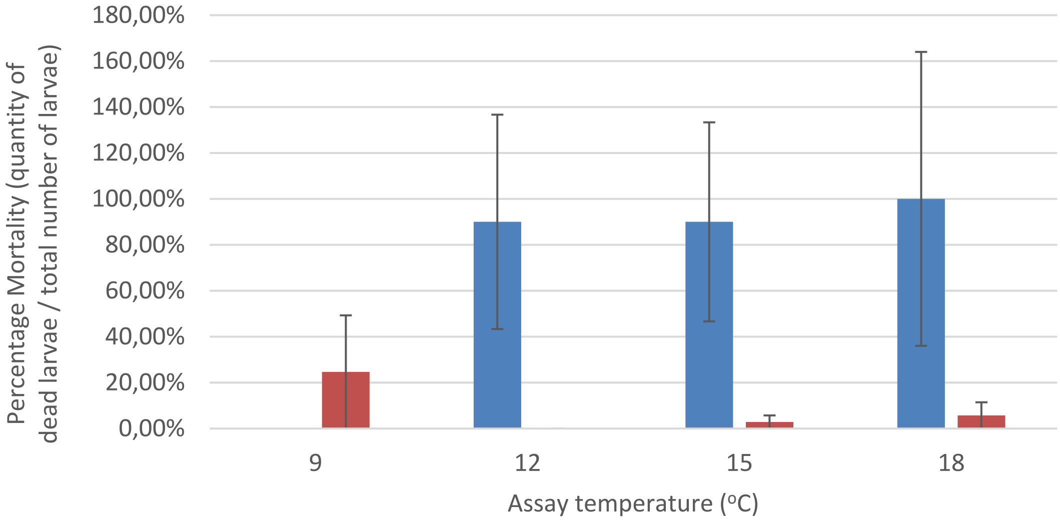


Figure 3.5. Impact of assay procedure on negative control mortality. Mean values and Standard Deviations are shown. Bars in blue indicate the assay method adopted from Guy et al. (2017). Bars in red indicate the assay adopted and amended from Kaya & Stock (1997).

A number of approaches were investigated, however, a modified version of a Petri dish method, described in Kaya & Stock (1997) was felt to give the best results. The final modified method developed involved the use of a 5cm Petri dish, the addition of 3.36g of incubator dried sand (70°C for 24 hours) and the addition of 225 µl / larvae, with 5 larvae added per dish. Our observation is that the more solution was added to the assay the more the efficacy of the nematodes was decreased. A rate of 100 Infective juveniles per larva or 500 Infective Juveniles per experimental dish was used based on 5 larvae per dish.

In terms of a conditioning regime, we stored commercially obtained entomopathogenic nematodes and held them in low volumes of water at approx. 2222 IJ / ml in 9cm diameter plastic tubs. Holes were made in the lids and the tubs were gently agitated by hand each day. Initially we tested a number of conditioning temperatures; however temperatures of 18°C resulted in significant nematode mortality, therefore we restricted our conditioning temperatures to the range 9 -15 °C but still included 18°C in our testing regime (Figure 3.6). Our initial time period for conditioning was 5 days. 5 larvae were used in each petri dish and replicated twice. Control mortality at 9°C was 40%, but at the other temperatures, negative control mortality was not recorded. When grouping the efficacy of the conditioned nematodes across the 4 tested temperatures, the overall mortality rates 58 – 70% were promising, compared to overall efficacy of the non-conditioned *S. feltiae* of less than 30%. However, the low level of *S. feltiae* efficacy was unexpected and required replication.

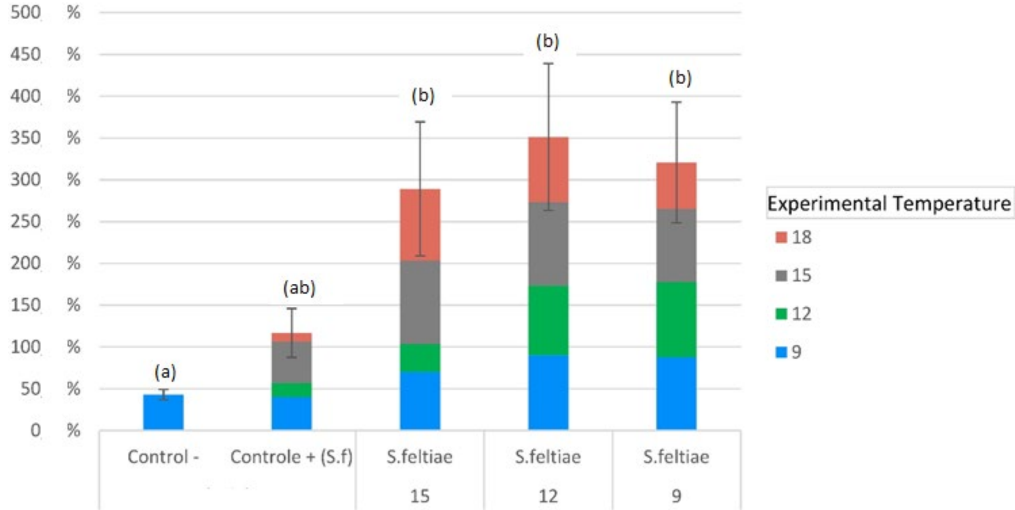


Figure 3.6. Impact of pre-conditioning of S. feltiae at three temperatures for 5 days. The treatments indicated on the Y axis include a negative control (no nematodes), a positive control (S. feltiae prepared on day of experiment) and three conditioned treatments, exposed to 9 °C, 12 °C or 15°C for 5 days. The x-axis illustrates the cumulative percentage mortality over the 4 temperatures. Error bars represent the Standard Deviation.

A further set of experiments was conducted, with an additional conditioning exposure treatment included of 12 days at 9°C (Figures 3.7, 3.8). Therefore, there were now three conditioning treatments (0, 5 and 12 days at 9°C) and four testing temperatures (9, 12, 15 and 18°C). The nematodes were conditioned and assayed as reported previously, however the replication was increased to 5 replicate dishes of 5 larvae per treatment (25 larvae per treatment). In this larger assay the performance of the non-conditioned nematodes was comparable to the conditioned nematodes. At the testing temperatures of 12 °C and 15 °C, mortality rates of 80% plus were observed, which indicates that *S. feltiae* had good ability to cause mortality of *S. feltiae* larvae. In order to directly confirm *S. feltiae* as the cause of larval mortality, cadavers were recovered from the assay and dissected for visual confirmation. Before dissection cadavers were placed in an 18°C incubator on moistened filter paper for 48 hours.

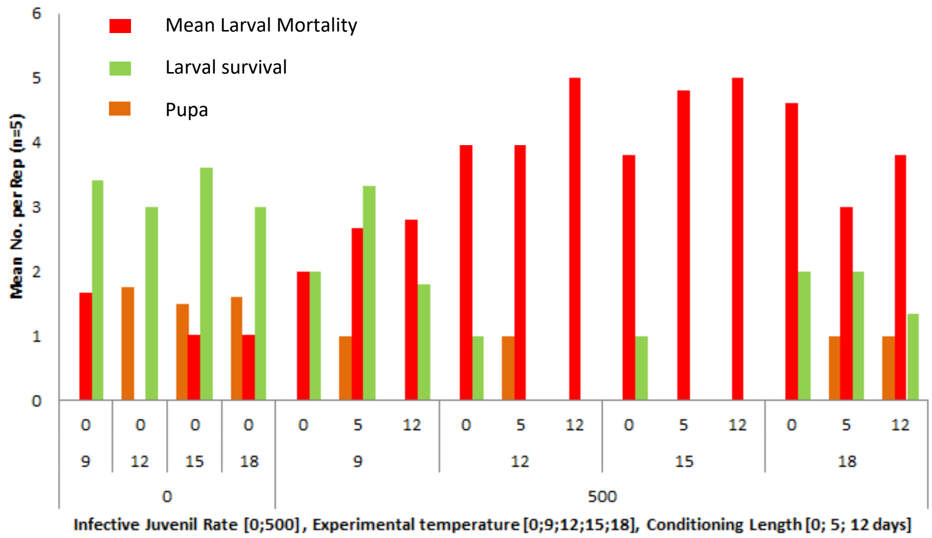


Figure 3.7. Impact of pre conditioning of S. feltiae at 9^{O}C for 5 and 12 days. The four treatments, the two conditioned treatments, a negative control and a positive control were assayed against the larvae of Delia radicum at 4 temperatures. The positive control consisted of a packet of commercial S. feltiae prepared on the day of the assay. The red bars indicate larval mortality, green bars indicate larval survival and the brown bars indicate a larva which formed a pupa during the course of the assay.

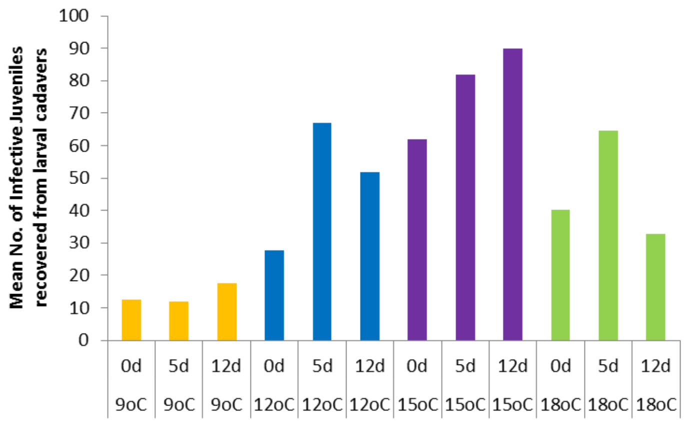


Figure 3.8. Mean number of male and female S. feltiae recovered per Delia radicum cadaver. No nematodes were recovered from the negative treatment and are therefore not displayed. The initial labels on the x axis (0d, 5d, 12d) indicate the length of time in days the nematodes were exposed to 9^{o}C. The next set of labels refers to the experimental temperature the assay was conducted at. The three treatments, the two conditioned treatments, and a positive control all indicated consistent presence of S. feltiae within the D. radicum larvae.

Overall assay temperature was a more significant factor, and this assay indicated a high level of *D. radicum* larval mortality when exposed to *S. feltiae*, which was confirmed through larval dissection. In some assays, there was evidence of enhanced efficacy of *S. feltiae* when exposed to a short conditioning regime (less than 12 days), however the findings were inconsistent and not comparable to the level and consistency of efficacy displayed across 4 different entomopathogenic nematode species in previous work (Guy *et al*., 2017). Therefore, it was decided to test both conditioned and non-conditioned nematodes in a field experiment. In order to help select the optimal conditioning regime to test in the field experiment, an assay was run to better understand the impact of conditioning time on nematode performance. The assay indicated that efficacy began to be impacted after 12 days (Figure 3.9). Also given the difficulties with previous attempts to condition large numbers of nematodes, and the indication from preliminary field experiments that a higher per plant application rate than was expected would be required (Task 3.7) it was felt that a shorter conditioning regime would be potentially less problematic, as previous attempts to condition large volumes of *S. feltiae* had been unsuccessful.

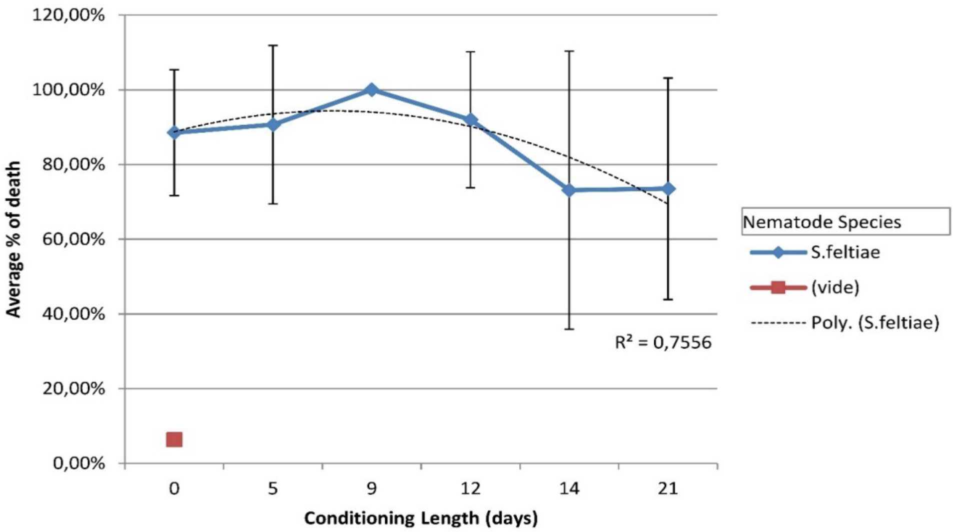


Figure 3.9. Impact of pre conditioning of S. feltiae at 9^{O}C for 5 and 12 days. The four treatments, the two conditioned treatments, a negative control and a positive control were assayed against the larvae of Delia radicum at 4 temperatures. The positive control consisted of a packet of commercial S. feltiae prepared on the day of the assay. The red bars indicate larval mortality, green bars indicate larval survival and the brown bars indicate a larva which formed a pupa during the course of the assay.

References:

Guy, A., Gaffney, M., Kapranas & Griffin, C.T. (2017) Conditioning the entomopathogenic nematodes *Steinernema carpocapsae* and Heterorhabditis by pre-application storage improves efficacy against black vine weevil, *Otiorhyncus sulcatus* (Coleoptera: Curculionidae) at low and moderate temperatures. *Biological Control* 108, 40-46

Kaya, H.K & Stock, S.P (1997) Techniques in Insect Nematology, in Lacey, L.A. (ed.) '*Manual of Techniques in Insect Pathology*' p281-321 https://doi.org/10.1016/B978-0-12-432555-5.X5000-3

Comments on deviations from original plan:

While this task was delayed due to an inability to recruit project staff and the unexpected inconsistency in using the target pest species in incubator studies, an assay was developed which allowed us to complete the task.

WP3- Task 7: T3.7 Test optimally conditioned EPNs for improved efficacy at field temperatures (M16-21, 28-33)

Partner: IE

Results obtained:

In order to field test conditioned nematodes, it was felt that establishing an application rate per plant would be required. Previous experiments indicated that an application rate between 35K and 70K per plant may be appropriate (Year 1 FlyIPM). This was replicated in year 2 in a larger experiment (using commercial nematodes, *S. feltiae* and *H. bacteriophora*), however the adverse climatic conditions resulted the failure of the experiment. The experiment was replicated in September 2018, testing concentrations from 0 to 140,000 IJs per plant. A total 15 plant roots and surrounding soil was removed from each experimental plot and searched for larvae and pupae.

When results from both nematode species were pooled, a significant difference between the top rate of 140K and the negative control was observed (Figure 3.10).

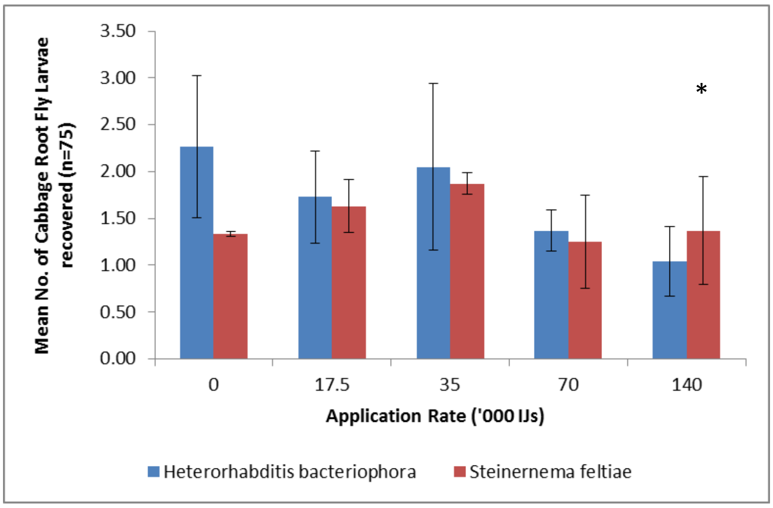


*Figure 3.10. Mean larval count (+/- SD) recovered from broccoli plants treated with 5 concentrations of 2 separate commercial entomopathogenic nematodes. * A significant difference is indicated for the application rate of 140K IJ against the untreated controls, when data from both nematode species is combined.*

A similar experiment was conducted in 2020 to confirm the application rate required, except in this instance, based on laboratory assays, a single nematode species, *Steinernema feltiae* was tested, at the same range of application rates per plant (Figure 3.11). However, for pre harvest parameters tested, larval count (p= 0.47) and visual root Score (p= 0.2013) the experiment was non-significant.

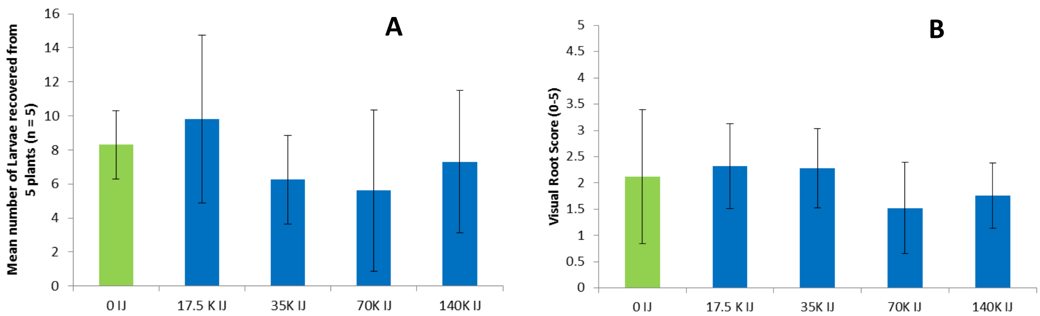


Figure 3.11. Mean larval count (A) and visual root score (B) from broccoli plants (var 'Parthenon') treated Steinernema feltiae at 5 separate concentrations.

Harvest data was taken from the experiment (Figure 3.12), however the analysis was not statistically significant for either total plot weight of broccoli crowns (p= 0.48), average crown weight (p= 0.48) or no. of crowns available for harvest (p= 0.58). While there are general trends towards improved plant performance as the rates of nematode application increase, it is unfortunate that the high degree of variability impacts upon the analysis.

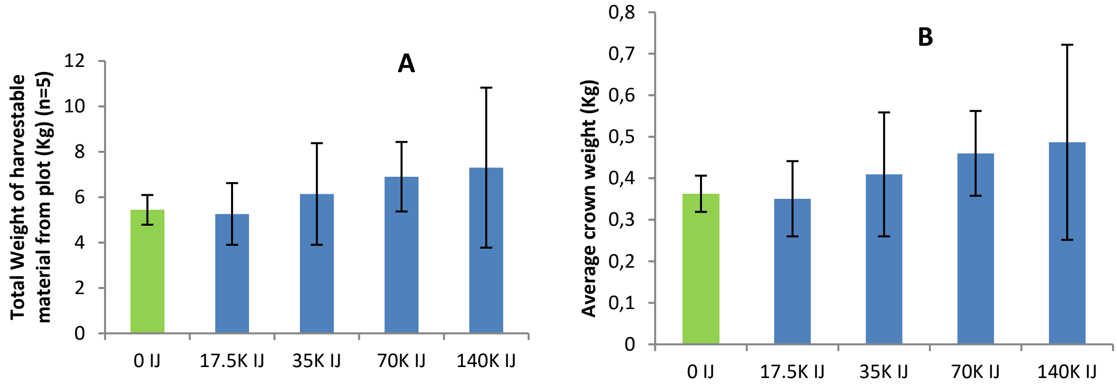


Figure 3.12. Total plot weight of harvestable crowns (A) and average crown weight (B) from broccoli plants (var 'Parthenon') treated Steinernema feltiae at 5 separate concentrations.

Use of low dose pesticide application in combination with *S. feltiae*

As the field efficacy of *S. feltiae* against *D. radicum* was uncertain from initial field evaluations, a preliminary experiment evaluating the use of 'low dose' insecticide applications in combination with *S. feltiae* was installed (Figure 3.13). Visual root damage scores were not significantly different (p= 0.2).

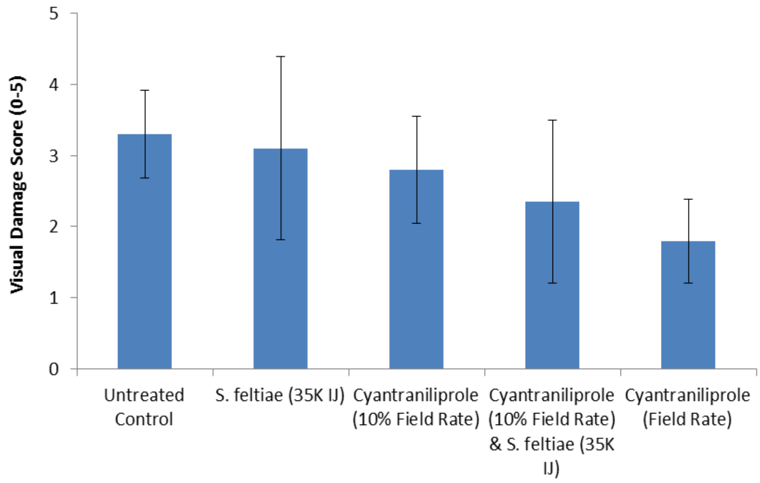


Figure 3.13. Visual damage assessment of Broccoli (var Parthenon) roots, randomly selected from plants, pre-head formation. Error bars represent Std Dev of 4 plots, 5 plants per plot.

Other parameters such as numbers of larvae recovered from soil surrounding the plant (p= 0.1) and plant biomass (p=0.47) before crown formation were also not significantly different. In direct comparison, the performance of the reduced rate of insecticide was comparable to the full rate of insecticide in terms of harvest yield and average head weight, but as the experimental model was non-significant, no overall conclusion on the approach can be made.

Field Testing of conditioned nematodes

An initial experiment to field test conditioned nematodes against *D. radicum* was established to coincide with the first generation of *D. radicum* in 2019. However, the conditioned nematodes failed, most probably due to the size of storage containers being used. The conditioning concentration was similar to that used previously, however in order to provide sufficient nematodes for field testing it was necessary to increase the volume of solution in containers. In an attempt to account for this, for the preceding experiment the volume of water was reduced by 50% and air was continuously pumped into the solution and the conditioning time was decreased.

The entomopathogenic nematodes exposed to a conditioning regime were evaluated against second generation *D. radicum*, exposing them to natural oviposition. Each treatment (Table 3.2) was replicated 5 times, with 33 plants per experimental plot, 3 rows of 11 spaced at 45cm on a 1.8m planting bed. The experimental treatments were commercially obtained entomopathogenic nematodes, *Steinernema feltiae* exposed to a conditioning regime of 9°C over a 7-day period (reduced from the planned 9 days due to a technical malfunction of the refrigeration unit). These were compared to non-conditioned nematodes from the same commercial source. EPNs were applied at 2 rates, 35k IJ per plant, either applied to the module pre planting or applied post planting as a drench. These treatments were also applied in combination and there was an additional treatment of a high rate (70K IJ per plant) drench only application. Additionally, these nematode treatments were compared with a pre-planting module drench of cyantraniliprole as per commercial rates and an untreated control treatment.

Table 3.2. List of Experimental Treatments.

Treatment 1	Untreated Control
Treatment 2	Cyantraniliprole Module Drench
Treatment 3	Conditioned Steinernema feltiae applied as a Drench at 35K
Treatment 4	Conditioned Steinernema feltiae applied in Plant plug at 35K
Treatment 5	Conditioned Steinernema feltiae applied as a Drench at 70K
Treatment 6	Conditioned Steinernema feltiae applied as a Drench at 35Kand in plant plug at 35K
Treatment 7	Steinernema feltiae applied as a Drench at 35K
Treatment 8	Steinernema feltiae applied in Plant plug at 35K
Treatment 9	Steinernema feltiae applied as a Drench at 70K
Treatment 10	Steinernema feltiae applied as a Drench at 35Kand in plant plug at 35K

The initial assessment consisted of root damage evaluation and an assessment of larval/pupal presence in and around the plant. Despite assessing over 250 soil and 250 modules for the presence of larvae /pupae, very few insects were recovered making statistical analysis meaningless. Root scores were taken using a 0-5 scale, following a method used by Collier, R (Pers Com). Visual damage assessment scores were conducted on a 0-5 scale, 0 indicating no damage, 1 indicating <5% damage, 2 indicating 6-10% damage, 3 indicating 11-25% damage, 4 indicating 26-50% damage and 5 indicating =>50% damage (Figure 3.14).

