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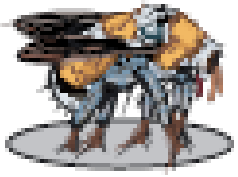

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Ecological approaches for IPM

TOOLS TO MANAGE SOILBORNE DISEASES

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Soilborne plant diseases can be caused by a wide range of pathogens, yet they share the ability to survive prolonged periods of time in the absence of a host. Application of pesticides is in most cases ineffective, especially when resting structures are involved. In addition they can cause unwanted environmental side-effects, as well as negative effects on non-target organisms. Other methods to kill pathogens, such as soil pasteurizing (high energy demand) and biological soil disinfestation (expensive) have their limitations as well. Therefore, control of soilborne pathogens in agronomic soils should be a combination of avoiding infestation with pathogens, reducing their population build-up, and management of soils as to maximize their disease suppression.

Reduction of soilborne diseases can be achieved by combinations of the following management strategies:

1. Avoidance of pathogens: using machinery and planting material that is free of soilborne pathogens.
2. Reducing the cropping frequency of hosts, which for the farm economics can be difficult to incorporate.
3. Cultural measures to prevent buildup of survival structures, e.g. the killing and cutting-off of potato haulms before *Verticillium dahliae* starts to form microsclerotia. However, the majority of soilborne pathogens produce their survival structure on infected roots.
4. Some specific effects of green manure crops, such as the cultivation of Tagetes to control *Pratylenchus penetrans* and the hatching of potato cyst nematode by *Solanum sisymbriifolium*.
5. Increasing the suppression of soilborne pathogens: suppression of soilborne pathogens is *a priori* a hard task because their survival structures are by definition less sensitive to invadors. There is a range of mechanisms involved, including specific and aspecific modes of action. In many cases both modes of action are quite active in agronomic soils, but they are rarely so prevalent that harmful expression of soilborne pathogens is nullified, especially not at high disease pressure.

To decide which management practices are needed, and eventually to set up early warning systems, soilborne pathogens need to be quantifiable at low densities.

AN EXPERIMENTAL TEST OF THE EFFECT OF MANAGEMENT STRATEGIES AND ROTATION ON PLANT-PATHOGEN SUPPRESSION BY SOIL MICROBIAL COMMUNITIES

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Soil is a highly complex habitat, with an exceptional diversity of microbial life. Interactions within the microbial community can be manipulated by rotation, tillage and organic amendment. However, the responses are not yet predictable, as the mechanisms linking these to soil suppression are not fully understood. The objective of the current research is to investigate and design management strategies to promote microbial mediated soil suppressiveness toward soil-borne pathogens and measure changes in soil biota due to these management strategies.

A wide range of soil biota as well as disease suppressive properties of the soil were assessed in a field trial with a winter wheat based rotation. The objective was to detect shifts in the communities of different soil biota due to cultural and management strategies. Such information could facilitate the design of management strategies to promote microbe-mediated soil suppressiveness toward soil-borne pathogens.

Two management systems were compared: (1) a control system including ploughing before sowing which is the currently applied system in the region, and (2) an innovative system targeting a better energy ratio, less greenhouse gas emissions, time saving for farmers and reduction of inputs especially nitrogen fertilization and pesticide applications. Both crop rotations consisted of winter wheat, winter oilseed rape, sugar beet and faba bean, but the innovative system had an additional crop linseed and cover crops between the main crops.

Soil management strategies and crop rotation influenced the communities of bacteria, fungi including arbuscular mycorrhizal fungi, and nematodes in soil. Community shifts could be either due to the preceding crop, or due to the management system. Soil suppressiveness differed for 1 out of 3 soil-borne pathogens tested. However, in general the natural soil in the assessed field was quite suppressive against the diseases, and several antagonistic bacteria (*Pseudomonas* and *Lysobacter*) were isolated from the soil samples.

The results showed the influence of management practices on soil biota and soil suppressiveness, indicating the potential of ecological engineering approaches to IPM through habitat manipulation at the field. However, distinct advises on management practices in relation to IPM will depend on the pathogens present in the field and the environmental conditions such as soil type, crop rotation and management. Extensive research is needed to get sufficient knowledge on the relevant soil processes before practical implementation is possible.