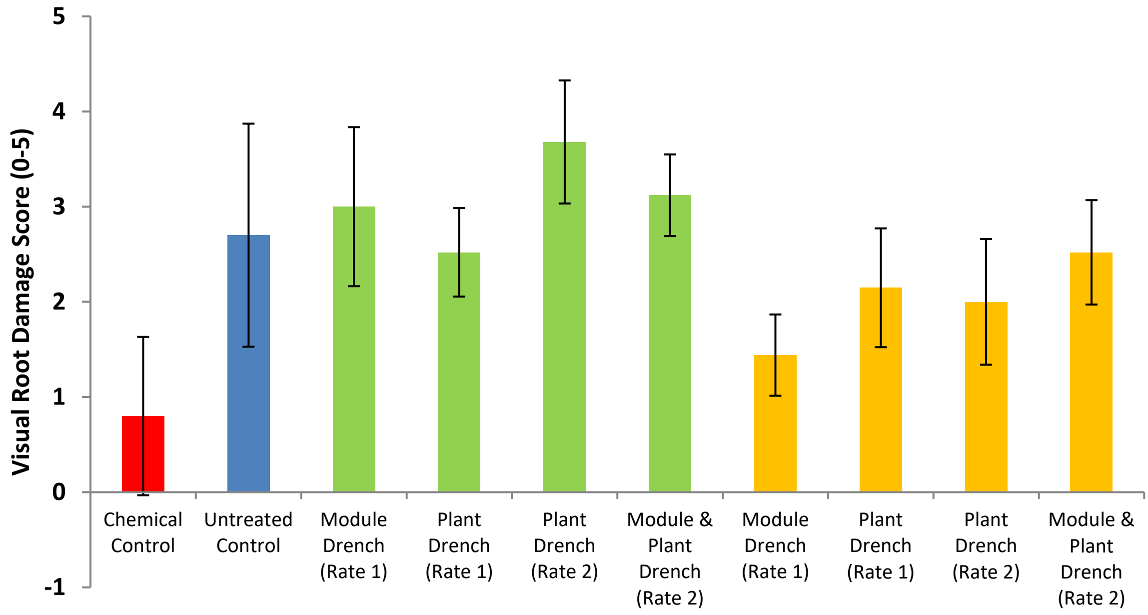


Figure 3.14. Visual damage assessment of Broccoli (var Parthenon) roots, randomly selected from plants, pre-head formation. Error bars represent Std Dev of 5 plots, 5 plants per plot. Nematode species used in experiment is Steinernema feltiae. (Rate 1 = 35K Infective Juvenile per plant; Rate 2 = 70K Infective Juvenile per plant). Treatments in green were exposed to a 7 Day conditioning period at 9°C. Treatments in gold were prepared on the day of application.

The initial assessments of root damage indicated that there was variation within the experiment (p=0.0087; F=3.03). Damage to plants where a synthetic insecticide was applied was significantly different to damage on the untreated controls (p= 0.04). In terms of direct comparisons with the entomopathogenic nematode treatments, the pesticide treatment was statistically significantly different from 6 of the 8 entomopathogenic nematode treatments. In regards to comparing the performance of the non-conditioned entomopathogenic nematodes to the conditioned nematodes, the non-conditioned nematodes led to lower damage scores when directly compared to application method and rate (Comparison Table 3.3 below). When grouped together and compared as a group, the plants treated with conditioned nematodes had a higher level of root damage (p= 0.007), while the impact of rate of application (35k v 70k) was non-significant (p= 0.1675).

Table 3.3. Direct comparison of conditioned and non-conditioned S. feltiae.

Application Method and Rate (IJ)	Direct comparison of conditioned and non-conditioned *S. feltiae* (p=)
Module Drench (Rate 1: 35K IJ)	0.021
Plant Drench (Rate 1: 35K IJ)	0.95
Plant Drench (Rate 2: 70K IJ)	0.019
Module & Plant Drench (Rate 2: 35K IJ + 35KIJ)	0.36

Before the plants commenced formation of the crown, the number of missing plants within each plot was recorded, and there was variation within the experiment (p= 0.028). When compared to the untreated controls, all treatments (apart from T3; p= 0.064) were statistically significantly different. When compared as a group, there was no significant difference between the number of plants remaining in the plots treated with conditioned (16.6) and non-conditioned nematodes

(17.15) (p= 0.087), and the effect of the rate of application was non-significant (p= 0.2824) (Figure 3.15).

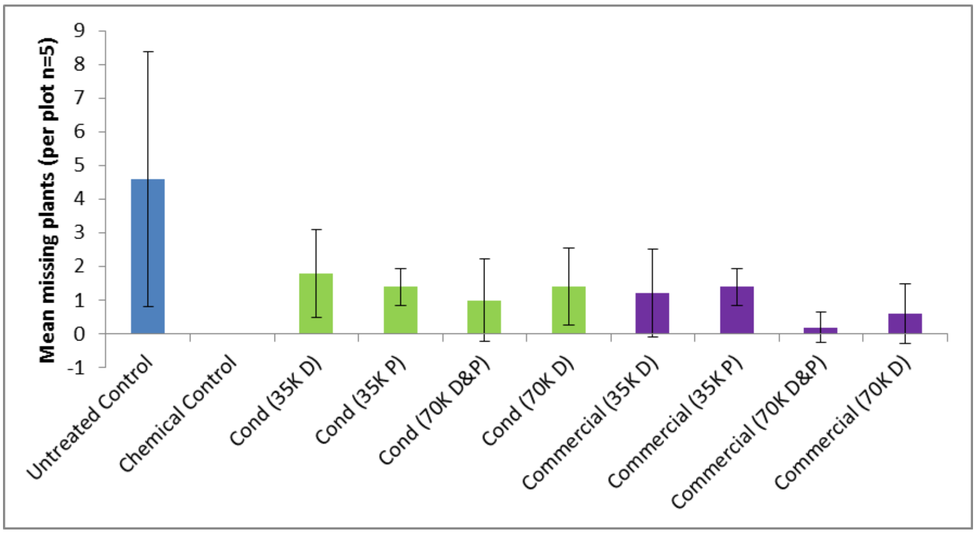


Figure 3.15. Mean number of plants missing from treated plots. Green columns indicate plants treated with conditioned nematodes, Purple columns are plants treated with non-conditioned nematodes. xxK= Application rate; D = Applied as Drench; P = Applied in Plant plug prior to planting; D&P = 50% of application rate applied as drench, 50% applied in plug prior to planting.

The assessments of roots immediately post-harvest did not result in a significant difference (p= 0.12). Similar to the pre-harvest assessment of root damage, there was a clear visual difference in the condition of the roots of the insecticide treated plants and those exposed to entomopathogenic nematodes and to no control treatments (Figure 3.16).

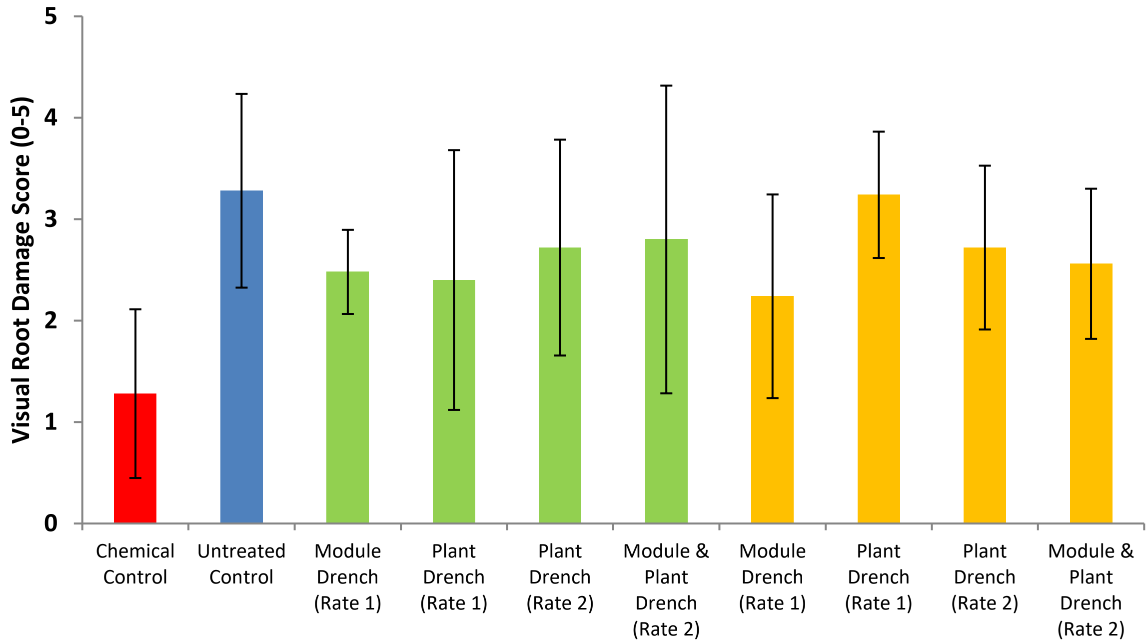


Figure 3.16. Visual damage assessment of Broccoli (var Parthenon) roots, randomly selected from plants, post-harvest. Error bars represent Std Dev of 5 plots, 5 plants per plot. Nematode species used in experiment is Steinernema feltiae. (Rate 1 = 35K Infective Juvenile per plant; Rate 2 = 70K Infective Juvenile per plant). Treatments in green were exposed to a 7 Day conditioning period at 9°C. Treatments in gold were prepared on the day of application.

When assessed to be of marketable quality, the middle row of each experimental plot was harvested, on three dates (29th Sept, 7th Oct and 15th Oct). There was a potential harvest of 13 plants per plot. The crop was assessed using 3 parameters, (1) broccoli crowns remaining for harvest, (2) total harvestable weight per plot and (3) average crown weight (Figure 3.17, 3.18, 3.19).

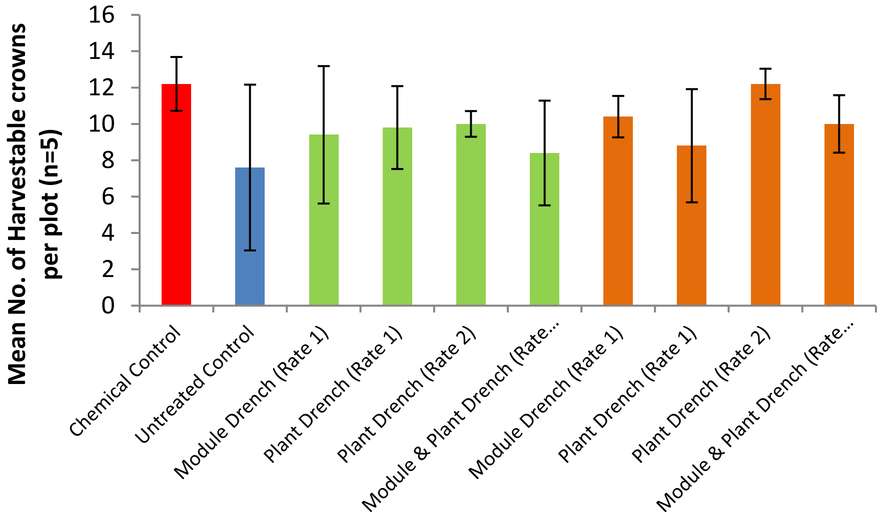


Figure 3.17. Mean no. of broccoli crowns harvested (var Parthenon) per plot (Maximum of 13 crowns available per plot). Error bars represent Std Dev of 5 plots. Nematode species used in experiment is Steinernema feltiae. (Rate 1 = 35K Infective Juvenile per plant; Rate 2 = 70K Infective Juvenile per plant). Treatments in green were exposed to a 7 Day conditioning period at 9°C. Treatments in gold were prepared on the day of application. (Please note that additional crowns were harvested from the Chemical control guard row and included in data, therefore an adjustment for the additional plants has been made).

There were no significant differences in relation to the numbers of crowns available for harvest (p= 0.125). When the analysis was conducted to directly compare nematode performance, there were non-significant differences for the application of conditioned and non-conditioned nematodes (p= 0.2) and for the effect of application rate (p=0.47).

In regards to total plot weight there was a significant effect of treatment (p= 0.02). The chemical control was significantly different from all other treatments, apart from the conditioned nematode applied as a drench at 35K IJ (p= 0.056) and Treatment 9, the unconditioned nematode applied as a drench at 70K IJ (p= 0.25). Treatment 9 was the only nematode treatment to be significantly different from the untreated control (p= 0.018). When analysed as a group, there was no statistically significant difference between the treatments to which conditioned nematodes or unconditioned nematodes were applied to (p= 0.47), nor was the application rate a significant factor (p= 0.83).

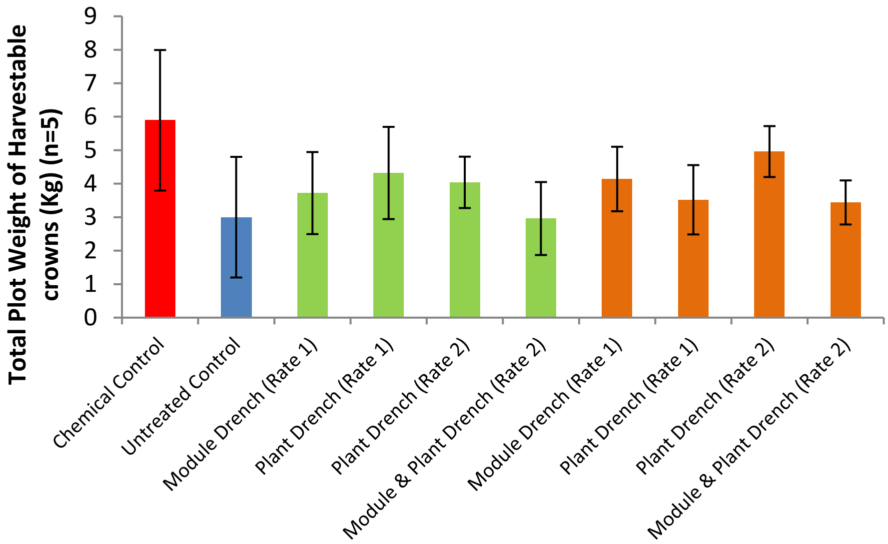


Figure 3.18. Total plot weight of broccoli crowns harvested (var Parthenon) (Maximum of 13 crowns available per plot). Error bars represent Std Dev of 5 plots. Nematode species used in experiment is Steinernema feltiae. (Rate 1 = 35K Infective Juvenile per plant; Rate 2 = 70K Infective Juvenile per plant). Treatments in green were exposed to a 7 Day conditioning period at 9°C. Treatments in gold were prepared on the day of application. (Please note that additional crowns were harvested from the Chemical control guard row and included in data, therefore an adjustment for the additional plants has been made).

There were no significant differences in relation to average crown weight (p= 0.44). When the analysis was conducted to directly compare nematode performance, there were non-significant differences between the application of conditioned and non-conditioned nematodes (p= 0.63) and for the effect of application rate (p=0.09).

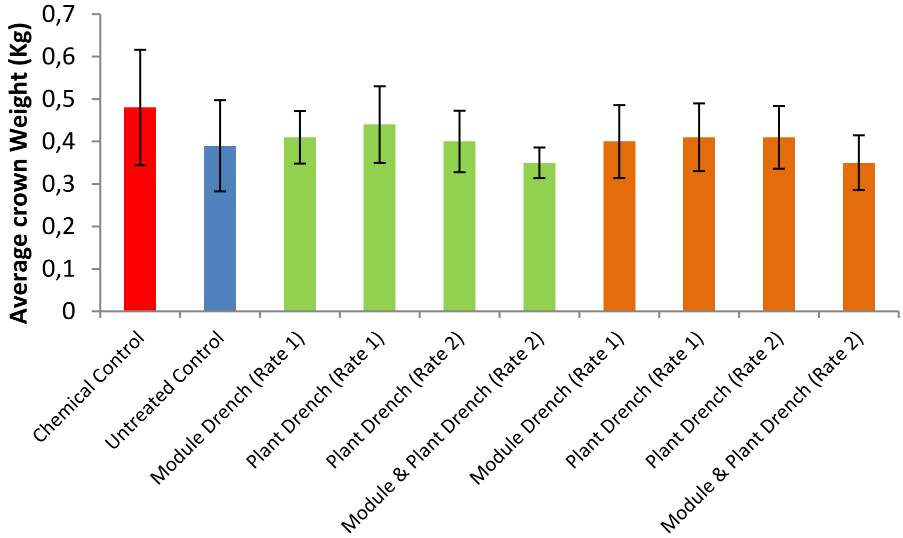


Figure 3.19. The average individual broccoli crown weight (var Parthenon) (Maximum of 13 crowns available per plot). Error bars represent Std Dev of 5 plots. Nematode species used in experiment is Steinernema feltiae. (Rate 1 = 35K Infective Juvenile per plant; Rate 2 = 70K Infective Juvenile per plant). Treatments in green were exposed to a 7 Day conditioning period at 9°C. Treatments in gold were prepared on the day of application.

Overall, this experiment indicated no benefit from subjecting the nematode *Steinernema feltiae* to a conditioning regime pre application, from an agronomic perspective. However, the experiment did indicate that a high rate application of *Steinernema feltiae* (70K IJ as a drench) did show some benefit in terms of plant performance. A possible explanation for this result is described below.

In order to better understand the ecology and behaviour of the entomopathogenic nematode in the soil, and to ensure they were present, a series of assessments were done, where plant roots and surrounding soil was sampled from each plot (Table 3.4). This soil was then placed in a 500ml container and incubated at 21 ^{0}C with 5 *Galleria mellonella* larvae added. After 72 hours the larvae were removed and assessed for mortality. Cadavers were incubated on moist filter paper for an additional 48 hours and then dissected, with the number of mature nematodes being recorded.

Table 3.4 Treatments included in nematode persistence study.

Treatment 1	Untreated Control
Treatment 3	Conditioned Nematode applied as a Drench at 35K
Treatment 4	Conditioned Nematode applied in Plug at 35K
Treatment 5	Conditioned Nematode applied as a Drench at 35K and Plug at 35K
Treatment 6	Conditioned Nematode applied as a Drench at 70K
Treatment 7	Commercial Nematode applied as a Drench at 35K
Treatment 8	Commercial Nematode applied in Plug at 35K
Treatment 9	Commercial Nematode applied as a Drench at 35K and Plug at 35K
Treatment 10	Commercial Nematode applied as a Drench at 70K

The boxplot below indicates the number of surviving *G. mellonella* larvae recovered from nematode treated soil (Table 3.4) versus the untreated control (Treatment 1). These samples were taken every 7 days for 4 weeks, commencing 1 week post application. Treatments 3 – 6 as labelled on the boxplot graph (Figure 3.20), refer to the plots where conditioned nematodes were applied and plots 7-10 refer to nematodes which were prepared on the day of application. The larval survival for conditioned nematodes was above 50% by week 5 post application for all conditioned nematode treatments, as opposed to the nematodes prepared on the day of application, where larval survival was approx. 40% for the 35 K IJ application rate, and between 0 and 20% for the 70 K IJ application rate.

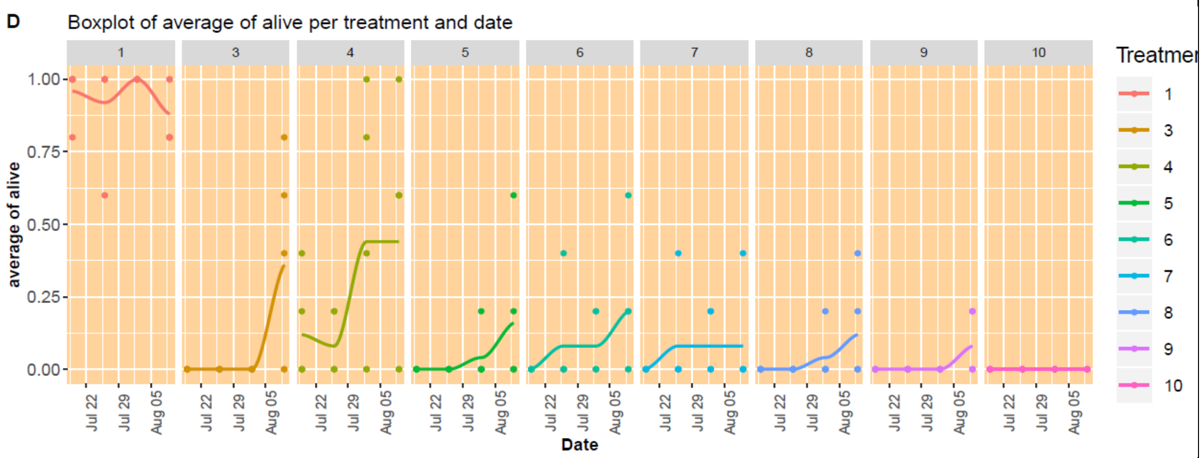


Figure 3.20. Box plot of percentage larval (Galleria melonella) survival when exposed to soil and plant modules recovered from field experiment.

As can be evidenced in the direct comparison of pre-harvest visual root damage scores reported above, significant differences were detected between treatments 4 (conditioned) and 8 (non-conditioned) (Module Drench 35K IJ) and 6 (conditioned) and 10 (non-conditioned) (Plant Drench 70K IJ) as per the box plots (Figures 3.20 and 3.21). With regards to the module drenches (T4, T8), the conditioned treatment (4) had relatively high level of larval survival, compared to the non-conditioned treatment (T8).

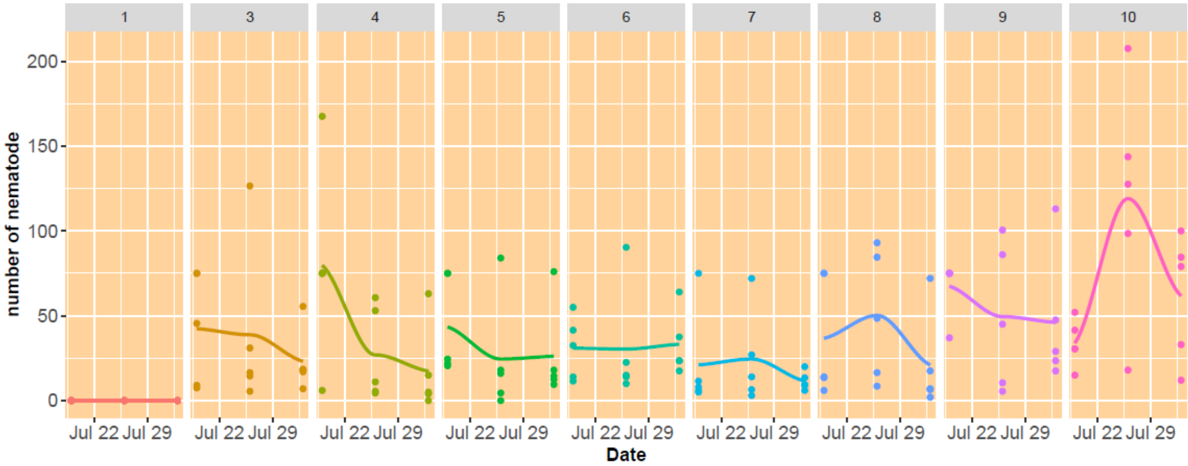


Figure 3.21. Mean number of mature S. feltiae recovered from Galleria melonella cadavers exposed to soil and plant modules recovered from field experiment.

Similarly, there was complete larval mortality and a high rate of mature nematodes recovery in Treatment 10, whereas in the comparative conditioned treatment, 35 days after application, there was over 50% larval survival. While not a quantitative method, there was a noticeable trend in that higher numbers of mature *S. feltiae* were recovered from *G. melonella* larvae exposed to the non-conditioned nematodes, particularly those applied at 70K IJ. Indeed 6 weeks post application; there were still an average of 23 mature *S. feltiae* being recovered from *G. melonella* larvae.

These data would indicate that delaying nematode application to coincide with the later larval instars may be required to enhance efficacy, but also potentially to reduce the required application rate, which at 70K IJ may not be economically feasible for commercial growers (Approx. 7 cents per plant, based on a general price of 1 euro per 1 million IJs, which is greater than current chemical control strategies (Based on Irish data)). However, as *D. radicum* oviposition will occur over several weeks, there would be a significant margin for error and time input required, in terms of monitoring. Also, there is the potential that plants will be negatively impacted by the smaller instars as they develop. Therefore, a strategy of frequent applications of entomopathogenic nematodes may be required for adequate management of *D. radicum*.

Comments on deviations from original plan:

Due to unexpectedly severe ground conditions, it was not feasible to install a planned field experiment for May 2018 (experimental field was flooded, making ground preparation for experiment impossible). Another experiment was installed in July 2018, to coincide with second generation *D. radicum* activity, however, possibly due to extremely high temperatures in Ireland at the time, no natural infestation of the experiment occurred, few viable eggs were recovered during pre-experiment monitoring and no larvae were observed in control plots. A third experiment was installed and reported on above. A field experiment was installed in May 2019, to assess the impact of conditioned nematodes against first generation *D. radicum*, however a malfunction to the incubator in which the nematodes were being conditioned resulted in complete mortality of the nematodes days before they were to be applied in the field. Another experiment to coincide with second generation activity was installed in July 2019 and is reported on above. Several additional field experiments, not originally included in the original plan were conducted to ascertain the impact of application rate of *S. feltiae* against *D. radicum*, and to investigate the potential to use a low dose of insecticide in combination with *S. feltiae*. Additionally, a field experiment was planted in April 2020, and while it will fall outside the timeframe of the FLYIPM project, it is within the time frame of the Irish funding for the project and the results will help to verify the findings reported here.

WP3- Task 8: T3.8 Investigate behavioural responses of *D. radicum* adults to EPF-colonized trap plants identified in collaboration with WP2 (repellence/attraction) (M16-21, 28-33)

Partner: NO NIBIO/NMBU
Results obtained:
Behavioural studies were performed in a wind tunnel in a two-choice set up. This was to test which plants were more attractive for *D. radicum* flies: EPF-inoculated cauliflower plants or non-inoculated plants, and if visual and/or odour cues released from these plants influence the behaviour of the flies. Two of the selected EPF isolates were tested, NCRI 250/02 and KVL 16-36. In a first two-choice experiment whole plants were tested, i.e. giving visual and odour cues, with the following treatments: (1a) non inoculated plant vs. KVL 16-36 inoculated plant, 1b) non inoculated plant vs. NCRI 2050/02 inoculated plant. In a second two-choice experiment odour cues were tested only: (2a) non inoculated plant vs. KVL 16-36 inoculated plant, 2b) non inoculated plant vs. NCRI 2050/02 inoculated plant.

Testing the fly attraction to the whole plant (visual + odour cues), the EPF-inoculated plant was significantly more attractive to *D. radicum* than the non-inoculated plant, irrespective of the EPF isolate tested. In contrast, testing the fly attraction to odour cues of the plants only, the non-inoculated plant was significantly more attractive than the EPF-inoculated plant, regardless of EPF isolate.

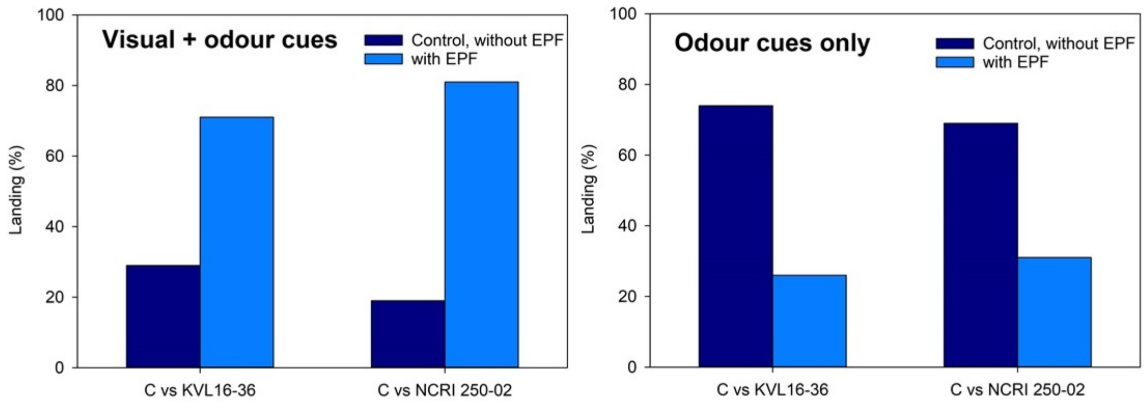


Figure 3.22. Behavioural responses of D. radicum in the wind tunnel testing visual and odour cues and odour cues only in a two-choice situation, i.e. non inoculated plants vs. inoculated plants, for the two selected EPF isolates NCRI 250/02 and KVL 16-36, respectively.

Indications were found that the entomopathogenic fungal treatment also causes a change in the chemical profile of the plant (phytohormones/volatile organic compounds) and a decrease in reflectance of host plant leaves in the photosynthetically active region, suggesting that the EPF-induced photosynthesis. These fungal-induced changes might alter odour and visual cues used by the flies in their host plant selection.

Comments on deviations from original plan:
No deviations from original plan.

Partner: FR IGEPP

Results obtained:

The French group conducted a field experiment to investigate the effects of EPF (*M. brunneum*) grown inside Chinese cabbage and broccoli seedling pots on *D. radicum* infestation. Young Chinese cabbage and broccoli plants colonized by EPF were transplanted into a field located in a vegetable production area and the numbers of larvae and pupae developing on plants were estimated (Figure 3.23). We observed no effect of the presence of EPF on the numbers of larvae and pupae collected.

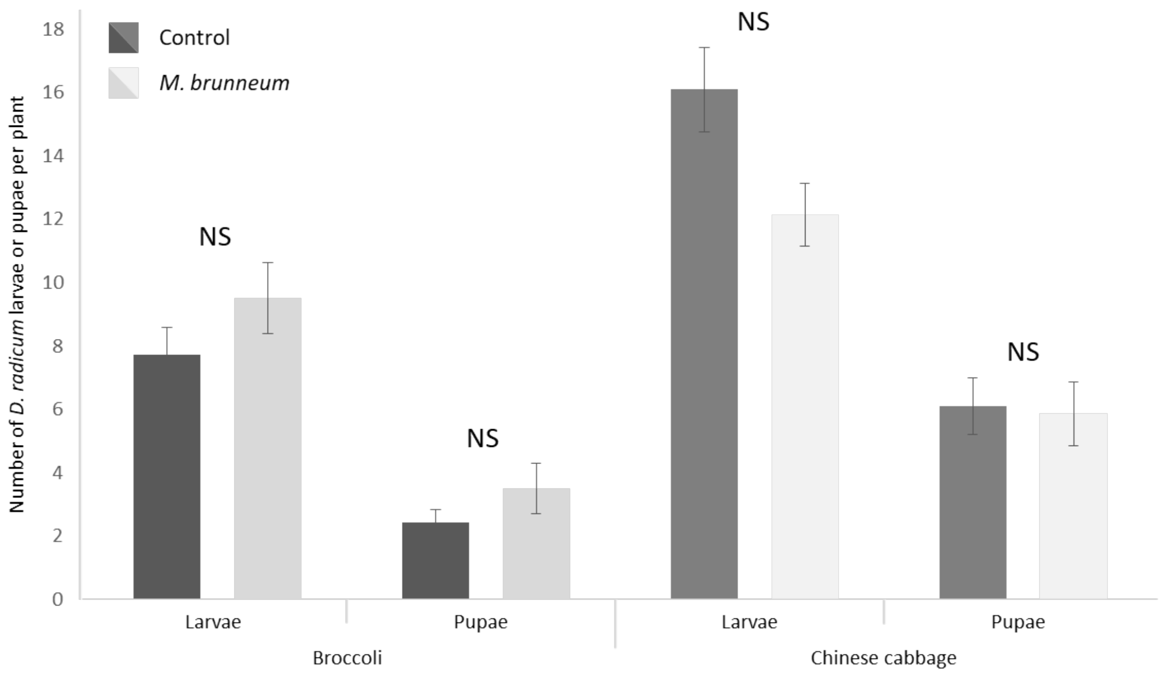


Figure 3.23. Mean number (± S.E.) of Delia radicum second and third stage larvae and pupae counted per plant depending on the plant inoculation status.

However, isolation of larvae collected from the plants revealed that 78% were contaminated with the EPF on inoculated broccoli plants and 67% were contaminated on the inoculated Chinese cabbage plants while no contamination was observed on control plants (Figure 3.24).

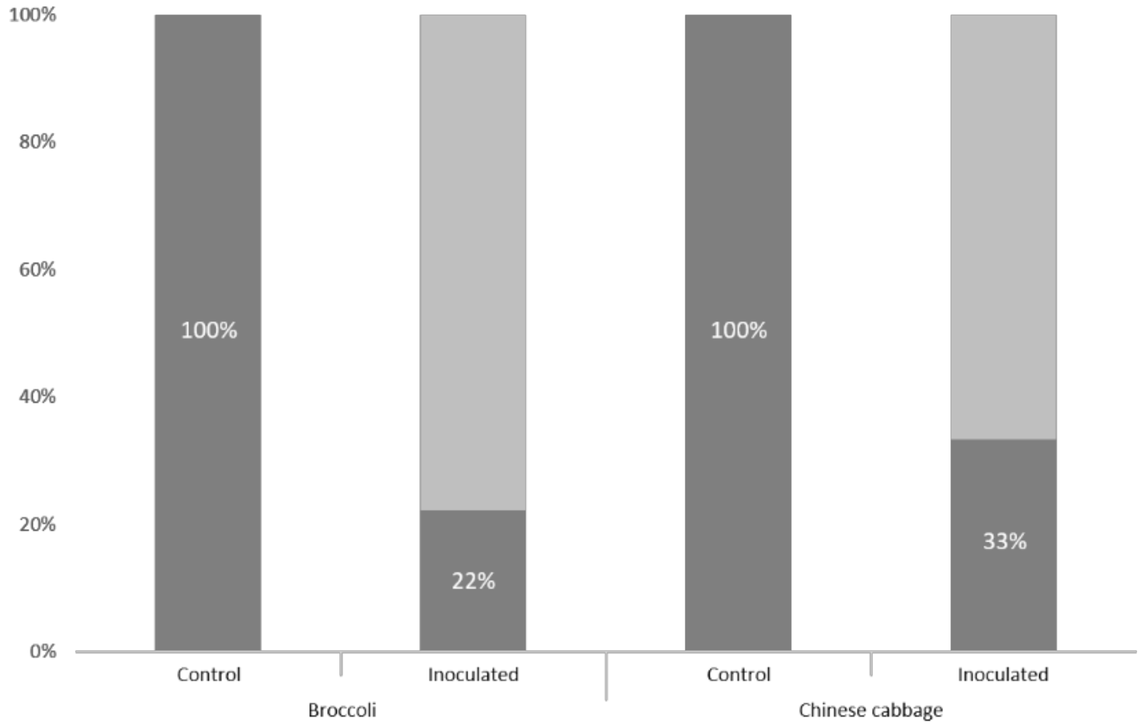


Figure 3.24. Percentage of healthy (dark grey) and contaminated (with the EPF) (light grey) larvae collected on plants depending on the plant inoculation status.

Very interestingly, at the end of the experiment, we observed the inoculation of plants with EPF plant significantly reduced the number of flies emerging both from Chinese cabbage and broccoli plants (Figure 3.25).

However, in accordance with the lack of a reduction in the numbers of larvae and pupae observed, no effect of EPF inoculation on plant mortality was observed (Figure 3.25).

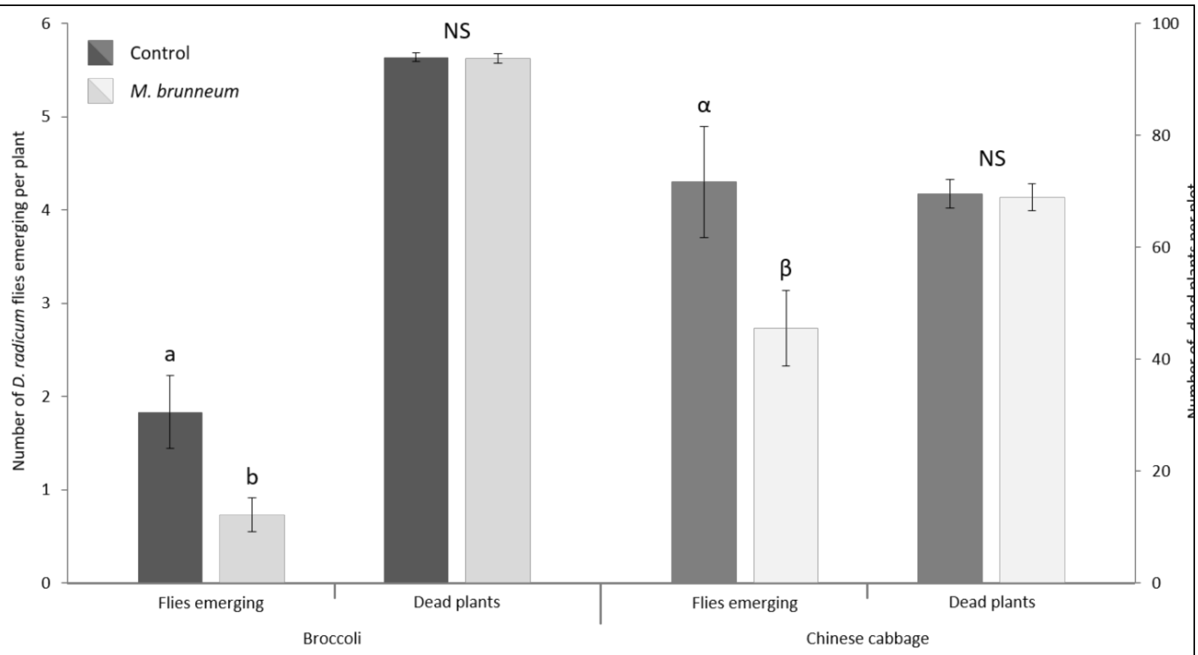


Figure 3.25. Mean number (± S.E.) of Delia radicum adults emerging from plants depending on the inoculation status and mortality of plants at the end of the experiment.

This experiment shows that EPF could be a very useful tool to reduce *D. radicum* infestation in the Chinese cabbage and turn it into an effective trap crop but that EPF could probably not be used to directly protect the target crop as it did not kill early larval stages of *D. radicum* and prevent damage.

WP3- Task 9: T3.9 Evaluate effects of temperature on establishment and infectivity of selected candidate EPF strains in pot trials/laboratory assays using field-realistic temperatures (M28-33)

Partner: UK University of Warwick
Results obtained:

Fungal culture
Stock cultures of the isolates (Table 3.5) were stored in liquid nitrogen (Chandler, 1994). Subcultures for laboratory experiments were grown on SDA from slant cultures and incubated in darkness at 23°C for 14 days prior to assay. Conidia were harvested in sterile 0.01% Triton X-100 and suspensions were filtered through milk filters (Lantor (UK), Bolton, UK) to remove hyphal fragments. Conidia were counted in an improved Neubauer hemacytometer and aliquots were prepared at concentrations of 10^7 in sterile 0.01% Triton X-100.

Table 3.5 Isolates used in this study.

Isolate- accession	Species	Notes/comments
KVL 16-36	*Metarhizium brunneum*	Obtained as pure culture directly from the commercial product Met52.
NCRI 250/02	*Metarhizium brunneum*	Root colonizer and infective against insect larvae at relatively low temperature (Klingen et al. 2015); Norwegian origin (NIBIO).

Fungal radial extension
A conidial suspension was prepared (10^7 spores per ml) and 100µl was spread evenly over SDA in Petri dishes and incubated in the dark at 23°C for 48 h. Plugs (6mm) cut from these plates with a

flame-sterilised cork borer were then placed upside down in the centre of fresh SDA in Petri dishes, one plug per plate. The plates were incubated for 28 days in darkness at 5°C, 10°C, 15°C, 20°C, 25°C, 30°C and 35°C with two plates for each isolate / temperature combination. Colony diameters were measured with a ruler using two cardinal diameters every 7d for the duration of the experiment.

Fungal germination

A conidial suspension was prepared (10^7 conidia per ml) and 20µl was pipetted onto three previously-marked circles (approx. 2cm diameter) on plates of SDA. The plates were incubated at either 5C, 10°C, 15°C, 20°C, 25°C, 30°C and 35°C in darkness for 24h. The germination assessment was carried out destructively by pipetting a drop of lactophenol methylene blue inside each circle. Treated plates were stored at 4°C before examination under a compound light microscope (Olympus BH-2, Tokyo, Japan) magnification x200. The numbers of germinated and ungerminated spores (conidia) were counted from a total sample of approximately 100 conidia per circle. Germination was defined as the point when an emerging germ tube was equal to, or longer than the width of the conidium.

Cabbage root fly larval development

Data on the effect of temperature on the development of cabbage root fly larvae was extracted from Sondgerath and Miiller-Pietralla (1996) and fitted to a non-linear model (Briere et al (1999) in RStudio (version 0.99.903 – © 2009-2016 RStudio, Inc) using the package Minpack.lm (version 1.2-0) and the optimum temperature for larval development estimated.

Results

Fungal growth

The temperature response of the isolates was characteristically asymmetric, with rapid inactivation at temperatures above the optimum (Figure 3.26). Both isolates did not grow at 5°C and grew slowly at 10°C and 35°C. The data was fitted to a non-linear model (Briere et al (1999) in RStudio (version 0.99.903 – © 2009-2016 RStudio, Inc) using the package Minpack.lm (version 1.2-0) and the optimum temperature for fungal growth estimated. The model fitted the data well, with r^2 values of 0.94 and 0.83 for KVL1636 and NCRI250/02 respectively. Optimum temperatures for growth were 28.3 (KVL1636) and 27.9 (NCRI250/02) (Table 3.6, Figure 3.27). The responses of the two isolates were similar and there was no evidence that NCRI250/02 grew at lower temperatures than KVL1636.

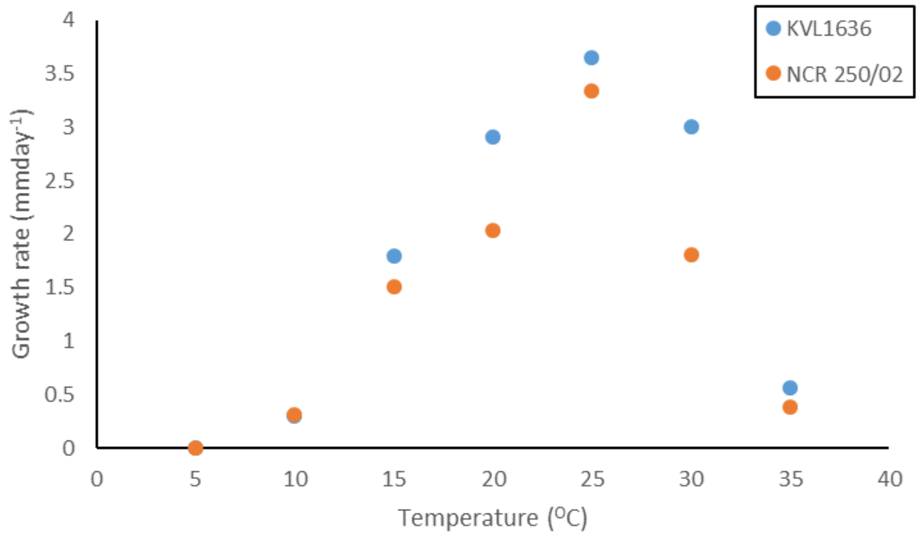


Figure 3.26 Growth response of Metarhizium brunneum (KVL1636 and NCRI 250/02) at eight temperatures ranging from 5-35°C.

Table 3.6 Predicted optimum and maximum temperatures (°C) for fungal growth.

Isolate	Species	Optimum Temperature (°C)	Maximum Temperature (°C)
KVL 16-36	*Metarhizium brunneum*	28.3	35.1
NCRI 250/02	*Metarhizium brunneum*	27.9	35.0

A

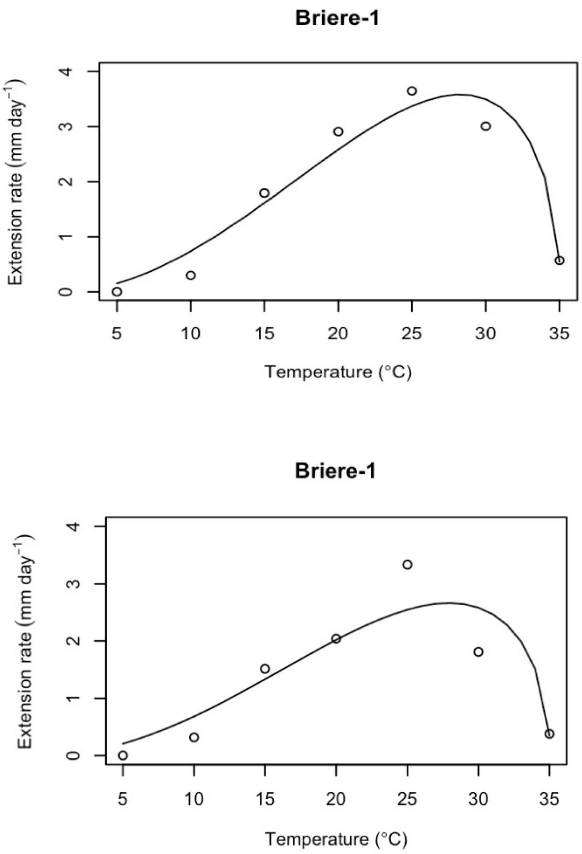


Figure 3.27. Briere-1 models fitted to mean colony extension rate (mm day^{-1}) plotted against temperature (°C) for Metarhizium brunneum (A: KVL1636 and B: NCRI 250/02).

<u>Fungal germination</u>

The temperature response of the isolates was characteristically asymmetric, with rapid inactivation at temperatures above the optimum (Figure 3.28). Neither isolate germinated at temperatures of 10°C or below. Isolate KVL1636 exhibited 28% germination at 15°C and both isolates exhibited greater than 95% germination at temperatures of 25°C and 30°C. Both isolates also germinated at 35°C exhibiting 74% and 84% germination respectively. Maximum temperatures at which germination still occurred were more than the maximum temperatures at which mycelial extension still occurred. The data was fitted to a non-linear model (Briere et al (1999) in RStudio (version 0.99.903 – © 2009-2016 RStudio, Inc) using the package Minpack.lm (version 1.2-0) and the optimum temperature for fungal germination estimated. The model fitted the data well, with r^2 values of 0.96 and 0.91 for KVL1636 and NCRI250/02 respectively. Optimum temperatures for germination were 29.8 (KVL1636) and 30.1 (NCRI250/02) (Table 3.5, Figure 3.29).

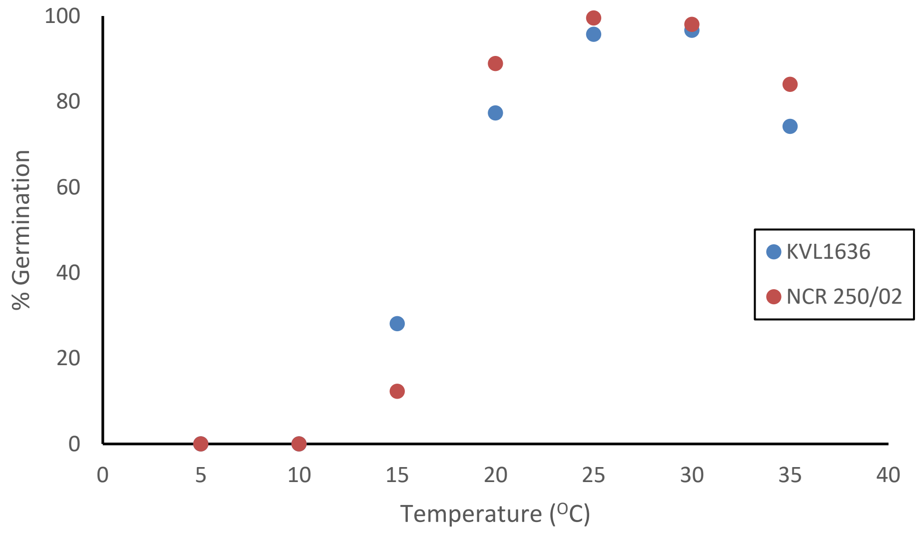
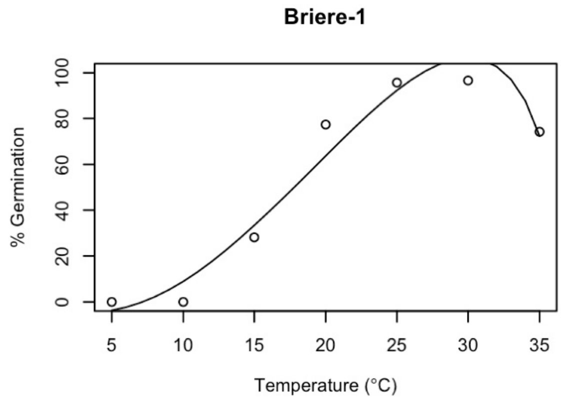


Figure 3.28. Germination response of Metarhizium brunneum (KVL1636 and NCRI 250/02) at eight temperatures ranging from 5-35°C.

Table 3.7. Predicted optimum and maximum temperatures (°C) for fungal germination.

Isolate	**Species**	**Optimum Temperature (°C)**	**Maximum Temperature (°C)**
KVL 16-36	*Metarhizium brunneum*	29.8	36.5
NCRI 250/02	*Metarhizium brunneum*	30.1	36.7

A



B

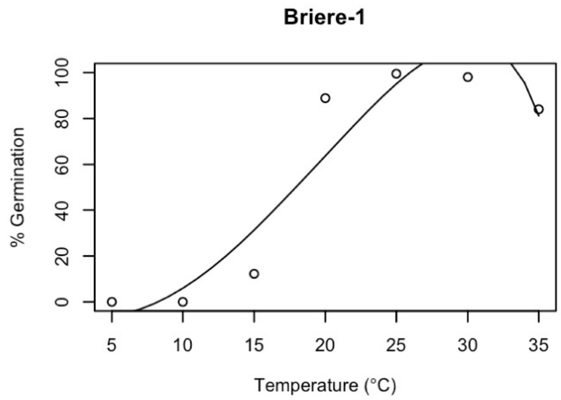


Figure 3.29 Briere-1 models fitted to mean % germination plotted against temperature (°C) for Metarhizium brunneum (A: KVL1636 and B: NCRI 250/02).

Cabbage root fly larval development

Larval development was characteristically asymmetric, with rapid inactivation at temperatures above the optimum (Figure 3.30). No development was observed at 35°C. The model fitted the data well, with a r^2 value of 0.94. The predicted optimum temperature for larval development was 28.7°C (Figure 3.30).

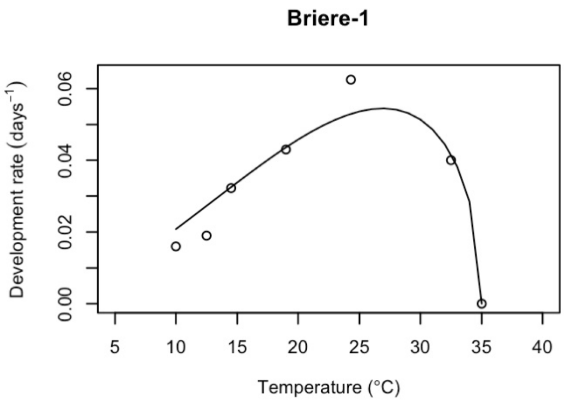


Figure 3.30 Briere-1 model fitted to larval development (taken from Sondgerath and Miiller-Pietralla (1996)) plotted against temperature (°C).

CONCLUSIONS

- The germination and mycelial (= colony) extension rates for two EPF isolates were quantified at a range of temperatures. This was done to provide an indication of the likely performance of the isolates under field conditions, and in particular to identify isolates able to develop well at 10 - 20°C, and which might therefore be suitable for use as a biopesticide against cabbage root fly under typical UK temperature conditions.

- The two isolates showed similar responses in terms of the effect of temperature on the germination of fungal conidia and mycelial growth. Maximum germination occurred between 20 to 30°C. Neither isolate germinated at 5 or 10°C. The estimated optimum temperatures for growth were 28.3°C (KVL1636) and 27.9°C (NCRI250/02), while the optimum temperatures for germination were 29.8°C (KVL1636) and 30.1°C (NCRI250/02). The temperature profiles of both isolates matched well with the predicted optimum temperatures of larval development.

- This is encouraging, as a mismatch in thermal profiles could mean that biocontrol failure will occur under certain temperature conditions, i.e. if the pest insect is able to grow and function at temperatures at which the EPF is inactive.

- An important caveat is that we measured spore germination at 24 h and used it as an indicator of spore viability and infectivity. This is a standard system used by us and many other labs. However, it could be that the speed of germination is reduced at higher temperatures rather than an absolute reduction in germination. Thus, spores that have not germinated after 24 h at a particular temperature may still be viable and germinate after 48 h or longer. The downside for this is that a reduction in the time to germinate would be expected to reduce the virulence of the isolate to the target pest. However, this needs to be tested.

Comments on deviations from original plan:
No deviations from original plan.

WP3- Task 10: T3.10 Develop a simple model to forecast fungal pathogenicity at different, field-realistic temperatures (including fluctuating temperatures) (M31-36)

Partner: UK University of Warwick
Results obtained:

Development of the model is described under T3.9, above.

Comments on deviations from original plan:
No deviations from original plan.

WP4	**Building the IPM Toolbox**
WPL: **Richard Meadow NO** Responsible partners: DK, FR, DE, IE, NO NMBU, SL, CH, UK.	
Overall summary of main results and conclusions WP4 The consultation with growers and advisors to determine which IPM tools are used already and which are considered to be most promising was collected from the partner countries. This overview was presented at a project workshop. The IPM toolbox will incorporate a combination of the different tactics and control methods that were investigated in WP 1-3.	

Control methods were investigated in WP 4, both as individual practices and in combination. Workpackages 1-3 have given results that aid in the choice of the best combinations of tactics. The tactics investigated in WP 4 in 2018 and 2019 included a large field experiment in Norway with cauliflower as the main crop and the following methods to reduce attack by *D. radicum*: trap cropping (Chinese cabbage as trap), repellent+trap crop, exclusion fences, trap crop+exclusion fences. The results have not yet been completely analyzed, but there was a clear reduction in attack rate in the treatments with exclusion fences with or without trap crop, compared to all other treatments.

Greenhouse and field experiments in Switzerland investigated the repellent effects of sage extracts in different formulations and in combination with other IPM tools. Sage extracts were tested in different combinations with an attractant (rutabaga juice), fungal biocontrol agents and insect netting. The sage extracts greatly reduced the number of *D. radicum* eggs laid and the number of larvae that developed on the plants in the greenhouse experiments. The fungal biocontrol agent also reduced the number of larvae and pupae in the greenhouse experiments, as well as the amount of damage in the field experiments. Insect netting was the most beneficial in the Swiss field experiments.

In an experiment in the UK several biological insecticides were compared either as pre-planting or at planting applications. Root and foliage weight was greater and root and stem damage was reduced by pre-planting treatment with spinosad (produced from metabolites of soil bacteria) or azadirachtin (from extracts of the neem tree). The combination of a reduced dose of spinosad and the fungal agent gave slightly less effect and the fungus alone showed little difference from the control.

Field trials in Germany in 2018 and 2019 investigated fungi and nematodes as biological control agents for *Delia radicum*. The 2019 trials added a trap crop and a repellent to combine the elements of push-pull. The timing of the trials was according to the SWAT forcasting model, in order to test the benefits of using this model in an IPM strategy. The 2018 trial showed a significant reduction in *D. radicum* survival in the plots treated with the fungal biocontrol. Overall, the applied biocontrol agents were not very effective in controlling *D. radicum*. Reasons for this result are discussed in this report. The 2019 trial showed that the different methods or "IPM tools" could easily be combined to develop a push-pull strategy. However, more research is needed to optimise conditions to favour the biological control agents.

Report on the results obtained (A) and changes to the original plan/ WP objectives (B) by tasks and partners:

WP4- Task 1: T4.1 Consult growers and advisors in partner countries to determine which IPM tools are used already and which are considered to be most promising. Ensure that interested growers and advisors can keep in close contact with WP4 activity (M1-8)

The survey covered the IPM tools for 4 species of root flies *Delia radicum, D. floralis* and *D. platura* as pests of brassica crops and *Chamaepsila rosae* in carrots. The survey addressed current practice in the use of different tools from the "IPM toolbox".

The tools that were considered were: resistant or partially resistant cultivars, delayed sowing or planting date, early harvesting date, crop rotation, spatial separation of crops, biological control with released arthropods, biological control with entomopathogens, conservation biocontrol, insect netting, exclusion fences, management of cover crops, use of volatiles to manage pests (push/pull), insecticides (which and how applied), pesticides using plant extracts e.g. pyrethrins, garlic, monitoring with traps, forecasting with traps, forecasting with models.

Partner: CH Agroscope
Results obtained:

In Switzerland crop rotation is part of the Swiss IPM concept, so it is in practice for pests such as *D. radicum, D. platura* and *C. rosae*. Netting is used in radish growing against *D. radicum*. Monitoring and forecasting are used for *D. radicum* and *C. rosae*. None of the other IPM tools are in widespread use in Switzerland. *D. floralis* is not known as a pest in Switzerland.

IPM Tool: "Swiss info bulletin of the forecasting and monitoring network": information about the actual occurrence of the pests in vegetable crops in Switzerland. Our findings: using a pest exclusion net can reduce yield loss caused by the cabbage root fly (*Delia radicum*) in some vegetable crops, but it may lead at the same time to an increased root damage caused by flea beetle larvae.

Comments on deviations from original plan

No deviations from the original plan.

Partner: DE JKI
Results obtained:

In Germany crop rotation is always practiced for *D. radicum* and *C. rosae*. Spatial separation is also used to reduce attack by *C. rosae*. In addition the crop is placed in locations that are unfavourable for the pest due to wind. Furthermore it is recommended to grow carrots at sites without hedgerows or similar surrounding vegetation to reduce immigration of overwintering individuals. When the risk of damage by *C. rosae* is high, the growers sometimes will use early harvesting of the crop or edges of the crop to save the yield. Netting is used to protect against *D. radicum* and on fields under 1 ha for *C. rosae*. Monitoring by visual inspection or traps is practiced for *D. radicum* and *C. rosae*, respectively.

Comments on deviations from original plan

No deviations from the original plan.

Partner: DK University of Copenhagen
Results obtained:

Crop rotation is commonly practiced against *D. radicum* and *C. rosae*. The same holds for delayed sowing or planting dates and to some extent spatial separation of crops. Insect netting is widely used against these two species, as is forecasting. *Chamaepsila rosae* is monitored with traps and in some cases producers evaluate flight and damage to design strategies for the following season.

Some growers use onion oil to repel *P. rosae*. *Delia floralis* and *D. platura* are not considered as pests in Denmark.

Comments on deviations from original plan

No deviations from the original plan.

Partner: FR IGEPP
Results obtained:

In France crop rotation is sometimes practiced for *C. rosae* but rarely for *D. radicum* (especially in the North West area of production). Concerning carrots, it is recommended to grow them at sites without hedgerows or similar surrounding vegetation to limit immigration of overwintering individuals. Delayed sowing or planting dates is used for broccoli, cauliflower or carrot in organic production. As in in Germany, when the risk of damage by *C. rosae* is high, the growers sometimes will use early harvesting of the crop or at the edges of the crop to save the yield. Netting is used to protect turnips against *D. radicum* and more rarely for *C. rosae*. Crops planted early in the spring are often protected by a thermal blanket which also acts as protection against *D. radicum* or *C. rosae.* Monitoring and forecasting are used for *D. radicum* and *C. rosae*. All of the conventional and organic growers use insecticides (Spinosad is allowed in organic production).

IPM Tool: “BSV : Bulletin de Santé du Végetal”: information about the actual occurrence of pests in vegetable crops in each region of France.

Comments on deviations from original plan

No deviations from the original plan.

Partner: IE Teagasc
Results obtained:

In Ireland there is some use by organic growers of partially-resistant carrot varieties against *C. rosae*. There is also some practice of delayed planting or sowing date for *D. radicum* and *C. rosae*. Crop rotation is practiced against *C. rosae*. Biological control using EPF against *D. radicum* or EPN against *C. rosae* is limited to hobby growers. Conservation biocontrol by reducing pesticide impact on beneficials was increasing in brassica production, but “contamination” of the products by beneficials resulted in a setback in this practice. Insect netting is in widespread use in both brassicas and carrots. Most or all of the conventional growers use insecticides. Garlic extracts are used to a limited extent in carrot production. Monitoring of *D. radicum* is by egg counts and for *C. rosae* it is by traps. Forecasting for *D. radicum* is temperature based, for *C. rosae* it is based mainly on traps. For both pests the pest bulletins that are issued are used for forecasting/warning.

Comments on deviations from original plan

No deviations from the original plan.

Partner: NO NMBU
Results obtained:

For *D. radicum, D. floralis* and *C. rosae* crop rotation is commonly practiced, as is use of insect netting. For *D. radicum* and *C. rosae* monitoring and forecasting are practiced, while only monitoring is available for *D. floralis.* In some districts exclusion fences are used against *D. radicum* and *D. floralis*. *D. platura* is not known as a pest in Norway.

Comments on deviations from original plan:

No deviations from the original plan.

Partner: UK University of Warwick
Results obtained:

The IPM tools used by growers in the UK are mostly implemented for *C. rosae*. In carrot production the growers always use crop rotation and some use forecasting information and others monitor fly activity. They also use insect netting instead of insecticides on some organic crops. Early harvesting of crop edges is also sometimes practiced. For *D. radicum* most root crops are protected using netting. Crop rotation is practiced but sometimes not after every crop. Some growers monitor *D. radicum* and others use forecasting information. The same practices are used for the closely related *D. floralis*, except that there is no forecasting model. For *D. platura* monitoring is the only IPM tool that is used in practice.

Comments on deviations from original plan:

No deviations from the original plan.

WP4- Task 2: T4.2 Use results from WP3 to test and optimise efficacy of EPF and EPN as biological control agents against *D. radicum* in an IPM approach, in conjunction with existing and newly-developed tools, by undertaking semi-field and/or field trials. It is important to do this across as wide a range of 'climates' as possible (M16-33)

Partner: CH Agroscope
Results obtained:

Agroscope focused on the control of the cabbage root fly (*Delia radicum*).

Investigation of the efficacy of EPF and EPN control agents against *D. radicum (2018)*
Field experiment; vegetable crop: white radish; pest: *D. radicum*; control agents: EPF (*Beauveria bassiana*) and EPN (*Steinernema feltiae*). A yellow pan water trap was evaluated on a weekly basis for the observation of the pest's flight activity. Date of sowing and evaluation of the experiment were scheduled on the basis of SWAT forecasts.
Results: Combination, or an increase in the frequency, of the treatments reduced the damage caused by *D. radicum* (Figure 4.1).

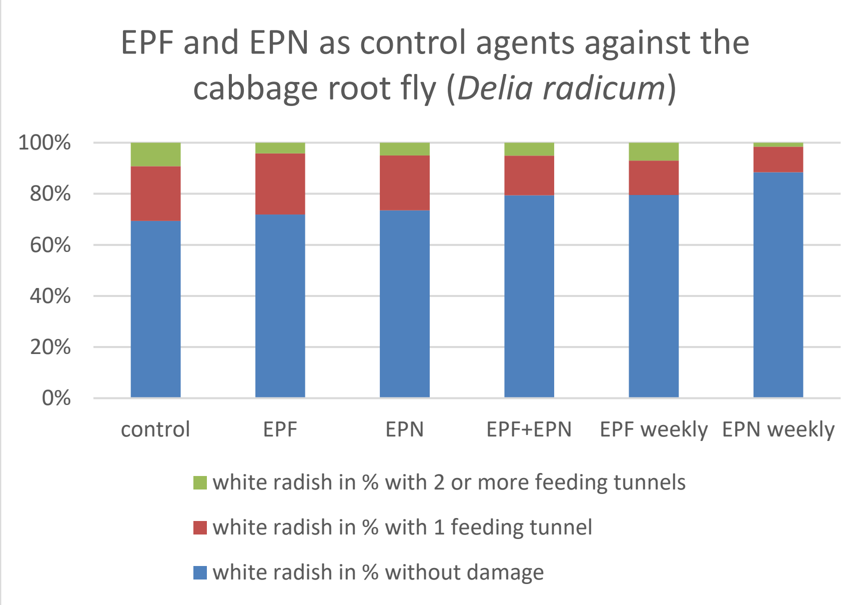


Figure 4.1. Investigation of the efficacy of EPF and EPN control agents against D. radicum.

2018.2.: Investigation of the efficacy of the EPF and EPN control agents, and the repellent effect of sage extracts against *D. radicum*. Greenhouse experiments: planned 3-4 setups; vegetable crop: Chinese cabbage; pest: *D. radicum*; control agents: EPF and EPN / repellent effect: sage extract

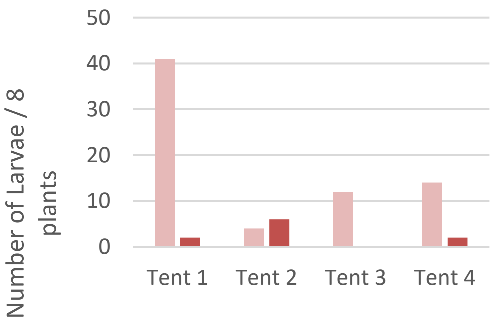
2018.3.: Studying the repellent effect of the sage extract, testing artificial diets. Laboratory experiments in climate chambers: starting: autumn 2018; more setups; pest: *D. radicum*.

The results of the experiments with sage extracts are summarized in Table 4.1 and shown in Figure 4.2. They show that (1) the application of sage extracts can reduce the egg-laying activity of the cabbage root fly; (2) the tested sage extracts all reduced egg-laying to a similar extent; (3) rutabaga juice can stimulate the landing and the egg-laying activity of the cabbage root fly. In some experiments we had additional treatments with entomopathogenic fungi (*M. brunneum* or Naturalis-L (*B.bassiana*)) as shown in the Figures.

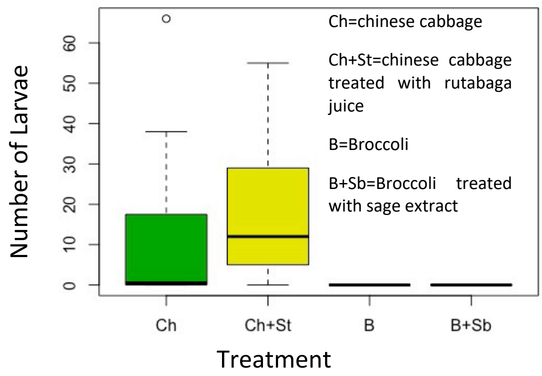
Table 4.1. Overview of experiments performed in 2018 and 2019 in the greenhouse and the field.

*Yes in three out of four replicate insect tents.

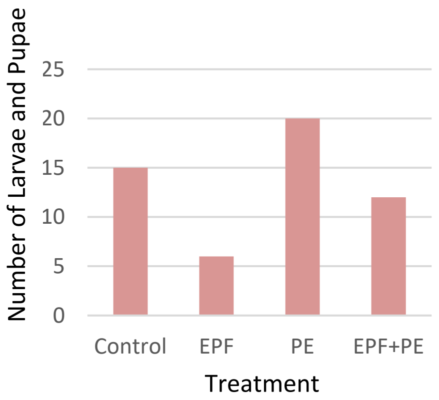
Experiments	Greenhouse experiment-1	Greenhouse experiment-2a	Greenhouse experiment-2b	Greenhouse experiment-3	Greenhouse experiment-4	Field experiment-5	Field experiment-6
Crops	Chinese cabbage	Chinese cabbage + broccoli	Chinese cabbage + broccoli	Chinese cabbage	Chinese cabbage	white radish	white radish
Infested with	naïve flies	naïve flies	naïve flies	naïve flies	naïve flies	natural occurring population, no artificial infestation	natural occurring population, no artificial infestation
Treatment	sage water solution	sage pellets, sage water solution and rutabaga juice	sage pellets, sage water solution and rutabaga juice	sage water solution and EPF	sage water solution, watered sage pellets and EPF	sage water solution, EPF and net	sage water solution, EPF and net
Reduction due to treatment in the number of eggs laid, larvae, pupae or damage: yes or no	yes (3/4)*	yes, but only on broccoli	yes, but only on broccoli	yes, in combination with EPF	yes	yes	no



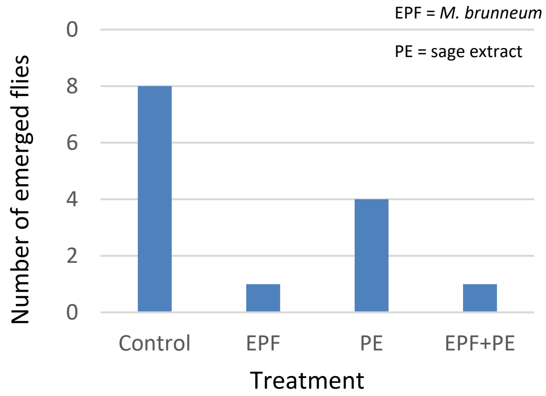
Greenhouse experiment 1



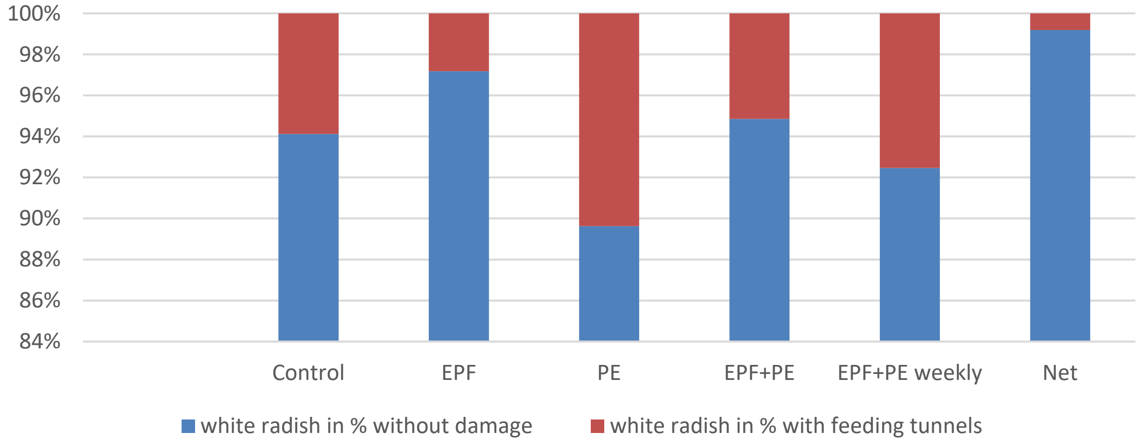
Greenhouse experiment 2a; 2b



Greenhouse experiment 3



Greenhouse experiment 4



Field experiment 5;6

Figure 4.2. Results of the greenhouse and field experiments.

<u>Publication:</u>

Boeriis, T., Mazzi, D., Vogler, U. (2020) Push (-and-pull) strategy with sage extracts may reduce crop losses caused by the cabbage root fly, *Delia radicum*. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Stratford-upon-Avon (UK), 13-16 October, 2019. Edited by R. Meadow. In press.

Comments on deviations from original plan:

No deviations from the original plan.

Partner: UK University of Warwick

Results obtained:

The aim of this trial in 2019 was to evaluate bio-insecticides as modular drench treatments in comparison with a standard treatment (Tracer – spinosad which is also biologically derived) for the control of cabbage root fly larvae in cauliflower roots. It was partly supported by the Agriculture and Horticulture Development Board (UK) as there were insufficient funds available within the FlyIPM project.

Methods

Nematode conditioning

Previous research (Michael Gaffney, Teagasc, Ireland) suggested that pre-conditioning nematodes prior to application can increase their efficacy. From a standard 50 million pack of nematodes (Nemasys) 25% of the weight was weighed into a 5 l water bottle and approximately 2500 ml of water was added. The bottle was gently agitated until the large clumps of carrier had dispersed. An aquarium pump was connected via tubing and a sparger (which was forced to the bottom of the bottle using a cane). The airflow was adjusted until sufficient air was supplied to keep the nematodes in suspension without being too strong to cause damage. The bottle was placed in a small box and propped at one end to attain an angle of approximately 45^0 and the end of the bottle was blocked with cotton wool. The bottle was then placed in an incubator (unlit) at 9 ^{0}C for 12 days. After 12 days, keeping the solution in motion, approximately 20 ml was decanted into a beaker. From this solution 50 µl was taken using a 200 µl pipette and transferred to a crowd counter. The concentration of nematodes was counted under a binocular. The process was repeated until consistent counts were achieved. Nematodes appearing coiled under a microscope are still viable. They slowly become active after a few seconds under the microscope light. Nematodes appearing very straight with a visible internal structure are no longer alive.

Field trial

The study was conducted at Warwick Crop Centre, Wellesbourne. All sites within Warwick Crop Centre are susceptible to attack from cabbage root fly. The plots were 1.5 m x 1 bed (1.83 m) in size and there were 5 replicates of 6 treatments. The trial was arranged as an incomplete 6 x 6 Latin square. Plants were planted at 50 cm spacing within rows (4 plants/row) and 3 rows per bed with 50 cm between rows. Cauliflower (cv Skywalker) was sown in 308 Hassy trays containing Scotts Levington M2 on 5 June 2019 and placed in a glasshouse. Plants were transferred to a polytunnel on 26 June. The pre-planting treatments (Table 4.2) were applied to the plants on 3 July, 1 day before planting. The treatments were applied using a 1 ml automatic pipette. All pre-planting treatments were applied in a volume of 1 ml per plant. The treatments were washed-on subsequently with the same volume of water. The transplants were planted on 4 July to catch the second generation of *D. radicum* (timed using the UK forecast) and the nematode treatment was applied (in 10 ml using a 10 ml automatic pipette) to the surface of the module immediately after planting but before the module was covered in soil.

Table 4.2 *Treatments applied to cauliflower pre-planting or at planting.*

	Product	Active substance	Rate (per 1000 plants)	Volume/plant (ml)	Timing
1	Untreated				
2	Met 52	*Metarhizium anisopliae*	28 ml	1	Pre-planting
3	Nemasys	*Steinenema feltiae*	35 million nematodes	7	At planting
4	Met 52 + Tracer (20% of approved dose)	*Metarhizium anisopliae* + Spinosad	28 ml + 2.4 ml	1	Pre-planting
5	Tracer	Spinosad	12 ml	1	Pre-planting
6	Coded	Azadirachtin	120 ml	1	Pre-planting

Cabbage root fly activity was monitored in a nearby plot of cauliflower by taking soil samples from around the base of cauliflower plants. Visual assessments of phytotoxicity were made on 11 July 2019 (7 days after transplanting). The trial was harvested on 12 August (all 12 plants in each plot were dug with roots intact). The foliage was removed and weighed in the field. The roots were collected, washed and assessed for root and stem damage on a 0-5 scale. The damage categories were 0%, <5%, 5-10%, 10-25%, 25-50% and >50% of the surface area affected by cabbage root fly larvae. These equate to damage scores of 0, 1, 2, 3, 4 and 5 respectively. The weight of the roots was also recorded. All analyses were carried out on plot means using Analysis of Variance (ANOVA) in Excel. The analyses were interpreted using treatment means together with standard errors for the differences (SED) between means and associated 5% least significant differences (LSD).

Results

The numbers of eggs laid on cauliflower plants in the nearby monitoring plot are shown in Figure 4.3. Egg laying by second generation flies started around 21 June and peaked on 12 July, approximately one week after the trial was transplanted.

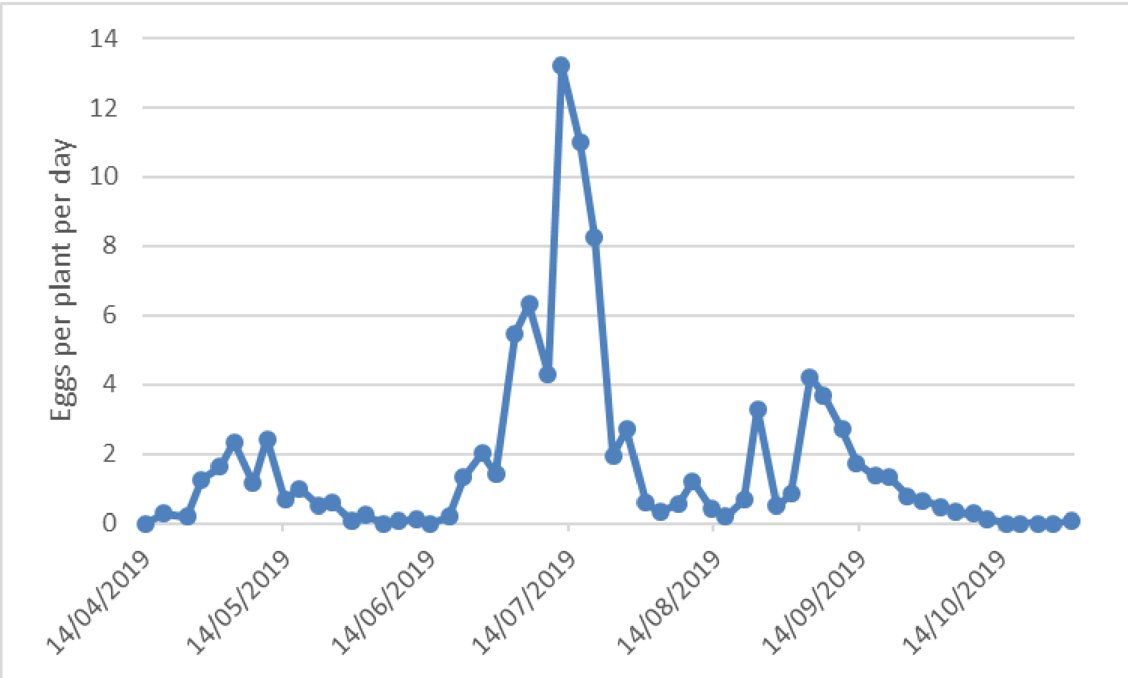


Figure 4.3. The numbers of cabbage root fly eggs laid per plant per day on cauliflower plants at Warwick Crop Centre, Wellesbourne in 2019.

All of the analyses were significant at the 5% level using an F-test and with the absence of any other factors all would be a function of cabbage root fly control. The results are presented in Table 4.3. Foliage (Figure 4.4) and root weight (Figure 4.5) were significantly increased by application of Tracer or Azadirachtin compared with the untreated control and additionally Met52 + Tracer 20% significantly increased root weight. Root damage (Figure 4.6) was significantly reduced by Tracer, Azadirachtin and Met52 + Tracer 20%. Stem damage (Figure 4.6) was significantly reduced by Tracer. In all cases there were no significant differences between the three effective treatments (Tracer, Azadirachtin and Met 52 + Tracer 20%)

The trial was timed to be exposed to the peak egg laying of the second generation of cabbage root flies and peak egg laying occurred in a nearby field 8 days after transplanting. Therefore, larval numbers were likely to be high and treatments fully tested. However, this was a small-scale trial so the significance of results could be overstated. The pre-planting treatments of Azadirachtin and Met 52 + Tracer (20% recommended dose) were as effective as the standard Tracer treatment both in terms of increased foliage and root weight and reduced root damage although the Tracer treatment itself was only partially effective. It is not clear if Met 52 provides an additive effect to the 20% dose of Tracer or if the reduced dose of Tracer is equally as effective as the full rate but it is clear that Met 52 alone is ineffective. The nematodes (Nemasys) were also ineffective even after pre-conditioning. In fact, there is some evidence that this treatment has decreased cabbage root fly control.

Table 4.3. Foliage weight, root weight, root damage and stem damage in cauliflowers treated with biological insecticides pre-planting or at planting.

	Weight		**Damage score**	
	Foliage	**Root**	**Root**	**Stem**
Untreated	117.3	7.27	2.40	2.87
Met 52	121.3	7.43	2.44	2.41
Nemasys	89.1	5.25	3.22	3.48
Met 52 + Tracer (20% of approved dose)	165.7	10.95	0.90	2.10
Tracer	202.9	13.00	0.93	1.68
Azadirachtin	197.8	12.83	1.10	2.00
F	6.666	9.838	8.713	4.362
p	<0.001	<0.001	<0.001	0.006
SED	25.60	1.465	0.470	0.443
LSD (5%) (two-sided)	52.83	3.023	0.970	0.915
df	24	24	24	24

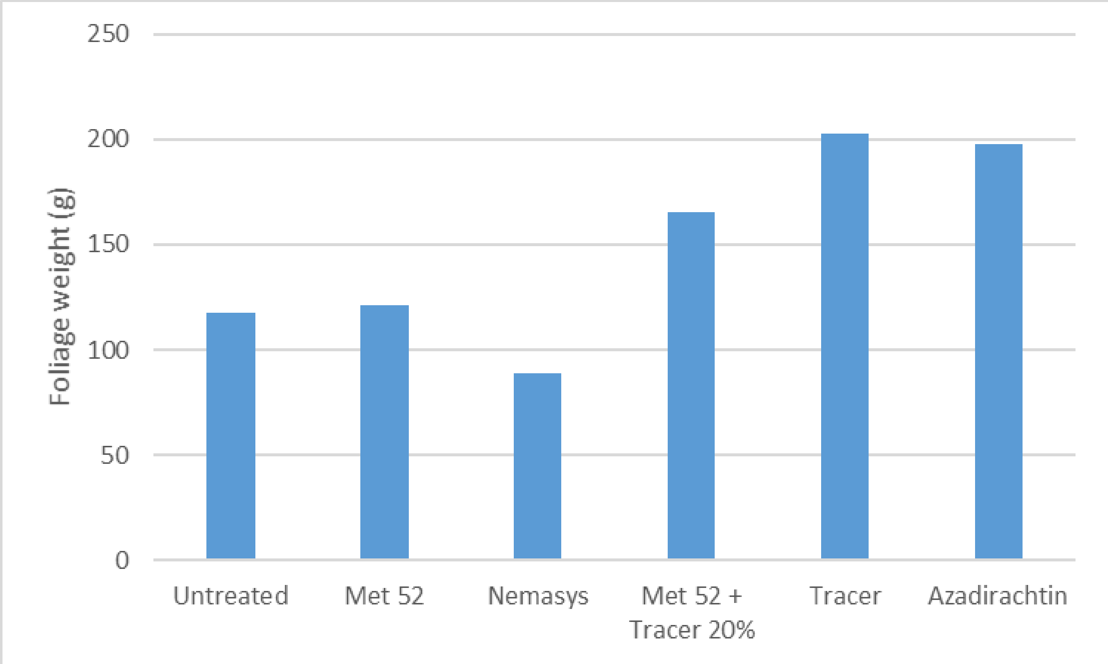


Figure 4.4. Foliage weight in cauliflowers treated with biological insecticides pre-planting or at planting.

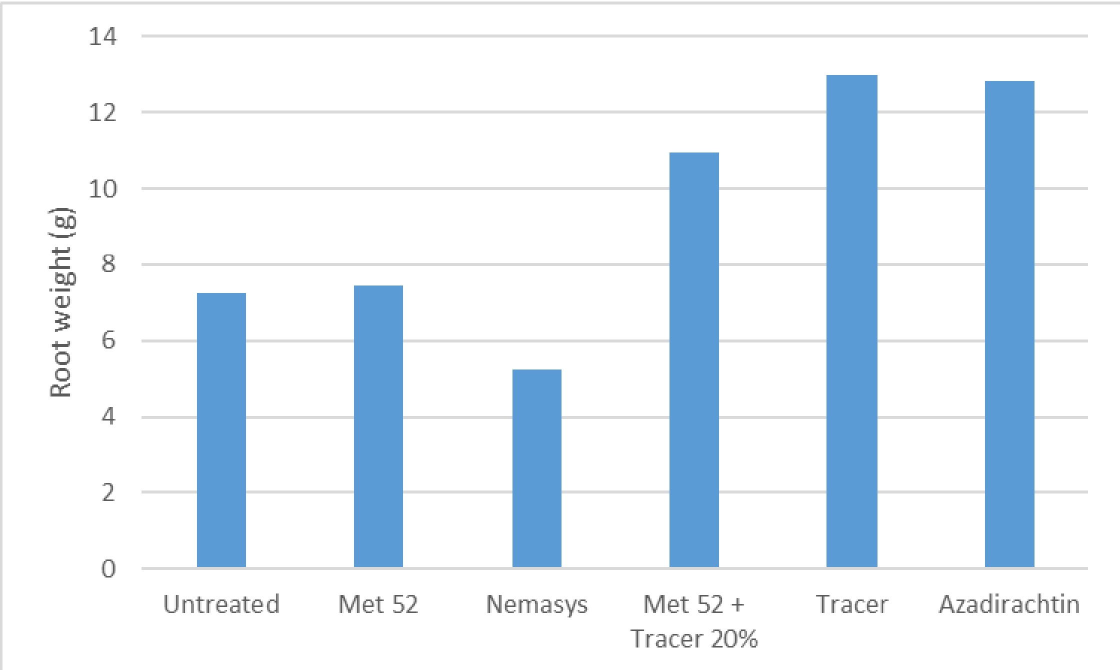


Figure 4.5. Root weight in cauliflowers treated with biological insecticides pre-planting or at planting.

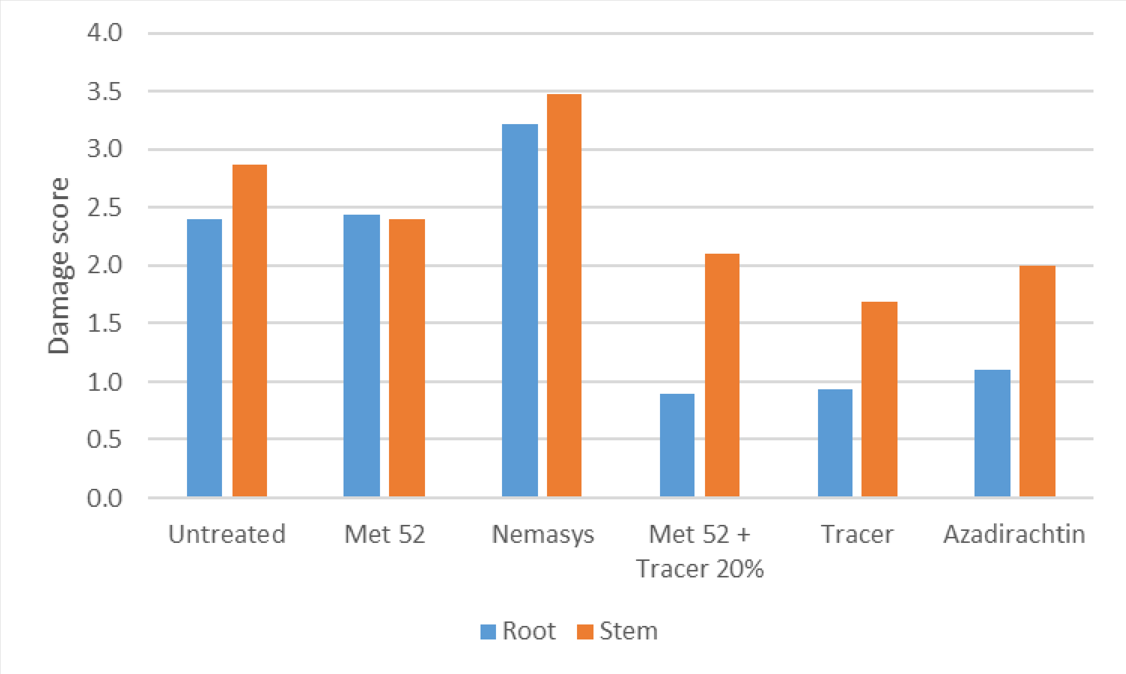


Figure 4.6. Root damage and stem damage in cauliflowers treated with biological insecticides pre-planting or at planting.

Comments on deviations from original plan:

This additional trial was supported by the UK Agriculture and Horticulture Development Board.

WP4- Task 3: T4.3 Determine whether it is possible to improve efficacy of physical barriers (fences /crop covers) by integrating them with deployment of trap crops and/or synthetic volatiles released to manipulate adult fly behaviour. (M5-33)

Partner: CH Agroscope

Results obtained:

Swiss farms and fields are small in size. In Switzerland there is no possibility to carry out any large scale experiments on barriers/trap crops.

Comments on deviations from original plan:

There have been no deviations from the original plan.

Partner: DE JKI

Results obtained:

In 2018 and 2019, two field trials were conducted in Braunschweig, Germany to test the effectiveness of entomopathogenic nematodes (EPN) and entomopathogenic fungi (EPF) against cabbage root fly (*D. radicum*). The cultivated plant was cauliflower (*Brassica oleracea*). Both trials lasted from beginning of June to middle of September in both years and covered the flight activity of the second generation of *D. radicum*. The treatments were: A) EPF, *Metarhizium brunneum* Strain NCRI 250/O2 obtained from University of Copenhagen, B) EPN, *Heterorhabditis bacteriophora* and *Steinernema feltiae* (ratio 1:1), and C) untreated control. Both EPF and EPN were transplanted with the seedlings into the field and served as preventive control measures. Inoculation of EPF was done by placing infected rice grains together with the seed in a planting hole. Inoculation of EPN was done by pouring EPN solution into the planting pots. The application rate of EPN was 500 000 IJ/m² for each EPN species. As plant substrate, an organic substrate from Klasmann & Deilmann based on peat 100 %, (Potground P, Klasmann & Deilmann) was used. Each treatment was replicated 5 times in 2018 and 4 times in 2019. In 2019 the treatments were amended to test the effectiveness of a trap crop in combination with a repellent, serving as "pull" and "push" components, respectively. The trap crop was Chinese Cabbage (*Brassica rapa* subsp. *pekinensis*). The trial was set up as a split plot trial, with 4 blocks planted with trap crops beside. The repellent was applied 5 times in intervals of 3 to 4 days during the egg laying period of *D. radicum*.

During both trials, egg laying by *D. radicum* was monitored weekly on two plants per plot by using egg collars (egg traps) or white sand which were placed at the base of the stem of each plant. At harvest, the weight and diameter of cauliflower heads of five randomly chosen plants per plot were recorded. The roots were washed and the number of larvae and pupae counted. Furthermore the roots were classified in damage categories 0 – no damage, 1 – low damage, marketable, 2 – medium damage, 3 - heavy damage. Four weeks before harvest, the virulence of the EPF and EPN was checked via bait tests in the field and the laboratory. Baits consisted of living *Tenebrio molitor* in densities of 10 individuals per vessel. In the laboratory, activity of baits was checked daily. After one week, EPF infection was checked visually and EPN occurrence was checked by preparation of dead individuals and inspection of body cavities both in field and laboratory tests.

The egg laying activity of *D. radicum* peaked during the trial in 2018, but not in 2019. Indeed, the egg laying activity was steadily decreasing from the beginning of the trial in 2019. Since the trial period was chosen based on data from the forecasting model SWAT, this might be a hint about the inaccuracy of the model. Furthermore, the application of the repellent did not decrease the egg laying activity on cauliflower plants within the push-pull blocks. In 2018 the development of cauliflower heads was not homogeneous, due to the slope of the trial field. Although, the field was irrigated 2-3 times a week, the water infiltrated the soil much better at one side, where the surface was more even. Consequently, cauliflower heads grew bigger at this side of the field. In 2019 the climatic conditions were comparable to 2018, it was dry and hot. Irrigation was necessary again. However, cauliflower heads developed homogenously in all treatments. None of the treatments had an influence on the size or weight of cauliflower heads.

The number of pupae found in the rhizosphere of cauliflower plants was significantly smaller for EPF-treated plants in 2018, but not in 2019. In 2019 none of the treatments had an effect on the number of pupae in the rhizosphere of cauliflower plants. However, the number of pupae around the Chinese Cabbage plants was significantly increased, showing the superior attractiveness of Chinese Cabbage. Because the cauliflower plants in the push-pull blocks did not show decreased numbers of pupae no pull effect on *D. radicum* was observed. The results of the bait tests suggest that the virulence of the nematodes at the time of sampling was too low to efficiently control *D. radicum* larvae in the rhizosphere. Neither nematodes nor fungal infection was determined as the cause of death of the *T. molitor* used in laboratory tests. In field tests, the overall mortality rate was about 3%.

In conclusion, the applied treatments were mainly not effective for control of *D. radicum*. The reason for this might be found in different factors: A) climatic conditions rendered soil conditions unfavourable for the virulence of the biological agents used for preinoculation, B) the spatial dimensions of the trials were too small to adequately reveal the effects of push and pull methods and C) timing of measurements was not good, due to inaccurate forecasting of the SWAT model.

Entomopathogenic nematodes are aquatic organisms by nature, for movement and respiration they depend on very thin water films on soil particles. They might have switched to quiescence or even died under the dry and hot conditions at the trial locations during the summers of 2018 and 2019, despite irrigation. The chosen species differ in their ecological strategy and temperature optimum. *Heterorhabditis bacteriophora* is an active forager with a temperature optimum of 12 °C, whereas *S. feltiae* is an ambush predator with an even lower temperature optimum of 8 °C. The fungus *Metarhizium brunneum* might not have been affected to the same extent, since it showed some potential to decrease the *D. radicum* population by diminishing the number of pupae in 2018. A better performance of the fungus might have come from its higher temperature optimum, which is between 18 and 30 °C.

The size of the trial in 2019 was 24 m x 26 m. Two rows of Chinese Cabbage were planted next to a push-pull block to pull the *D. radicum* away from cauliflower and to concentrate egg laying on it. The push-pull blocks were separated only by 2 m from blocks without trap crops and might have been still attractive to *D. radicum* present in the latter. To see an effect of trap crops on cauliflower for egg counts and infestation, the distance between blocks might have been too small. However, it is difficult to determine the necessary distance between plots with and without trap crops for small-scale field trials. The "catchment area" of trap crop attractiveness could be very large, due to the high mobility of *D. radicum*. To replicate at the plot/field level rather than the sub-plot level might be better suited to test their effectiveness. Certainly, this approach would mean a much larger effort and an increased number of replicates due to larger variation in abiotic and biotic factors between trial fields. Such an effort is likely to be hindered by the limits of research facilities.

For the integration of repellents in the push-pull method, timing is very important. It is necessary to place spray applications during the period when egg laying is intensive to prevent a significant amount of damage. Therefore it is critical to develop reliable forecasting models which are able to integrate climatic variation and spatial dynamics at scales relevant for both research stations and commercial production sites. For example, the area and management of oil seed rape in the vicinity of cabbage fields can directly influence the population density of flies in cabbage. Additionally, more research is needed to discover the effects of climate change on *D. radicum* population dynamics.

The trials showed conducted that particular methods could easily be combined to form a push-pull strategy, but more research on pest population dynamics, crop management to create favourable conditions for biological control agents will be necessary.

Comments on deviations from original plan:

There have been no deviations from the original plan.

Partner: NO NMBU/NIBIO

Results obtained:

The tactics investigated in 2018 and 2019 included a large field experiment in Norway with cauliflower as the main crop and the following methods to reduce attack by *D. radicum*: trap cropping (Chinese cabbage as trap crop), repellent+trap crop, exclusion fences, trap crop+exclusion fences.

The results have not yet been completely analyzed, but there is a clear reduction in attack rate in the treatments with exclusion fences with or without trap crop, compared to all other treatments (Figure 4.7).

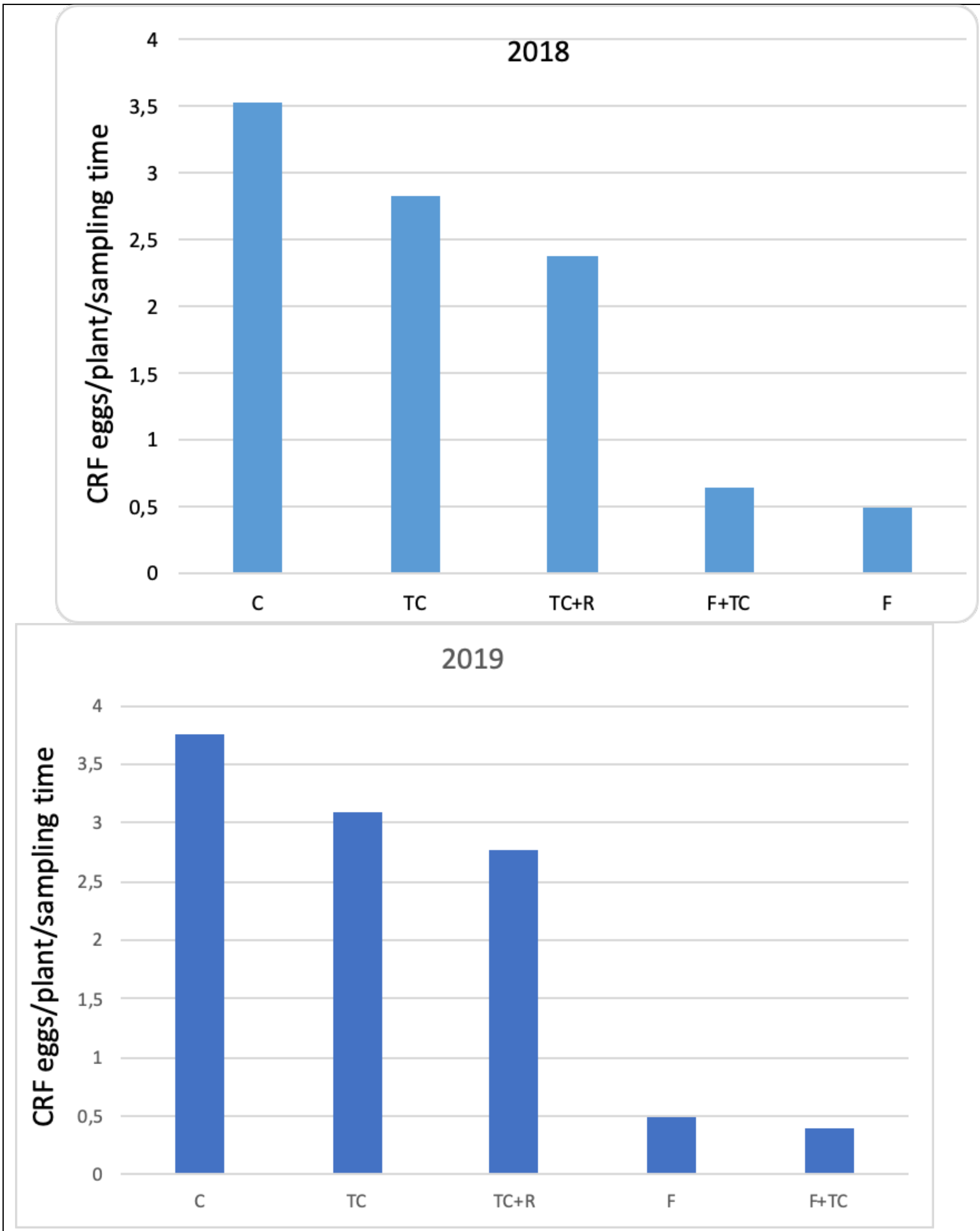


Figure 4.7. Field experiment in Norway with cauliflower as the main crop and the following methods to reduce attack by D. radicum: C=control, TC=trap cropping (Chinese cabbage as trap), TC+R=trap crop+repellent, F=exclusion fences, F+TC=trap crop+exclusion fences.

Comments on deviations from original plan:

There have been no deviations from the original plan.

WP4- Task 4: T4.4 Use monitoring and forecasting approaches to time treatments with biological control agents and to time release of volatiles to manipulate behaviour of *D. radicum* and *D. floralis* (M 18-33)

Partner: CH Agroscope
Results obtained:
In 2019: sowing date as well as dates of the treatments and evaluation as above were scheduled on actual SWAT forecasts.

Comments on deviations from original plan:
There have been no deviations from the original plan.

Partner: DE JKI
Results obtained:
The SWAT forecasts were used to time trials using biological control agents as above.

Comments on deviations from original plan:
There have been no deviations from the original plan.

Partner: UK University of Warwick
Results obtained:
The UK forecasts and monitoring data were used to time trials using biological control agents as above.

Comments on deviations from original plan:
There have been no deviations from the original plan.

WP5	**Assimilation and dissemination of information on 'best practice'**
WPL: CH Responsible partners: DK, FR, DE, IE, NMBU, NIBIO NO, SL, CH, UK	
Overall summary of main results and conclusions WP5 We established a project web site. We reviewed the methods of information dissemination to growers and advisors in most partner countries and more widely. We produced information for different stakeholder audiences, adapted to local situations and languages, and disseminated it. This included 24 non-scientific publications. In addition to a total of 35 stakeholder activities in our countries, we also participated in a European meeting, which was the IOBC/WPRS Working Group meeting 'Integrated Protection of Field Vegetables, in Stratford-upon-Avon, UK, 13-16 October 2019. We published 13 research papers and a further 7 are in preparation. Ute Vogler who was Workpackage Leader for WP5 left Agroscope and is now working at JKI, Braunschweig in Germany. A new WP leader, Dominique Mazzi, was appointed.	

Report on the results obtained (A) and changes to the original plan/ WP objectives (B) by tasks and partners:

WP5- Task 1: T5.1 Review methods of information dissemination in partner countries and more widely. Identify 'best practice' for different audiences (M1-12)

Partner: CH Agroscope
Results obtained:

Agroscope have collated and summarised information on dissemination from the partner countries. This has currently been summarised in a large table. This will form the basis of a paper reviewing methods of disseminating information to different stakeholders (D5.1).
They have provided information for the review on information dissemination – summary here:

Publications: Agroscope datasheets; FibL datasheets (only for organic production); Articles and information in Gemüsebau Info: https://www.agroscope.admin.ch/agroscope/de/home/themen/pflanzenbau/gemuesebau/gemuesebau-info.html; Irregular publication of articles in grower magazines: e.g. Der Gemüsebau / Le Maraîchère; Summary of publications: https://www.agroscope.admin.ch/agroscope/de/home/themen/pflanzenbau/gemuesebau/publikationen/pflanzenschutz-gemuesebau.html.

Advisors – government organisations: Regional advisors from the regional government.

Advisors – independent organisations: Specialized, private advisors from Europe; Regional, private advisor http://www.beratungsring.ch/.

Advisors selling control methods: Regional, private advisor http://www.beratungsring.ch/.

Meetings for growers and advisors: Regional visits of field sites and experiments on a certain topic or vegetable crop, organized by regional advisors; Every two years: Visit of the experimental site at Agroscope in Wädenswil, organized by Agroscope; Mainly for advisors: Seminar on plant protection in vegetable crops, organized by Agroscope.

Web sites: Gemüsebau Info / Info Cultures Maraîchères / Orto Fito Info: http://www.gemuesebau-info.agroscope.ch/.

Email: Gemüsebau Info / Info Cultures Maraîchères / Orto Fito Info: sent electronically to subscribers via Email.

Comments on deviations from original plan:
There have been no deviations from the original plan.

Partner: DE JKI
Results obtained:
They have provided information for the review on information dissemination – summary here:

Publications:

2018

Szikora T., Vogler U. (2018) Gemüseschädlinge alternativ bekämpfen. Der Gemüsebau / Le Maraîchère 34

Vogler U., Collier R., Cortesero A.-M., Gaffney M., Hommes M., Johnsen T., Meadow R., Vitt Meyling N., Trdan S., Mazzi D. (2018): FlyIPM – Integrated control of root-feeding fly larvae infesting vegetable crops. 31. Deutsche Pflanzenschutztagung. Herausforderungen Pflanzenschutz – Wege in die Zukunft; 11.-14. September 2018, Universität Hohenheim – Kurzassungen der Vorträge und Poster. Julius-Kühn-Archiv 461, Braunschweig 416

2019

Boeriis T., Mazzi D., Vogler U. (2019) FlyIPM – ein europäisches Projekt für die integrierte Bekämpfung von Gemüsefliegen. Gemüsebau Info 2

Paap M., Vogler U. (2019) Deutscher Gartenbautag. GartenbauProfi 107:50-52

Schmon R., Sauer C., Vogler U. (2019) Die Kleine Kohlfliege (Delia radicum): Bioglogie und Bekämpfungsmöglichkeiten. Agroscope Merkblatt Nr. 91

Vogler U. (2019) Krankheiten und Schädlinge durch Klimaveränderungen – Neue Pflanzenschutzstrategien. Deutscher Gartenbautag 2019 des ZVG, Neckarsulm. 06. September 2019

Schorpp Q. (2019). FlyIPM – Biologische Gegenspieler für die integrierte Kontrolle von Wurzelfliegen-Larven. BMEL Symposium zum nicht-chemischen Pflanzenschutz, Berlin.

Schorpp Q., Vogler U. (2019). Preventive biological control of root-feeding fly larvae in cauliflower . IOBC-WPRS Working Group "Integrated Protection of Field Vegetables". Stratford upon Avon, UK. 13.-16. October 2019

Schorpp, Q. (2019) Fly-IPM – Eine „Push+Pull“ Strategie für die integrierte Kontrolle von Gemüsefliegen-Larven. 29. Tagung der Fachreferenten für Pflanzenschutz im Gemüse- und Zierpflanzenbau/Baumschulen, Braunschweig. 05.-07. November 2019.

2020

Vogler U., Schorpp Q. (2020) FlyIPM – Ein europäisches Projekt zum integrierten Pflanzenschutz – Forscher tricksen Gemüsefliegen aus. Gemüse 56:30-31

Vogler U., Schorpp Q. (2020) Vorbeugende biologische Kontrolle der Kleinen Kohlfliege im „Push Pull“-System. 93. Arbeitssitzung Deutscher Pflanzenschutzdienst, Hamburg. 02.03.2020

Submitted

Schorpp Q., Vogler U. (submitted) Preinoculation and push-pull methods for the control of cabbage root fly in cauliflower – a critical reflection of field trials.

Advisors – government organisations: Presentation of results at the biannual conference “Fachreferententagung” at the JKI, Braunschweig, held for members of national plant protection services; Presentation at the annual conference “Lücken-Indikation” at the JKI Braunschweig, held for members of national plant protection services.

Advisors – independent organisations: No information about platforms, so far

Advisors selling control methods: No information about platforms, so far.

Meetings for growers and advisors: No information about platforms, so far.

Web sites: Homepage of the Julius Kühn-Institute for Plant protection in horticulture and forestry https://www.julius-kuehn.de/gf/.

Comments on deviations from original plan:

There have been no deviations from the original plan.

Partner: DK University of Copenhagen

Results obtained:

They have provided information for the review on information dissemination – summary here:

Publications; Gartnertidende http://www.gartnertidende.dk/ .

Advisors – government organisations: None.

Advisors – independent organisations: Helle Mathiasen (HMAT@seges.dk) and Ole Scharff (ohs@seges.dk), HortiAdvice Scandinavia A/S (GartneriRådgivningen A/S) http://www.gartneriraadgivningen.dk/.

Advisors selling control methods: Borregaard BioPlant http://bioplant.dk/.

Meetings for growers and advisors: Plantekongres https://www.seges.dk/da-dk/kongresser/plantekongres annual meeting on plant production in Denmark.

Web sites: HortiAdvice Scandinavia A/S; www.gartneriraadgivningen.dk.

Email; GrønsagsNyt, newsletter for members of HortiAdvice Scandinavia A/S; http://www.gartnershop.dk/Nyhedsbreve-til-gartnerier.

Facebook: HortiAdvice Scandinavia – Gartnerirådgivningen; https://www.facebook.com/search/top/?q=gartnerir%C3%A5dgivningen.

Other: Newsletter from Department of Plant and Environmental Sciences, UCPH http://plen.ku.dk/nyhedsbrev/.

Comments on deviations from original plan:

There have been no deviations from the original plan.

Partner: FR IGEPP

Results obtained:

They have provided information for the review on information dissemination – summary here:

Publications: Magazines of regional experimental stations and technical institute such as: "CTIFL Infos" from CTIFL (www.ctifl.fr), "Jardins du littoral" from SILEBAN (http://www.jardinsdenormandie.com/sileban.aspx), "Aujourd'hui et demain" from CATE (https://www.station-cate.fr/), Commercial Technical revues : "Réussir Fruits et Légumes" and "Cultures légumières".

Advisors – government organisations: "Chambres d'agriculture" (http://chambres-agriculture.fr/) : One "Chambre d'agriculture" by region or by department.

Advisors – independent organisations: Several independent advisors.

Meetings for growers and advisors: These are held mainly by regional experimental stations and "Chambres d'agriculture".

Web sites: GIS PICLég: https://www.picleg.fr/, CTIFL: www.ctifl.fr, EcophytoPIC: http://www.ecophytopic.fr/.

Other: Local newsletters to vegetable farmers from regional "Chambres d'agriculture" (eg: http://www.bretagne.synagri.com/synagri/bsv-cultures-legumieres-et-pommes-de-terre).

Comments on deviations from original plan:

There have been no deviations from the original plan.

Partner: IE Teagasc

Results obtained:

They have provided information for the review on information dissemination – summary here:

Publications: In terms of grower magazines, growers would access many of the trade publications and AHDB available to growers in the UK; AHDB Factsheets https://horticulture.ahdb.org.uk/sector/field-vegetables; Grower Magazine (AHDB) goes to all growers above a certain size; Vegetable Farmer magazine https://www.vegetablefarmer.co.uk/; AHDB project reports https://horticulture.ahdb.org.uk/sector/field-vegetables; In terms of Irish Specific publications, there is a magazine called Horticulture Connected issued on a quarterly basis (https://horticultureconnected.ie/); Within Teagasc, once a project is completed a 'Technology Update' is produced, usually a 4 page grower friendly synopsis of the work completed, and these are available online https://www.teagasc.ie/publications/.

Advisors – government organisations: Pesticide regulations and implementation of Integrated Pest Management are communicated directly to the Pesticide Control Service within the Department of Agriculture (www.pcs.agriculture.gov.ie) . Teagasc would meet regularly with them to update on emerging issues and highlight any deficit in control options for growers. Where appropriate they also may be represented on the steering committees of larger projects in the area of IPM and resistance management. Overall communication is frequent, but limited to email and verbal.

Advisors – independent organisations: Teagasc have 2 vegetable advisory specialists who work with field vegetable growers. In reality, they also work with the independent consultants to increase technology adoption. Again there is a high level of cross over in terms of agronomists between Ireland, Northern Ireland and the main land UK.

Advisors selling control methods: Similar to the UK, they also have a number of PPP companies and traders who provide agronomic advice. Again the pool of these people is small and Teagasc would have regular direct contact with most of them.

Meetings for growers and advisors: These are usually organised by the advisory staff in Teagasc, often in partnership with Bord Bia, who are the Agriculture and Food promotions board in Ireland. They aim for 2 seminars a year, the themes of which vary, depending on current industry issues. IPM would be frequently a topic of part of seminars, mainly to assist private agronomists in maintaining their IPM CPD points.

Web sites: They attempted a small pilot in 2017 on providing growers with a pest update, it was moderately successful and may be repeated in 2018. https://www.teagasc.ie/crops/horticulture/plant-health/pest-update/. Again after that, they would access a lot of the UK websites, as they are very appropriate to the region also.

Text/SMS: Apart from a Blight warning our meteorological service would issue, no other such service is commonly used.

Twitter: Michael Gaffney (Teagasc) would issue warnings on horticulture and tillage pests through his twitter account @mick_gaffney.

Comments on deviations from original plan:
There have been no deviations from the original plan.

Partner: NO NMBU
Results obtained:

They have provided information for the review on information dissemination – summary here:

Publications: Gartneryrket (grower journal); Norsk Landbruk (grower journal).

Advisors – government organisations: Annual meetings with vegetable advisors in NLR.

Advisors – independent organisations: Annual meeting with plant protection companies, scientists in plant health and advisors.

Meetings for growers and advisors: Local meetings in field (growing season) and indoors (winter) in regional units in NLR with vegetable farmers and advisors. Other advisors and companies often participate.

Web sites: Webpage for NLR www.nlr.no central unit; Webpage for NLR Norwegian Agricultural Extention Service www.nlr.no regional units.

Other: Local newsletters to vegetable farmers from regional units in NLR.

Comments on deviations from original plan:
There have been no deviations from the original plan.

Partner: UK University of Warwick
Results obtained:

They have provided information for the review on information dissemination – summary here:

Publications: AHDB Factsheets https://horticulture.ahdb.org.uk/sector/field-vegetables; Grower Magazine (AHDB) goes to all growers above a certain size; Vegetable Farmer magazine https://www.vegetablefarmer.co.uk/; AHDB project reports https://horticulture.ahdb.org.uk/sector/field-vegetables.

Advisors – government organisations: None – except with regard to pesticide regulations (CRD).

Advisors – independent organisations: Several and there is a Vegetable Consultants Association who meet and exchange information with themselves and with researchers. http://www.vegconsultants.com/; LIAISON – pesticide information https://secure.fera.defra.gov.uk/liaison/.

Advisors selling control methods: Large companies such as Agrii, Agrovista, Hutchinsons – have vegetable experts.

Meetings for growers and advisors: These are held mainly by the AHDB https://horticulture.ahdb.org.uk/ but may also be held by research and development organisations or grower associations through the British Growers Association http://britishgrowers.org/.

Web sites: AHDB web site https://horticulture.ahdb.org.uk/; Syngenta web site https://www.syngenta.co.uk/vegetables; AHDB Pest Bulletin - https://www.syngenta.co.uk/ahdb-pest-bulletin; Migrant moth monitoring - https://warwick.ac.uk/fac/sci/lifesci/wcc/research/pests/plutella/sightings2018/, https://warwick.ac.uk/fac/sci/lifesci/wcc/research/pests/plutella/trapping2018/; AHDB Pest blog http://blogs.warwick.ac.uk/rosemarycollier/.

Text/SMS: Not much in UK.

Email: Warnings to growers from AHDB.

Twitter; Warnings/updates https://twitter.com/AHDB_Hort, https://twitter.com/Warwickpestnews.

Two Masters students at the University of Warwick (one in 2017 and one in 2018) have considered different aspects of knowledge transfer to growers in their dissertations.

Comments on deviations from original plan:
There have been no deviations from the original plan.

WP5- Task 2: T5.2 Establish, manage and contribute to FlyIPM website (M1-36)

All partners have contributed information to the web site and will continue to contribute more information as the results are published.

Partner: CH Agroscope
Results obtained:

The project web site was established on the Agroscope web site https://www.agroscope.admin.ch/agroscope/en/home/topics/plant-production/plant-protection/flyipm.html and continues to be maintained from there.

Comments on deviations from original plan:

There have been no deviations from the original plan.

WP5- Task 3: T5.3 Collaborate to design and plan stakeholder engagement activities in each partner country (M1-30).

In addition to stakeholder activities in each country we also participated in a European meeting (**D5.4** One European Meeting with stakeholders and project partners involved (**M36**)). This was the IOBC/WPRS Working Group meeting ‘Integrated Protection of Field Vegetables, in Stratford-upon-Avon, UK, 13-16 October 2019.

- Isabella Hutchison (Norges Miljø-Og Biovitenskapelige Universitet, Norway), Nicolai V Meyling, Sundar Thapa (Københavns Universitet, Denmark), Liv Berge, Luc Brard (Norges Miljø-Og Biovitenskapelige Universitet, Norway) & Richard Meadow (Norges Miljø-og Biovitenskapelige Universitet, Norway; Norsk Institutt for Biøkonomi, Norway) (2019). Biological control of cabbage root fly using an entomopathogenic fungus. IOBC/WPRS Working Group meeting 'Integrated Protection of Field Vegetables, October 2019.
- Sundar Thapa, Belén Cotes & Nicolai V Meyling (University of Copenhagen, Denmark) (2019). Inoculating entomopathogenic fungi for control of the cabbage root fly Delia radicum in soil. IOBC/WPRS Working Group meeting 'Integrated Protection of Field Vegetables, October 2019.
- Quentin Schorpp (Julius Kühn-Institut, Braunschweig, Germany). Preventive biological control of root-feeding fly larvae in cauliflower. IOBC/WPRS Working Group meeting 'Integrated Protection of Field Vegetables, October 2019.
- Richard Meadow (Norwegian University of Life Sciences, Norway; Norwegian Institute of Bioeconomy Research, Ås, Norway), Tor J Johansen, Gunda Thöming, Anette F Schjøll (Norwegian Institute of Bioeconomy Research, Ås, Norway), Belén Cotes (University of Copenhagen, Fredriksberg C, Denmark) & Christian Nansen (University of California, Davis, USA) (2019). Integrated control of rootflies in Brassica vegetables. IOBC/WPRS Working Group meeting 'Integrated Protection of Field Vegetables, October 2019.
- Fabrice Lamy, Cécile Burtin, Héloïse Royer, Loïc Daniel, Valérie Chaminade, Vincent Faloya & Anne Marie Cortesero (IGEPP, INRA, Agrocampus Ouest, Université de Rennes 1, Rennes, France) (2019). Control of *Delia radicum*: selecting and testing the potential of oviposition inhibitors in a Push-Pull strategy. IOBC/WPRS Working Group meeting 'Integrated Protection of Field Vegetables, October 2019.
- Rosemary Collier, Marian Elliott, Daniel Wilson (University of Warwick, UK), Dawn Teverson, Sue Cowgill (AHDB, UK) Phenology and abundance of pest insects of vegetable and salad crops in Britain: decision support for growers. IOBC/WPRS Working Group meeting 'Integrated Protection of Field Vegetables, October 2019.

Partner: CH Agroscope

Results obtained:

- Partners met in Switzerland in October 2017 and started preliminary discussions on stakeholder and engagement activities.
- Schmon R., Sauer C., Vogler U. (2019) Die Kleine Kohlfliege (Delia radicum): Bioglogie und Bekämpfungsmöglichkeiten. Agroscope Merkblatt Nr. 91
- Boeriis T., Mazzi D., Vogler U. (2019) FlyIPM – ein europäisches Projekt für die integrierte Bekämpfung von Gemüsefliegen. Gemüsebau Info 2
- Vogler U. (2017) " Die Kleine Kohlfliege Delia radicum " in German at Wädenswiler Gemüsebautag Agroscope (CH). Poster.

Comments on deviations from original plan:

There have been no deviations from the original plan.

Partner: DE JKI

Results obtained:

- Paap M., Vogler U. (2019) Deutscher Gartenbautag. GartenbauProfi 107:50-52
- Schorpp Q. (2019). FlyIPM – Biologische Gegenspieler für die integrierte Kontrolle von Wurzelfliegen-Larven. BMEL Symposium zum nicht-chemischen Pflanzenschutz, Berlin.
- Schorpp Q., Vogler U. (submitted) Preinoculation and push-pull methods for the control of cabbage root fly in cauliflower – a critical reflection of field trials.
- Schorpp, Q. (2019) Fly-IPM – Eine „Push+Pull" Strategie für die integrierte Kontrolle von Gemüsefliegen-Larven. 29. Tagung der Fachreferenten für Pflanzenschutz im Gemüse- und Zierpflanzenbau/Baumschulen, Braunschweig. 05.-07. November 2019.
- Szikora T., Vogler U. (2018) Gemüseschädlinge alternativ bekämpfen. Der Gemüsebau / Le Maraîchère 34
- Vogler U. (2019) Krankheiten und Schädlinge durch Klimaveränderungen – Neue Pflanzenschutzstrategien. Deutscher Gartenbautag 2019 des ZVG, Neckarsulm. 06. September 2019
- Vogler U., Collier R., Cortesero A.-M., Gaffney M., Hommes M., Johnsen T., Meadow R., Vitt Meyling N., Trdan S., Mazzi D. (2018): FlyIPM – Integrated control of root-feeding fly larvae infesting vegetable crops. 31. Deutsche Pflanzenschutztagung. Herausforderungen Pflanzenschutz – Wege in die Zukunft; 11.-14. September 2018, Universität Hohenheim – Kurzassungen der Vorträge und Poster. Julius-Kühn-Archiv 461, Braunschweig 416

- Vogler U., Schorpp Q. (2020) FlyIPM – Ein europäisches Projekt zum integrierten Pflanzenschutz – Forscher tricksen Gemüsefliegen aus. Gemüse 56:30-31
- Vogler U., Schorpp Q. (2020) Vorbeugende biologische Kontrolle der Kleinen Kohlfliege im „Push Pull"-System. 93. Arbeitssitzung Deutscher Pflanzenschutzdienst, Hamburg. 02.03.2020

Comments on deviations from original plan:

There have been no deviations from the original plan.

Partner: DK University of Copenhagen

Results obtained:

- Article in growers' magazine "Gartner Tidende" to communicate the FlyIPM project: Meyling NV, Cotes B, Thapa S (2019). Gør kål på kålfluerne. Gartner Tidende 4/2019 40-41.
- Meyling, N.V. (2019) Reducing pest populations by direct and indirect effects using fungal inoculations in horticultural crops. Invited talk at Plant Biologicals Network Symposium, University of Copenhagen, Frederiksberg, Denmark, 13-14 November, 2019
- Meyling, N.V. (2020) Interaktioner mellem planter og insektpatogene svampe. Invited talk (in Danish) at PlanteKongres, MCH Herning Kongrescenter, Denmark, 14-15 January, 2020

Comments on deviations from original plan:

There have been no deviations from the original plan.

Partner: FR IGEPP

Results obtained:

- Cortesero, A.M. ; Lamy, F. ; Le Ralec, A. ; Faloya, V. (2017). Mobiliser les processus écologiques pour contrôler les insectes ravageurs : application de la stratégie *push-pull* en production de brassicacées légumières. *Carrefours de l'Innovation Agronomique « Construire et diffuser des systèmes légumiers multi-performants »*. Angers.
- Cortesero A.M., Lamy F., Le Ralec A., Faloya V. (2019). Recherche de solutions de biocontrôle contre un ravageur de cultures de brassicacées légumières : de l'écologie chimique aux plantes de service (*and back*). Rencontres Plant2Pro « Plantes de services et services des plantes », Paris.
- Lamy F., Faloya V. & Cortesero A. M. (2018). Brocoli : le push-pull. *Techniques culturales, 136*, 17-18.

Comments on deviations from original plan:

There have been no deviations from the original plan.

Partner: IE Teagasc

Results obtained:

- Gaffney, M. 'Innovation in Fresh Produce Production from File to Field to Fork' Ireland.

Comments on deviations from original plan:

There have been no deviations from the original plan.

Partner: NO NIBIO/NMBU

Results obtained:

- Richard Meadow held an invited talk at the conference marking the centenary of the Journal of Horticultural Science and Biotechnology in Charlecote, UK, "Methods investigated for management of insect pests in field vegetables in Norway" in May 2019. The conference was attended by growers, suppliers, processors, retailers, advisors and scientists. The information was summarized in an article in The Vegetable Farmer, September 2019 pp. 28-29.
- The Norwegian participants in the project held a seminar and field visit to the project research site in June 2019. The event was attended by students of plant protection at the Norwegian University of Life Sciences and by the advisors in vegetable crops of the Norwegian Agricultural Extension Service.

- An article "Kålfluene i Norge og Europa" (Cabbage Flies in Norway and Europe) will be published in the June 2020 edition of the growers journal "Gartneryrket". The article describes the results from the project. The authors are Tor J. Johansen (NIBIO), Annette F. Schjøll (NIBIO) and Richard Meadow (NMBU).

Comments on deviations from original plan:

There have been no deviations from the original plan.

Partner: SL University of Ljubljana

Results obtained:

Comments on deviations from original plan:

There have been no deviations from the original plan.

Partner: UK University of Warwick

Results obtained:

- Collier, R. (2019). FlyIPM – a European project on root-feeding flies. The Vegetable Farmer, April 2019, p21.
- Pest insects infesting carrot and other Apiaceous crops. AHDB Factsheet revision. In press.
- Rosemary Collier - part of presentation at '*Advancing the use of biopesticides and IPM in field vegetables' 5th February 2020 – Wellesbourne UK*

Comments on deviations from original plan:

There have been no deviations from the original plan.

WP5- Task 4: T5.4 Publish research papers on experimental work (M12-36)

Open Access papers

- Lamy, F., Bellec, L., Rusu-Stievenard, A., Clin, P., Ricono, C., Olivier, D., Mauger, S., Poinsot, D., Faloya, V., Daniel, L., et al. Oviposition preference of the cabbage root fly towards some chinese cabbage cultivars: A search for future trap crop candidates. *Insects* 2020, *11*, doi:10.3390/insects11020127

- Collier, R., Mazzi, D., Folkedal Schjøll, A., Schorpp, Q., Thöming, G., Johansen, T.J., Meadow,R., Meyling, N.V., Cortesero, A., Vogler, U., Gaffney, M.T., Hommes, M. (2020) The potential for decision support systems to improve the management of root-feeding fly pests of vegetables in Europe. *Insects*. Under review.

Peer-reviewed papers in preparation

- Collier, R. Phenology of *C. rosae* in the UK and use and accuracy of the UK forecasts.
- Collier, R. Phenology of *Delia radicum* in the UK and use and accuracy of the UK forecasts.
- Gaffney, M. The efficacy of Steinernema feltiae to manage D. radicum in field Broccoli'
- Lamy, Thapa, Vitt Meyling, Faloya & Cortesero "An entomopathogenic fungus to reduce root-feeding pest proliferation inside the trap crop of a Brassicaceae vegetable push pull system" in prep for Biological control.
- Thapa S, Cotes B and Meyling NV (in prep.) Inoculation and rhizosphere establishment of the entomopathogenic fungi *Metarhizium* spp. for cabbage root fly control. Manuscript under preparation.

- Thapa S, Uslu H, Cotes B and Meyling NV (in prep.) Evaluation of biological control potential of the entomopathogenic fungus *Metarhizium brunneum* against the larval stage of *Delia radicum* under semi-field conditions. Manuscript under preparation.

Non-peer-reviewed scientific papers

- Boeriis, T., Mazzi, D., Vogler, U. (2020) Push (-and-pull) strategy with sage extracts may reduce crop losses caused by the cabbage root fly, *Delia radicum*. IOBC-WPRS Bulletin: Proceedings of the Meeting at Stratford-upon-Avon (UK) 13-16 October 2019. (*in press*).
- Collier, R.; Elliott, M.; Wilson, D.; Teverson, D.; Cowgill, S. Phenology and abundance of pest insects of vegetable and salad crops in Britain: decision support for growers. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Stratford-upon-Avon (UK), 13-16 October, 2019. Edited by R. Meadow. Submitted.
- Hutchison, I., Meyling, N.V., Thapa, S., Berge, L., Meadow, R. (2020) Biological control of cabbage root fly using an entomopathogenic fungus. IOBC-WPRS Bulletin: Proceedings of the Meeting at Stratford-upon-Avon (UK) 13-16 October 2019. (*in press*).
- Johansen, T.J., Cortesero, A.-M., Gaffney, M., Meadow, R., Schorpp, Q., Collier, R. (2020) Phenology of brassica root flies (*Delia radicum* and *D. floralis*) in northern Europe. IOBC-WPRS Bulletin: Proceedings of the Meeting at Stratford-upon-Avon (UK) 13-16 October 2019. (*in press*).
- Lamy, F., Wetzel, G., Daniel, L., Faloya, V., Poinsot, D., Cortesero, A.-M. (2019) The spatial implantation of the trap crop used as Pull component has to be considered to maximize the efficiency of a Push-Pull strategy against the cabbage root fly. IOBC-WPRS Bulletin: Proceedings of the Meeting at Wädenswil/Arneberg (Switzerland) 02-06 October, 2017. 142:59-64.
- Mesmin, X., Faloya, V., Maret, M., Cortesero, A.-M., Le Ralec, A. (2019) Carabid predation on Delia radicum: the early bird catches the worm. IOBC-WPRS Bulletin: Proceedings of the Meeting at Wädenswil/Arneberg (Switzerland) 02-06 October, 2017. 142:65-72.
- Sauer, C. (2019) Possible impacts of climate change on carrot fly's population dynamics in Switzerland. IOBC-WPRS Bulletin: Proceedings of the Meeting at Wädenswil/Arneberg (Switzerland) 02-06 October, 2017. 142:31-41.
- Schorpp, Q., Vogler, U. (2020) Preinoculation and push-pull methods for the control of cabbage root fly in cauliflower – a critical reflection of field trials. IOBC-WPRS Bulletin: Proceedings of the Meeting at Stratford-upon-Avon (UK) 13-16 October 2019. (*in press*).
- Thapa, S., Cotes, B., Uslu, H., Meyling, N.V. (2020) Inoculation of the entomopathogenic fungus *Metarhizium brunneum* to target the larvae of the cabbage root fly *Delia radicum*. IOBC-WPRS Bulletin: Proceedings of the Meeting at Stratford-upon-Avon (UK) 13-16 October 2019. (*in press*).
- Thöming, G., Schjøll, A.F., Johansen, T.J. (2019) Developing tools for monitoring and forecasting of onion fly *Delia antiqua* in Norway. IOBC-WPRS Bulletin: Proceedings of the Meeting at Wädenswil/Arneberg (Switzerland) 02-06 October, 2017. 142:42-49.
- Vogler, U., Szikora, T. (2019) A vegetable brassica based diet to test individual traits to control the cabbage root fly. IOBC-WPRS Bulletin: Proceedings of the Meeting at Wädenswil/Arneberg (Switzerland) 02-06 October, 2017. 142:50-58.

WP5- Task 5: T5.5 Produce information for dissemination to different stakeholder audiences, adapt to local situation and language and disseminate information (M18-36)

Partner: CH Agroscope
Results obtained:

Schmon R., Sauer C., Vogler U. (2018) "Die Kleine Kohlfliege (*Delia radicum*): Biologie und Bekämpfungsmöglichkeiten" datasheet (Merkblatt) in German, Agroscope (CH).

Szikora T., Vogler U. (2018) Gemüseschädlinge alternativ Bekämpfen. Article in German and French for Der Gemüsebau / Le Maraichère (CH) 6, 2018, 34.

Boeriis T., Mazzi D., Vogler U. (2019) FlyIPM - ein europäisches Projekt für die integrierte Bekämpfung von Gemüsefliegen. Article in German, French and Italian for the Gemüsebau Info, 22, 2019, 2.

The project was presented in German at the Wädenswiler Gemüsebautag meeting of growers and advisors held on 28.08.2019 in Wädenswil. The produced illustrated flyer was distributed to the participants for further dissemination.

Comments on deviations from original plan:

There have been no deviations from the original plan.

Partner: DE JKI

Results obtained:

- In The years 2018 to 2020 information about the projects progress and experiences from with implementing a push+pull strategy in field trials have been discussed with consultants of the plant protection services of the federal states of Germany during the meeting of the working group "Lückenindikation" at the JKI in Braunschweig.
- Paap M., Vogler U. (2019) Deutscher Gartenbautag. GartenbauProfi 107:50-52
- Schorpp Q. (2019). FlyIPM – Biologische Gegenspieler für die integrierte Kontrolle von Wurzelfliegen-Larven. BMEL Symposium zum nicht-chemischen Pflanzenschutz, Berlin.
- Schorpp Q., Vogler U. (submitted) Preinoculation and push-pull methods for the control of cabbage root fly in cauliflower – a critical reflection of field trials.
- Schorpp, Q. (2019) Fly-IPM – Eine „Push+Pull" Strategie für die integrierte Kontrolle von Gemüsefliegen-Larven. 29. Tagung der Fachreferenten für Pflanzenschutz im Gemüse- und Zierpflanzenbau/Baumschulen, Braunschweig. 05.-07. November 2019.
- Vogler U., Schorpp Q. (2020) FlyIPM – Ein europäisches Projekt zum integrierten Pflanzenschutz – Forscher tricksen Gemüsefliegen aus. Gemüse 56:30-31
- Vogler U., Schorpp Q. (2020) Vorbeugende biologische Kontrolle der Kleinen Kohlfliege im „Push Pull"-System. 93. Arbeitssitzung Deutscher Pflanzenschutzdienst, Hamburg. 02.03.2020

Comments on deviations from original plan:

There have been no deviations from the original plan.

Partner: DK University of Copenhagen

Results obtained:

- Article in growers' magazine "Gartner Tidende" to communicate the FlyIPM project: Meyling NV, Cotes B, Thapa S (2019). Gør kål på kålfluerne. Gartner Tidende 4/2019 40-41.
- Presentation in Danish to growers and other stakeholders within plant procution about application potential of entomopathogenic fungi at the annual national PlanteKongres, session "Plant Biologicals" MCH Herning Kongrescenter, Denmark, 14-15 January, 2020.

Comments on deviations from original plan:

There have been no deviations from the original plan.

Partner: FR IGEPP

Results obtained:

The project was presented at different technical meetings. Outcomes of WP2 and WP4 in particular were presented every year to growers in the Brittany area (groupe technique Choux du CTIFL, experiment station Terre d'essais). Field visits of the large field push-pull bioassay conducted in 2019 were organized. More presentations to growers in Brittany and Normandy were planned this year but were postponed due to the Covid-19 crisis.

Articles in technical papers:

Lamy F., Faloya V. & Cortesero A. M. (2018). Brocoli : le push-pull. *Techniques culturales, 136*, 17-18.

Presentations

Cortesero, A.M. ; Lamy, F. ; Le Ralec, A. ; Faloya, V. (2017). Mobiliser les processus écologiques pour contrôler les insectes ravageurs : application de la stratégie *push-pull* en production de brassicacées légumières. *Carrefours de l'Innovation Agronomique « Construire et diffuser des systèmes légumiers multi-performants »*. Angers.

Cortesero A.M., Lamy F., Le Ralec A., Faloya V. (2019). Recherche de solutions de biocontrôle contre un ravageur de cultures de brassicacées légumières : de l'écologie chimique aux plantes de service (*and back*). Rencontres Plant2Pro « Plantes de services et services des plantes », Paris.

Comments on deviations from original plan:
There have been no deviations from the original plan.

Partner: IE Teagasc
Results obtained: A series of articles synthesising the final report and outputs of FLYIPM will be prepared for 3 publications aimed at both growers and stakeholders. These publications are Teagasc's science publication, Tresearch, a trade magazine, Horticulture Connected and finally to a grower focused organic association magazine. In addiditon a Technology Update on the project will be complied and hosted on the Teagasc Website.

Comments on deviations from original plan:
There have been no deviations from the original plan.

Partner: NO NIOBIO/NMBU
Results obtained:
Presentation made about FlyIPM and Norwegian results that was sent to all the vegetable extension agents (advisors) for them to further disseminate. Also made a page (in Norwegian) for the extension service website. Further, Norwegian partners held a seminar and field site visit summer 2019 and distributed the presentations to advisors and university students in plant protection. They have published 2 articles in the Norwegian growers journal "Gartneryrket".

Comments on deviations from original plan:
There have been no deviations from the original plan.

Partner: UK University of Warwick
Results obtained:
Article: Collier, R. (2019). FlyIPM – a European project on Root-feeding flies. The Vegetable Farmer, April 2019, p21.

Two grower meetings on bean seed fly management and opportunities in collaboration with AHDB.

Updated AHDB Factsheet on carrot pest managment.

Comments on deviations from original plan:

There have been no deviations from the original plan.

Etc. (same for all WPs)

Status of milestones and deliverables

Milestone No.	Milestone name	Planned delivery month[1)]	Actual delivery month[1)]	Reasons for changes/delay and explanation of consequences
M1.1.	**M1.1** Phenological/weather data assimilated and summarised	6	6	Not as much data available as anticipated before project
M1.2	**M1.2** Monitoring and forecasting systems compared and forecasts validated	18	18	Not as much data available as anticipated before project
M1.3	**M1.3** Optimised monitoring/forecasting systems agreed	30	30	
M1.4	**M1.4** Impacts of climate change summarised	24	24	
M1.5	**M1.5** Information disseminated	35	35+	Ongoing post-project
M2.1	**M2.1** Trap crop varieties to be used in a push-pull approach at different planting times in different countries identified	21	21	
M2.2	**M2.2** Optimal spatial arrangement of suitable trap crop varieties proposed	33	33	
M2.3	**M2.3** Potential for combination of volatiles and plants in push-pull design determined	33	33	Due to unreliability of field results when using volatiles, contact compounds were identified and used for combination with trap plant
M2.4	**M2.4** Volatile dispenser design optimized	21	n/a	NA with contact compounds Contacts are made with 2 companies for optimization of use
M2.5	**M2.5** Optimal spatial arrangement of volatile dispensers determined	33	n/a	NA with contact compounds (sprayed on target plants)
M2.6	**M2.6** Impact on natural enemies and non-target pests determined	33	33	
M2.7	**M2.7** Commercial scale testing achieved	33	33	But see comments in report about homologation problems
M3.1	**M3.1** EPF strains for experiments selected	3	3	
M3.2	**M3.2** Cultivation-dependent and -independent (PCR-based) protocols developed and implemented	7	7	

M3.3	**M3.3** Methods for different inoculation methods established	12	12	
M3.4	**M3.4** Identification of optimal conditioning regime for EPNs against *D. radicum*	16	24	Milestone was delayed due to a failure to recruit a PhD student.
M3.5	**M3.5** Ability of EPF inoculum to reach *D. radicum* larvae via roots evaluated	24	20	
M3.6	**M3.6** Effects of EPF inoculation on *D. radicum* establishment and survival tested	24	24	
M3.7	**M3.7** Optimal conditioning regimes for EPNs identified and tested in field	30	30	
M3.8	**M3.8** Methods to investigate behavioural responses of *D. radicum* adults	21	21	
M3.9	**M3.9** EPF colonization ability on host plants at variable temperatures evaluated	33	33	
M3.10	**M3.10** Prediction model of fungal pathogenicity against *D. radicum* at field-realistic temperatures	35	35	
M4.1	**M4.1** Preliminary consultation with growers/advisors in all participating countries concluded	8	8	
M4.2	**M4.2** Field/semi-field trials with biological control agents concluded	33	31	
M4.3	**M4.3** Trials on integrating physical barriers/cover crops with trap crops and/or volatiles concluded	33	31	
M4.4	**M4.4** Trials using monitoring and forecasting for timing treatments with biological control agents and timing release of volatiles concluded	33	N/A	There is not the basis for this due to the great variability in the results for the biological control agents and the release of volatiles
M5.1	**M5.1** Methods of information dissemination reviewed	12	12	
M5.2	**M5.2** FlyIPM website established	3	3	
M5.3	**M5.3** Engagement activities held in all partner countries	33	33	
M5.4	**M5.4** Information on root fly IPM developed and disseminated	35	35+	Ongoing post-project

Deliverable No.	Deliverable name	Planned delivery month[1)]	Actual delivery month[1)]	Reasons for changes/delay and explanation of consequences
D1.1.	**D1.1** Scientific manuscript on phenology of root flies in Europe and potential impact of climate change **(M30)**	30	32 (second paper submitted)	Sauer, C. (2019) Possible impacts of climate change on carrot fly's population dynamics in Switzerland. IOBC-WPRS Bulletin: Proceedings of the Meeting at Wädenswil/Arneberg (Switzerland) 02-06 October, 2017. 142:31-41. Johansen, T.J., Cortesero, A., Gaffney, M.T., Meadow, R., Schorpp, Q., Collier, R. (2020). Phenology of brassica root flies (*Delia radicum* and *D. floralis*) in northern Europe. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Stratford-upon-Avon (UK), 13-16 October, 2020. Edited by R. Meadow. Submitted.
D1.2	**D1.2** Scientific manuscript reviewing monitoring/forecasting and dissemination of information to users **(M36)**	36	37 (submitted)	Collier, R., Mazzi, D., Folkedal Schjøll, A., Schorpp, Q., Thöming, G., Johansen, T.J., Meadow,R., Meyling, N.V., Cortesero, A., Vogler, U., Gaffney, M.T., Hommes, M. (2020) The potential for decision support systems to improve the management of root-feeding fly pests of vegetables in Europe. *Insects*. Under review.
D1.3	**D1.3** Monitoring/forecasting tools and protocols available **(M30)**	30	30	
D2.1	**D2.1** Suitable trap crop varieties for *D. radicum* (**M21**)	21	21	
D2.2	**D2.2** Volatile dispensers to be used in the field against insect pests (**M21**)	21	21	
D2.3	**D2.3** Scientific manuscript on varietal differences in trap crop suitability for *D. radicum* control (**M27**)	27	32 (published)	Lamy, F., Bellec, L., Rusu-Stievenard, A., Clin, P., Ricono, C., Olivier, D., Mauger, S., Poinsot, D., Faloya, V., Daniel, L., et al. Oviposition preference of the cabbage root fly towards some chinese cabbage cultivars: A search for future trap crop candidates. *Insects* 2020, *11*, doi:10.3390/insects11020127

D2.4	**D2.4** Scientific manuscript on optimal spatial arrangements of trap crops and volatiles in a push-pull design against *D. radicum* (**M36**)	36	12	Lamy, F., Wetzel, G., Daniel, L., Faloya, V., Poinsot, D., Cortesero, A.-M. (2019) The spatial implantation of the trap crop used as Pull component has to be considered to maximize the efficiency of a Push-Pull strategy against the cabbage root fly. IOBC-WPRS Bulletin: Proceedings of the Meeting at Wädenswil/Arneberg (Switzerland) 02-06 October, 2017. 142:59-64.
D2.6	**D2.5** Scientific manuscript and technical report on potential of behavioural manipulation in IPM strategies for management of root-feeding fly larvae (**M37**)	37	>37	Lamy, Thapa, Vitt Meyling, Faloya & Cortesero "An entomopathogenic fungus to reduce root-feeding pest proliferation inside the trap crop of a Brassicaceae vegetable push pull system" in prep for Biological control.
D3.1	**D3.1** Protocol for molecular detection of *Metarhizium* in inoculated root samples (**M9**)	9	9	
D3.2	**D3.2** Prediction model of fungal pathogenicity against *D. radicum* at field-realistic temperatures (**M36**)	36	36	
D3.3	**D3.3** Scientific manuscript on fungal establishment and infectivity against *D. radicum* larvae using different inoculation methods under laboratory and greenhouse conditions (**M33**)	33	32 (submitted)	Thapa, S., Cotes, B., Uslu, H., Meyling, N.V. (2020) Inoculation of the entomopathogenic fungus *Metarhizium brunneum* to target the larvae of the cabbage root fly *Delia radicum*. IOBC-WPRS Bulletin: Proceedings of the Meeting at Stratford-upon-Avon (UK) 13-16 October 2019. (*in press*).
D3.4	**D3.4** Scientific manuscript on pest control potential of EPF on *D. radicum* larval survival and oviposition (**M36**)	36	>37	Thapa S, Uslu H, Cotes B and Meyling NV (in prep.) Evaluation of biological control potential of the entomopathogenic fungus *Metarhizium brunneum* against the larval stage of *Delia radicum* under semi-field conditions. Manuscript under preparation. Expected submission Aug. 2020.
D3.5	**D3.5** Scientific manuscript on effect of temperatures on establishment and infectivity of different EPF strains against *D. radicum* (**M36**)	36	>37	Thapa S, Cotes B and Meyling NV (in prep.) Inoculation and rhizosphere establishment of the entomopathogenic fungi *Metarhizium* spp. for cabbage root fly control. Manuscript

				under preparation. Expected submission June 2020.
D4.1	**D4.1** Report on current level of IPM for root fly management in participant countries (**M12**)	12	12	Internal report
D4.2	**D4.2** Scientific manuscript on biological control of root flies in field/semi-field trials (**M36**)	36	32+	Hutchison, I., Meyling, N.V., Thapa, S., Berge, L., Meadow, R. (2020) Biological control of cabbage root fly using an entomopathogenic fungus. IOBC-WPRS Bulletin: Proceedings of the Meeting at Stratford-upon-Avon (UK) 13-16 October 2019. (*in press*). Lamy, Thapa, Vitt Meyling, Faloya & Cortesero "An entomopathogenic fungus to reduce root-feeding pest proliferation inside the trap crop of a Brassicaceae vegetable push pull system" in prep for Biological control. Schorpp, Q., Vogler, U. (2020) Preinoculation and push-pull methods for the control of cabbage root fly in cauliflower – a critical reflection of field trials. Working Group "Integrated Protection in Field Vegetables”. Proceedings of the Meeting at Stratford-upon-Avon (UK), 13-16 October, 2019. Edited by R. Meadow. In press.
D4.3	**D4.3** Scientific manuscript(s) on effect of physical barriers/cover crops with trap crops and/or volatiles (**M36**)	36	36	Boeriis, T., Mazzi, D., Vogler, U. (2020) Push (-and-pull) strategy with sage extracts may reduce crop losses caused by the cabbage root fly, *Delia radicum*. IOBC-WPRS Bulletin: Proceedings of the Meeting at Stratford-upon-Avon (UK) 13-16 October 2019. (*in press*). Schorpp, Q., Vogler, U. (2020) Preinoculation and push-pull methods for the control of cabbage root fly in cauliflower – a critical reflection of field trials. IOBC-WPRS Bulletin: Proceedings of the Meeting at Stratford-upon-Avon (UK) 13-16 October 2019. (*in press*).
D4.4	**D4.4** Scientific manuscript on monitoring and forecasting for timing treatments with	36		There is not the basis for this manuscript due to the great variability in the results for the

	biological control agents and timing release of volatiles (**M36**)			biological control agents and the release of volatiles.
D5.1	**D5.1** Scientific publication reviewing methods of disseminating information to different stakeholders (**M30**)	30	32 (Paper submitted)	Collier, R.; Elliott, M.; Wilson, D.; Teverson, D.; Cowgill, S. Phenology and abundance of pest insects of vegetable and salad crops in Britain: decision support for growers. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Stratford-upon-Avon (UK), 13-16 October, 2019. Edited by R. Meadow. (*in press*).
D5.2	**D5.2** FlyIPM website (**M3**)	3	3	https://www.agroscope.admin.ch/agroscope/de/home/themen/pflanzenbau/pflanzenschutz/flyipm.html
D5.3	**D5.3** One stakeholder engagement activity in each partner country (**M24**)	24	24+	See Task 5.3.
D5.4	**D5.4** One European Meeting with stakeholders and project partners involved (**M36**)	36	30	IOBC/WPRS Working Group meeting 'Integrated Protection of Field Vegetables, in Stratford-upon-Avon, UK, 13-16 October 2019.

1) Measured in months from the project start date (month 1)

Outputs of the consortium

Publications

List of published scientific papers in peer-reviewed journals. Please indicate accessibility of the publication (Open Access, Thomson Reuters Web of Science, SCOPUS etc.)

Open Access papers

1. Lamy, F., Bellec, L., Rusu-Stievenard, A., Clin, P., Ricono, C., Olivier, D., Mauger, S., Poinsot, D., Faloya, V., Daniel, L., et al. Oviposition preference of the cabbage root fly towards some chinese cabbage cultivars: A search for future trap crop candidates. *Insects* 2020, *11*, doi:10.3390/insects11020127
2. Collier, R., Mazzi, D., Folkedal Schjøll, A., Schorpp, Q., Thöming, G., Johansen, T.J., Meadow,R., Meyling, N.V., Cortesero, A., Vogler, U., Gaffney, M.T., Hommes, M. (2020) The potential for decision support systems to improve the management of root-feeding fly pests of vegetables in Europe. *Insects*. Under review.

In preparation

1. Collier, R. Phenology of *C. rosae* in the UK and use and accuracy of the UK forecasts.
2. Collier, R. Phenology of *Delia radicum* in the UK and use and accuracy of the UK forecasts.
3. Gaffney (M). The efficacy of Steinernema feltiae to manage D. radicum in field Broccoli'
4. Lamy, Thapa, Vitt Meyling, Faloya & Cortesero "An entomopathogenic fungus to reduce root-feeding pest proliferation inside the trap crop of a Brassicaceae vegetable push pull system" in prep for Biological control.
5. Thapa S, Cotes B and Meyling NV (in prep.) Inoculation and rhizosphere establishment of the entomopathogenic fungi *Metarhizium* spp. for cabbage root fly control. Manuscript under preparation.

6. Thapa S, Uslu H, Cotes B and Meyling NV (in prep.) Evaluation of biological control potential of the entomopathogenic fungus *Metarhizium brunneum* against the larval stage of *Delia radicum* under semi-field conditions. Manuscript under preparation.

Total number of items at this level: 1

List of non-peer-reviewed scientific publications, proceedings and books:

1. Boeriis, T., Mazzi, D., Vogler, U. (2020) Push (-and-pull) strategy with sage extracts may reduce crop losses caused by the cabbage root fly, *Delia radicum*. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Stratford-upon-Avon (UK), 13-16 October, 2019. Edited by R. Meadow. In press.
2. Collier, R.; Elliott, M.; Wilson, D.; Teverson, D.; Cowgill, S. Phenology and abundance of pest insects of vegetable and salad crops in Britain: decision support for growers. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Stratford-upon-Avon (UK), 13-16 October, 2019. Edited by R. Meadow. In press.
3. Collier, R.H. & Villeneuve, F. (2019). 'Pests of carrot' in Carrot and other vegetable Apiaceae' CABI. In press.
4. Hutchison, I., Meyling, N.V., Thapa, S., Berge, L., Meadow, R. (2020) Biological control of cabbage root fly using an entomopathogenic fungus. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Stratford-upon-Avon (UK), 13-16 October, 2019. Edited by R. Meadow. In press.
5. Johansen, T.J., Cortesero, A.-M., Gaffney, M., Meadow, R., Schorpp, Q., Collier, R. (2020) Phenology of brassica root flies (*Delia radicum* and *D. floralis*) in northern Europe. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Stratford-upon-Avon (UK), 13-16 October, 2019. Edited by R. Meadow. In press.
6. Lamy, F., Wetzel, G., Daniel, L., Faloya, V., Poinsot, D., Cortesero, A.-M. (2019) The spatial implantation of the trap crop used as Pull component has to be considered to maximize the efficiency of a Push-Pull strategy against the cabbage root fly. IOBC-WPRS Bulletin: Proceedings of the Meeting at Wädenswil/Arneberg (Switzerland) 02-06 October, 2017. 142:59-64.
7. Mesmin, X., Faloya, V., Maret, M., Cortesero, A.-M., Le Ralec, A. (2019) Carabid predation on Delia radicum: the early bird catches the worm. IOBC-WPRS Bulletin: Proceedings of the Meeting at Wädenswil/Arneberg (Switzerland) 02-06 October, 2017. 142:65-72.
8. Sauer, C. (2019) Possible impacts of climate change on carrot fly's population dynamics in Switzerland. IOBC-WPRS Bulletin: Proceedings of the Meeting at Wädenswil/Arneberg (Switzerland) 02-06 October, 2017. 142:31-41.
9. Schorpp, Q., Vogler, U. (2020) Preinoculation and push-pull methods for the control of cabbage root fly in cauliflower – a critical reflection of field trials. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Stratford-upon-Avon (UK), 13-16 October, 2019. Edited by R. Meadow. In press.
10. Thapa, S., Cotes, B., Uslu, H., Meyling, N.V. (2020) Inoculation of the entomopathogenic fungus *Metarhizium brunneum* to target the larvae of the cabbage root fly *Delia radicum*. Working Group "Integrated Protection in Field Vegetables". Proceedings of the Meeting at Stratford-upon-Avon (UK), 13-16 October, 2019. Edited by R. Meadow. In press.
11. Thöming, G., Schjøll, A.F., Johansen, T.J. (2019) Developing tools for monitoring and forecasting of onion fly *Delia antiqua* in Norway. IOBC-WPRS Bulletin: Proceedings of the Meeting at Wädenswil/Arneberg (Switzerland) 02-06 October, 2017. 142:42-49.
12. Vogler, U., Szikora, T. (2019) A vegetable brassica based diet to test individual traits to control the cabbage root fly. IOBC-WPRS Bulletin: Proceedings of the Meeting at Wädenswil/Arneberg (Switzerland) 02-06 October, 2017. 142:50-58.

Total number of items at this level: 12

List of non-scientific publications:

1. Boeriis T., Mazzi D., Vogler U. (2019) FlyIPM - ein europäisches Projekt für die integrierte Bekämpfung von Gemüsefliegen. Article in German, French and Italian for the Gemüsebau Info, 22, 2019, 2.
2. Collier, R. (2019). FlyIPM – a European project on Root-feeding flies. The Vegetable Farmer, April 2019, p21
3. Johansen, T.J., Schjøll, A.F., Meadow, R. (2020) "Kålfluene i Norge og Europa". Gartneryrket (growers journal) in press.
4. Lamy F., Faloya V. & Cortesero A. M. (2018). Brocoli : le push-pull. *Techniques culturales, 136*, 17-18.

5. Meyling NV, Cotes B, Thapa S (2019) "Gør kål på kålfluerne". Gartnertidende, vol. 4, pp. 40-41.
6. Paap M., Vogler U. (2019) Deutscher Gartenbautag. GartenbauProfi 107:50-52
7. Pest insects infesting carrot and other Apiaceous crops. AHDB Factsheet revision. In press.
8. Poster on FlyIPM was presented at an international meeting 'Future IPM' on 15-20 October 2017, Riva del Garda, Italy.
9. Schmon R., Sauer C., Vogler U. (2018) "Die Kleine Kohlfliege (*Delia radicum*): Biologie und Bekämpfungsmöglichkeiten" datasheet (Merkblatt) in German, Agroscope (CH).
10. Schorpp Q. (2019). FlyIPM – Biologische Gegenspieler für die integrierte Kontrolle von Wurzelfliegen-Larven. BMEL Symposium zum nicht-chemischen Pflanzenschutz, Berlin.
11. Schorpp Q., Vogler U. (submitted) Preinoculation and push-pull methods for the control of cabbage root fly in cauliflower – a critical reflection of field trials.
12. Schorpp, Q. (2019) Fly-IPM – Eine „Push+Pull" Strategie für die integrierte Kontrolle von Gemüsefliegen-Larven. 29. Tagung der Fachreferenten für Pflanzenschutz im Gemüse- und Zierpflanzenbau/Baumschulen, Braunschweig. 05.-07. November 2019.
13. Szikora T., Vogler U. (2018) Gemüseschädlinge alternativ Bekämpfen. Article in German and French for Der Gemüsebau / Le Maraichère (CH) 6, 2018, 34.
14. Vogler U. (2017) " Die Kleine Kohlfliege Delia radicum " in German at Wädenswiler Gemüsebautag Agroscope (CH). Poster.
15. Vogler U. (2019) Krankheiten und Schädlinge durch Klimaveränderungen – Neue Pflanzenschutzstrategien. Deutscher Gartenbautag 2019 des ZVG, Neckarsulm. 06. September 2019
16. Vogler U., Collier R., Cortesero A.-M., Gaffney M., Hommes M., Johnsen T., Meadow R., Vitt Meyling N., Trdan S., Mazzi D. (2018): FlyIPM – Integrated control of root-feeding fly larvae infesting vegetable crops. 31. Deutsche Pflanzenschutztagung. Herausforderungen Pflanzenschutz – Wege in die Zukunft; 11.-14. September 2018, Universität Hohenheim – Kurzassungen der Vorträge und Poster. Julius-Kühn-Archiv 461, Braunschweig 416
17. Vogler U., Collier R., Cortesero A-M., Gaffney M., Hommes M., Johansen T., Meadow R., Vitt Meyling N., Trdan S., Mazzi D., Szikora T. FlyIPM Integrated control of root-feeding fly larvae infesting vegetable crops. 61st German Plant Protection Conference.
18. Vogler U., Schorpp Q. (2020) FlyIPM – Ein europäisches Projekt zum integrierten Pflanzenschutz – Forscher tricksen Gemüsefliegen aus. Gemüse 56:30-31
19. Vogler U., Schorpp Q. (2020) Vorbeugende biologische Kontrolle der Kleinen Kohlfliege im „Push Pull"-System. 93. Arbeitssitzung Deutscher Pflanzenschutzdienst, Hamburg. 02.03.2020
20. Article on Extension service website, 18.05.2020, Norway
21. Written information about the project for the extension agents, 04/06/2018, Norway
22. Written information about the project for the extension agents, 03/04/2019, Norway
23. Nye metoder for å stoppe kålfluer" (New methods to stop cabbage flies). in Gartneryrket 9.2019. pp. 20-25. Author is Gerd Guren, the Norwegian Agricultural Extension Service.
24. "Kålfluene i Norge og Europa" (Cabbage Flies in Norway and Europe) will be published in the June 2020 edition of the growers journal "Gartneryrket". The article describes the results from the project. The authors are Tor J. Johansen (NIBIO), Annette F. Schjøll (NIBIO) and Richard Meadow (NMBU).

Total number of items at this level: 24

List of <u>press releases, interviews and TV appearances</u>:

Total number of items at this level: 0

Events with stakeholders (if applicable)

No.	Year	Event	Aim/ location/ date	Approximate number of attendees
1	2016	Oral at a meeting with vegetable extension agents	02/11/2016 Norway Vegetable extension agents	ca 15
2	2017	IOBC Working Group "Integrated Protection in Field Vegetables" Meeting at Wädenswil/Arenenberg (Switzerland), 02-06 October, 2017.	Sauer, C. (2019). Possible impacts of climate change on carrot fly's population dynamics in Switzerland.	50
3	2017	IOBC Working Group "Integrated Protection in Field Vegetables" Meeting at Wädenswil/Arenenberg (Switzerland), 02-06 October, 2017.	Gunda Thöming, Annette Folkedal Schjøll, Tor J. Johansen (2019). Developing tools for monitoring and forecasting of onion fly *Delia antiqua* in Norway.	50
4	2017	"Integrated Protection in Field Vegetables" Meeting at Wädenswil/Arenenberg (Switzerland), 02-06 October, 2017.	Ute Vogler, Timea Szikora (2019). A vegetable brassica based diet to test individual traits to control the cabbage root fly. IOBC Working Group	50
5	2017	"Integrated Protection in Field Vegetables" Meeting at Wädenswil/Arenenberg (Switzerland), 02-06 October, 2017.	Xavier Mesmin, Vincent Faloya, Marion Maret, Anne-Marie Cortesero, Anne Le Ralec (2019). Carabid predation on *Delia radicum*: the early bird catches the worm. IOBC Working Group	50
6	*2017*	*IOBC-WPRS Meeting, WG Integrated Protection in Field Vegetables*, Arenenberg, Switzerland, 02-06 October, 2017.	Lamy, F., Wetzel, G., Poinsot, D., Cortesero, A.M. (2017). Controlling the cabbage root fly using a push-pull strategy: current status and perspectives	50
7	*2017*	*Carrefours de l'Innovation Agronomique « Construire et diffuser des systèmes légumiers multi-performants »*. Angers.	Cortesero, A.M. ; Lamy, F. ; Le Ralec, A. ; Faloya, V. (2017). Mobiliser les processus écologiques pour contrôler les insectes ravageurs : application de la stratégie *push-pull* en production de brassicacées légumières.	50
8	2017	Oral (by Skype) at annual meeting of vegetable extension	20/01/2017 Norway Vegetable extension agents	10
9	2018	Grower seminar: Innovation in Fresh Produce Production from File to Field to Fork'	Presentation on future approaches to crop protection in fresh produce. FlyIPM highlighted as relevant research project. Ireland	80
10	2018	Opening of New Horticultural Research Facilities at Ashtown, Dublin 15, Ireland.	To inform horticultural stakeholders of current research in Horticulture (FlyIPM poster on Irish activities presented). Location Teagasc Horticultural Research Centre, Ashtown, Dublin 15. Date May 17th 2018	150
11	2018	C-IPM workshop, 22-23 November 2018, Paris.	Integrated control of root-feeding fly larvae infesting vegetable crops.	50
12	2018	Oral at annual plant protection meeting of extension service	24/01/2018 Norway Vegetable extension agents, plant protection companies, NIBIO	ca 25
13	2018	Oral at a meeting with vegetable extension agents	30/08/2018 Norway Vegetable extension agents	10

14	2019	"Plant Biologicals Network Seminar", Denmark. Academia and company representatives in Denmark/Sweden.	Presentation of main results as part of talk on use of entomopathogenic fungi as plant inoculants. Copenhagen, Denmark, 14th Nov 2019.	120
15	2019	Seminar: Centenary of the Journal of Horticultural Science and Biotechnology	To inform an audience of growers, suppliers, processors, retailers, advisors and scientists about recent and ongoing research on IPM in vegetables. Location Charlecote, UK, May 9 2019.	100
16	2019	MUCF Meeting, 27th March 2019, Brussels.	Integrated control of root-feeding fly larvae infesting vegetable crops.	40
17	2019	IOBC/WPRS Working Group meeting 'Integrated Protection of Field Vegetables, October 2019.	Isabella Hutchison (Norges Miljø-Og Biovitenskapelige Universitet, Norway), Nicolai V Meyling, Sundar Thapa (Københavns Universitet, Denmark), Liv Berge, Luc Brard (Norges Miljø-Og Biovitenskapelige Universitet, Norway) & Richard Meadow (Norges Miljø-og Biovitenskapelige Universitet, Norway; Norsk Institutt for Biøkonomi, Norway) (2019). Biological control of cabbage root fly using an entomopathogenic fungus.	50
18	2019	IOBC/WPRS Working Group meeting 'Integrated Protection of Field Vegetables, October 2019.	Sundar Thapa, Belén Cotes & Nicolai V Meyling (University of Copenhagen, Denmark) (2019). Inoculating entomopathogenic fungi for control of the cabbage root fly Delia radicum in soil.	50
19	2019	IOBC/WPRS Working Group meeting 'Integrated Protection of Field Vegetables, October 2019.	Quentin Schorpp (Julius Kühn-Institut, Braunschweig, Germany) (2019). Preventive biological control of root-feeding fly larvae in cauliflower.	50
20	2019	29. Tagung der Fachreferenten für Pflanzenschutz im Gemüse- und Zierpflanzenbau/Baumschulen vom 05. bis 07. November 2019 am Julius Kühn-Institut in Braunschweig	Quentin Schorpp (Julius Kühn-Institut, Braunschweig, Germany) (2019). Oral presentation of the FlyIPM Project. "Fly-IPM – Eine „Push+Pull" Strategie für die integrierte Kontrolle von Gemüsefliegen-Larven"	80
21	2019	The project was presented in German at the Wädenswiler Gemüsebautag meeting of growers and advisors held on 28.08.2019 in Wädenswil.	The produced illustrated flyer was distributed to the participants for further dissemination.	80
22	2019	IOBC/WPRS Working Group meeting 'Integrated Protection of Field Vegetables, October 2019.	Richard Meadow (Norwegian University of Life Sciences, Norway; Norwegian Institute of Bioeconomy Research, Ås, Norway), Tor J Johansen, Gunda Thöming, Anette F Schjøll (Norwegian Institute of Bioeconomy Research, Ås, Norway), Belén Cotes (University of Copenhagen, Fredriksberg C, Denmark) & Christian Nansen (University of California, Davis, USA) (2019). Integrated control of rootflies in Brassica vegetables	50
23	2019	IOBC/WPRS Working Group meeting 'Integrated Protection of Field Vegetables, October 2019.	Fabrice Lamy, Cécile Burtin, Héloïse Royer, Loïc Daniel, Valérie Chaminade, Vincent Faloya & Anne Marie Cortesero (IGEPP, INRA, Agrocampus Ouest, Université de Rennes 1, Rennes, France) (2019). Control of *Delia radicum*: selecting and testing the potential of oviposition inhibitors in a Push-Pull strategy.	50
24	2019	Meeting of the IOBC-WPRS Working Group "Microbial and Nematode Control of	Nicolai V Meyling (2019). 52nd Annual Meeting of the Society for Invertebrate Pathology & 17th	50

		Invertebrate Pests") in Valencia, August 2019		
25	2019	Rencontres Plant2Pro « Plantes de services et services des plantes », Paris.	Cortesero A.M., Lamy F., Le Ralec A., Faloya V. (2019). Recherche de solutions de biocontrôle contre un ravageur de cultures de brassicacées légumières : de l'écologie chimique aux plantes de service (*and back*).	70
26	2019	Oral at a meeting with vegetable extension agents	01/11/2019 Norway Vegetable extension agents	ca 15
27	2019	Oral at annual plant protection meeting of extension service	30/01/2019 Norway Vegetable extension agents, plant protection companies, NIBIO	ca 25
28	2019	Presentation of the project at field day for early production in Rogaland county	09/05/2019 Norway Vegetable growers and industry	35
29	2019	Distribution of presentation	13/05/2019 Norway Vegetable extension agents and other extension agents	60
30	2019	Seminar and project field site visit	18/06/2019 Norway Vegetable extension agents and university students	15
31	2019	Oral at annual plant protection meeting of extension service	30/01/2019 Norway Vegetable extension agents, plant protection companies, NIBIO	ca 25
32	2020	"Plantekongres", session "plant biologicals". Annual event for plant production in Denmark.	Presentation of the concept of using entomopathogenic fungi as plant inoculants. Herning, Denmark, 14th Jan 2020.	200
33	2020	'Biocontrol technologies in the current and future farmers' toolbox' Brussels, 23 January 2020, Meeting organised by IBMA/COPA COGECA.	Rosemary Collier - part of presentation on IPM.	40
34	2020	'Advancing the use of biopesticides and IPM in field vegetables' 5th February 2020 – Wellesbourne UK	Rosemary Collier - part of presentation on PM.	100
35	2020	Workshop on 'Minor uses and speciality crops: the way forward in Europe' Paris, 18th- 20th February 2020.	Rosemary Collier - part of presentation on IPM.	40

Training sessions conducted (if applicable)

Description of training course	Approximate number of attendees
MSc student Isabella Hutchinson from NMBU, Norway, visited University of Copenhagen to receive training in production of entomopathogenic fungi on culture media and rice for use in own experiment during 2019/20. Period: 2 weeks Nov. 2018.	1

Methods, techniques, tools etc. (if applicable)

Description of methods, techniques, tools etc. developed in the frame of the project:

	Description
New methods, techniques, tools e.g. a method to monitor or attract a specific pest species	Implementation of qPCR protocol for specific detection of EPF from root tissues (WP3).
Patent applications, other IP e.g. patent for extraction process of lure/attractant	None
Prototypes, pilots e.g. a trap prototype	None
Marketable product/service e.g. a trap, lure, pheromone etc.	None

Explanation of the use of resources

Funding

(All requested amounts should be ***expressed as thousands*** *of euros. E.g.: 1.357.900 euro should be written as € 1357.9 in the answer box.)*

Effective funding sources

Partner no.	EU funds (ERA-NET)		Other external public funds		External private funds		Own funds		**Total funds €**
	€	%	€	%	€	%	€	%	
P1			55,647				13,697		69,344
P2			195,216				351,510		546,726
P3			214,130				24,000		238,130
P4			0				12,600		12,600
P5			100,000				78,000		178,000
P6			178,000				0		178,000
P7			224,500				0		224,500
P8			110,500				90,000		200,500
P9			0				5,480		5,480
TOTAL			1,077,993				575,287		1,653,280

List any deviations in participant's use of resources pertinent to the project as a whole, describe corrective actions adopted for any deviations:

- P3 - the requested amount was €230400 but the actual amount awarded was €214130.
- P5 – own funds should be €78000
- P6 - due to an inability to recruit a PhD student, this portion of the budget was not utilised. The work envisaged for the student was completed by the PI, with additional help from permanent technical staff, visiting students and a short-term project from an MSc student. The travel budget is underspent as the PI was unable to travel to the first 2 project meetings due to personal circumstances (arrival of new child and leave due to an operation).
- P7 & P8 - the exchange rate is based on 2016 for euro/NOK.
- P9 – although this partner contributed to the application and planned to take part using their own funds, they did not take part in any of the activities.

Funded by the
European Union

Effective costs

Partner no.	Personnel	Travelling / meetings	Consumables /Equipment	Subcontracts	Other costs	**Total effective Costs**
P1	63,089	3,407	1,249		1,599	69,344
P2	460,715	17,567	50,740	10,195	7,508	546,725
P3	219,465	3,381	15,262			238,108
P4	10,500	900	1,200			12,600
P5	163,000	3,000	12,000			178,000
P6	65,547	320	12,296		23,448	101,611
P7	180,000	15,000	17,500	12,000		224,500
P8	180,000	15,000	5,500			200,500
P9	0	0	0	0	0	0
TOTAL	1,342,316	58,575	115,747	22,195	32,555	1,571,388

Human resources

Total number of people in partner teams

Indicate the number of employees of the following positions that were permanent staff members / that were hired especially for the project *(only include people that were paid by ERA-NET funds):*

Partner no.	Researchers with PhD more than 3 years / experienced scientists		Researchers PhD post-docs / young scientists		PhD students		Master students		Support or technical staff		Other	
	Permanent	Hired	Permanent	Hired	Permanent	Hired	Permanent	Hired	Permanent	Hired	Permanent	Hired
P1	2						1		3			
P2	5			1				6	4			
P3	1			2				1	1			
P4	1								1			
P5										1		
P6	1							1	2			1
P7	2		1				3		4			
P8	1								1			
P9	0											
TOTAL	13		1	3			4	8	16	1		1

How many people completed any of the following qualifications through their work on the ERA-NET funded project and/or using funding from the ERA-NET project?
Number of PhDs: 0
Number of MSc, MEng: 2 (UK) + 6 (FR)+ 1 (IE) + 2 (DK); Total = 11

Students associated with the project at IGEPP (FR):
Many students were involved each year in the field and laboratory work conducted by FR during the project:

April to August **2017** - Guillaume Wetzel - MSc – Thesis title: « Réponse de la mouche du chou et de ses prédateurs à différentes modalités d'implantation d'une culture piège »

Summer **2017** - BSc students: Justine Royer, Elvina Faucher, Alix LeBret

April to June **2018** - Laura Bellec - MSc - Thesis title: « Evaluation du potentiel attractif de 15 variétés de chou chinois (*Brassica rapa* L.) dans un contexte d'optimisation d'une stratégie *push-pull* contre la mouche du chou, *Delia radicum* L. (Diptera : Anthomyiidae) : du laboratoire au terrain

April to June **2018** - Marianne Cahierre - MSc - Thesis title: Carboxylic acids as inhibitors of the cabbage root fly oviposition: from the laboratory to the field and implementation in a push-pull system

Summer **2018** - BSc students: Manick Vigouroux, Salomé Chaumont, Chloé Fosse

March to August **2019** - Héloïse Royer, - MEng - Thesis title: « Sélection d'inhibiteurs de l'oviposition chez la mouche du chou : du laboratoire vers le développement d'une stratégie push-pull en pépinière de brassicacées. »

Mars à août **2019** - Cécile Burtin, - MEng - Thesis title: « Évaluation en plein champ d'une strategie push-pull pour la protection d'une culture de brocolis contre la mouche du chou (*Delia radicum*) »

April to June **2019** - Margaux Treguy - MSc - Thesis title: « Contrôler la mouche du chou *Delia radicum* avec le champignon entomopathogène *Metarhizium brunneum* dans le cadre du développement d'une stratégie 'push-pull' »

Students associated with the project at UCPH (DK):
Joana Carvalho Cachapa, MSc thesis in Biology (60 ECTS) "Faster and stronger: Enhanced defences in cauliflower triggered by the entomopathogenic fungus *Metarhizium brunneum*" defended 28th August 2018.
Meta van Ruijven, MSc minor thesis (24 ECTS) "Effect of coating seeds with entomopathogenic fungus *Metarhizium* on the above-ground herbivore the diamondback moth" defended Dec 2017.
Hasan Uslu, ERASMUS exchange student "Evaluation of infectivity of *Metarhizium brunneum* conidia cultivated on agar media vs. rice against *Delia radicum* larvae" August-October 2018.

Students associated with the project at University of Warwick (UK):
One MSc student (short project) and one French intern (10 weeks) worked on topics relevant to FlyIPM.

Students associated with the project at Teagasc (IE):
One MSc student (short project), Mr Cornetin Maslard and one French intern (8 weeks), Ms Camille Bau worked on aspects of the FLYIPM project. Both worked on the development of a Laboratory assay to identify efficacy of entomopathogenic nematodes against *D. radicum* and *G. melonella*. Mr

Cornetin Maslard completed a project entitled 'Efficacy of entomopathogenic nematodes in controlling cabbage root fly' at the Universite Angers in 2019).

Students associated with the project at Agroscope (CH):

One BSc student enrolled at ETH Zurich completed her thesis on the use of attractive and repellent plant extracts to steer oviposition of the cabbage fly *Delia radicum* away from broccoli. Her work was presented orally in an internal colloquium at Agroscope in Wädenswil.

From here onwards: for final reports only:

Outcomes - effects of the project on the team and the institutions

Knowledge

Short description of the effects the project had (regarding skills, understanding of the concerned research fields, stakeholder expectations, end users' needs and consortium partner's expertise). Did the research quality increase? *(Please compare to the period before the project started)*

The project improved collaboration between the partners with regard particularly to their understanding of the research fields concerned and also of the information that is available to stakeholders in each country and the routes that are used to disseminate that information. The project allowed for experimental testing of IPM approaches under near realistic conditions over longer periods, thus producing results that are relatively close to growers' practice, yet controlled. This represents a major step forward in understanding the implications of the tested IPM elements in a field situation. The partners also increased their knowledge and expertise about the different experimental approaches used and, for example, an MSc student Isabella Hutchinson from NMBU, Norway, visited the University of Copenhagen to receive training in production of entomopathogenic fungi on culture media and rice for use in own experiment during 2019/20. Richard Meadow from NMBU spent part of his study leave in spring 2019 with Anne-Marie Cortesero's group in France and then with Rosemary Collier's team in the UK and there was an exchange of ideas and expertise related to the project. It is difficult to say whether the research quality increased per se: but all partners have become more knowledgeable about the research areas of others and how their own research will fit into an IPM programme in the future.

Network and cooperation

Short description of the effects the project had on networking and cooperation (cooperation of consortium partners, formation of new R&D partnerships, improved public-private cooperation, increased transnationality or transdisciplinarity, access to complementary expertise) *(Please compare to the period before the project started)*

Most members of the consortium already knew one another quite well, mainly through the IOBC WPRS working group on 'Integrated Protection of Field Vegetables'. FlyIPM provided an excellent opportunity for the members of the consortium to work together and it has certainly improved cooperation, transfer of information, and potentially the formation of new partnerships. One aspect which a sub-group was intending to take forward was a discussion group/visit to JKI in Germany to discuss the detail of forecasting models. This unfortunately had *to be delayed and now it may not be possible to do this for some time due to COVID-19. The partners benefitted from complementary expertise within the consortium by exchange of materials and methods, creating a basis for experimental approaches that would not have been possible to accomplish by individual partners. The project has strengthened the collaboration in DK between the PI and the growers' advisory service, as well as promoting the IPM approach nationally through the regular meetings of the Danish EPA and presentation at national seminars and congresses to both researchers and stakeholders (industry and growers).*

Economy and strategy

Additional funding received through the achievement of this ERA-NET project (during or after the completion of the project). Please indicate the source(s) and amount(s) of funding received for carrying out (a) new project(s).
(All requested amounts should be expressed as thousands of euros. E.g.: 1.357.900 euro should be written as € 1357.9 in the answer box.)

Project acronym and approach[1)]	Participating partners (partner no.)	EU Framework Programmes / Horizon 2020 €	Other EU funds €	National funds €	Other public funds €	Private funds €	Own funds €	TOTAL €
PhD project on *D.platura/florilega*	UK (P1)					80		

[1)] R&D, Implementation, Commercialisation

Impacts - effect of the project on users and society at large

General Questions

How do you judge the information transfer of your results among the user communities? To what extent did your results reach the desired circles?
From the list of publications and events it is clear that there have been a good number of opportunities for information transfer. For most of our results further time/development will be required before the information can be used directly by growers. This applies particularly to the novel push-pull system and also to the approaches using a combination of IPM tools. The project has also helped some partners to re-examine the tools that are available to them e.g. JKI is going to undertake further work on the SWAT models to improve their accuracy. In the UK there are some situations where insecticidal control solutions are not effective or not available and, for example, UK researchers now have access to the knowledge and expertise of those developing other techniques, and it is quite likely that the UK will wish to evaluate the push-pull system for particular situations. Information transfer to the research/development community has been effective and it has been an excellent project to raise the profile of IPM strategies amongst that community.

Impacts on the research community

Do you know of any projects that were launched based on the results of your project? Yes If yes, please name them: PhD project on *D.platura/florilega* as above.

Please indicate the number of students/staff who have worked on the ERA-NET funded project (only if staff members were hired especially for the project, no permanent staff members), that chose the following (first) career destinations after finishing their involvement with the project.

Partner no.	Employment: private sector research	Employment: private sector non-research	Employment: public sector research	Employment: public sector non-research	Further study	Seeking employment	Don't know
P1		1			1		
P2							
P3	2				2	1	
P4							
P5							
P6							
P7							
P8							

Short description of the impacts the project had on the research environment (increased mobility of researchers, increased research activities, improved information exchange). *This project led principally to increased information exchange between partners and between partners and stakeholders. In DK, the project ensured increased awareness of the IPM strategy used, initiated additional collaboration with other scientists within the institution and formed the basis for two national research proposals. Richard Meadow (NO) spent part of his study leave at IGEPP and the University of Warwick.*

Impact on industry/ service sector

Short description of the impacts resulting from the project (requests received from end users/companies concerning the use of your results, further development or commercialisation of results by industry) *This research was unlikely to provide tools/techniques that would provide income through direct sales of a new product. The main impacts will be through increased flow of knowledge to stakeholders/end-users and uptake of new approaches by growers if they perceive them to be viable economically. As above, there is interest in the UK in IPM approaches where there are no insecticidal alternatives. The postdocs working on the project in DK were recruited by the private sector for R&D within development of biological solutions for pest control.*

Funded by the
European Union

Anticipated impact on farmers and society at large

Short description of the anticipated impacts resulting from the project (anticipated implementation of your solution by farmers, improvement of the situation of farmers, impact on society at large) *There is a great need to provide effective non-insecticidal methods of pest control to farmers and growers and this was the main focus of this project. There is a new impetus from the EU through the Biodiversity Strategy and Farm to Fork Strategy and similar initiatives are developing in the UK. In addition, there are some pest/crop situations where no effective pesticide treatments are available. Thus, whilst the impacts of this project may not be immediate in all respects, they are a further step along the pathway to providing farmers with the tools that they need, and society with high quality food produced with less pesticide.*

Grant agreement no.: 618110 – Final report

In the European Union, the Directive 2009/128/EC on the sustainable use of pesticides makes it mandatory to implement the principles of Integrated Pest Management (IPM). To face this challenge member states of the European Union has co-funded an initiative to coordinate Integrated Pest Management (C-IPM) through an ERA-NET funding programme under the Seventh Framework Programme on research and development.

The present report is the result of a project with participating institutes from and co-funded by parties from the UK, France, Denmark, Germany, Switzerland, Ireland, Norway, and Slovenia.

'Integrated control of root-feeding fly larvae infesting vegetable crops (FlyIPM)' has focused on the tools and approaches that might be part of an IPM package to manage root-feeding fly larvae on vegetables and this is particularly 1) biocontrol with entomopathogens and nematodes, 2) physical barriers, 3) combinations of attractants and repellents and 4) the development of a push-pull strategy using trap crops. Underlying all of this is a need to know when pests are present, through crop monitoring and weather-based forecasts. With the exception of monitoring and forecasting, very few of the tools are used by growers currently. The research focus was particularly on the cabbage root fly (Delia radicum).

Of the tools that have been evaluated, there seems to be real potential for improved forecasting systems for several species. In addition to the current use of crop covers to exclude certain pests, vertical barriers seem to be a good option for management of D. radicum in certain situations. Whilst the push-pull technique requires further work before it is commercially-viable, there is real potential to use it as part of an IPM strategy for D. radicum in future. Interestingly, although this research has confirmed that the mortality of D. radicum larvae achieved by the fungal pathogens tested is 'too late' to protect the current crop, it could be applied to a trap crop to improve its function as a 'dead end'.

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