DESIGNING MULTIFUNCTIONAL MARGINS FOR BIOCONTROL IN WHEAT-OSR ROTATIONS

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Agricultural intensification has led to fragmentation of semi-natural habitats within the farmed landscape causing a loss of biodiversity and concern about the deterioration of important ecosystem services. Managed field margins that deliver multiple ecosystem services and take account of agronomic practicality could help to redress the balance and are essential if 'land-sharing' agri-environmental schemes are to be optimized. Provision for birds and pollinators has been a primary driver for field margin design to date and the value of margins for biocontrol of crop pests has been less studied. A number of studies have shown the potential of grassy margins which support cereal aphids and their natural enemies for improved biocontrol in cereal crops. However, most arable rotations in Europe include oilseed rape (*Brassica napus*) and we have shown that margins that do not contain brassicas do not support well the specialist natural enemies important in the biocontrol of oilseed rape pests.

Our work has focussed on designing field margins to increase the abundance of natural enemies and to provide biocontrol across the wheat-oilseed rape crop rotation. We tested a range of brassicas as potential 'banker plants' to provide resources for specialist natural enemies of oilseed rape pests. In the PURE project we assessed the value of field margins containing brassicas to invertebrate biodiversity and their effect on biocontrol in cereal and OSR crops. Our initial results suggest that while the brassica margins did increase the abundance and diversity of natural enemies found in field margins, there was little positive effect on biocontrol in the crop or on yield. It seems that getting biocontrol agents into the open field remains one of the greatest challenges in delivering crop protection via conservation biocontrol.

CONSERVATION BIOLOGICAL CONTROL AT THE LANDSCAPE SCALE

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Pest problems are usually viewed at the scale of the field, orchard or other individual crop unit, yet many pests are capable of moving between fields and may even spend part of their life cycle in habitats outside of the crop. Therefore, it should not be surprising that pests of various types respond to habitat characteristics of the landscape in which they appear or to landscape scale patterns in cropping and crop management. In addition to the direct habitat effects, a landscape may also act on pest populations indirectly and in a top-down way as a result of the influence of landscapes on the natural enemies of pests. It follows from these insights that to achieve a comprehensive picture of the factors driving pest pressure it is necessary to understand and account for the landscape ecology of pests and natural enemies. While this presents a challenge to modern IPM it also offers the opportunity to develop new tools for the regulation of pests through the appropriate management of farm landscapes.

To this end, a substantial investigation of ecological processes underlying the influence of landscapes on populations of pests and their natural enemies was undertaken as part of PURE with the overall objective of promoting the design and management of pest suppressive landscapes.

We used a combination landscape scale observational studies and computer simulation modelling to explore the ways in which the different habitats in the crop production environment can be managed.

In three contrasting studies the response of different pest and natural enemy groups to local and landscape conditions was assessed. Despite considering pests as diverse as moths and weeds, natural enemies such as parasitoids and generalist predators and cropping systems as different as cereal rotations and apple orchards, the significance of the surrounding landscape in determining the abundance of pests and natural enemies was clear. These effects included the influence of crop management at the landscape scale as well as non-crop habitats.

To explore the mechanisms underlying these responses and suggest possible landscape management strategies we have taking a modelling approach which combines the dynamics of crop production with the population dynamics of pests and their natural enemies. The approach has been designed to be flexible allowing us to look at a wide range of ecologically based strategies for pest control. Some of the ideas trialled so far include optimizing the use of pesticides in space and time, designing natural enemy based conservation strategies, and assessing the impact on pest control of interference between multiple natural enemies.

QUANTIFY THE CONTRIBUTION OF SEMI-NATURAL HABITATS TO ESSENTIAL ECOLOGICAL SERVICES – QUESSA

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The vegetation in semi-natural habitats supports ecosystem services (ES) essential for the development of sustainable farming systems. The EU project QuESSA aims to quantify some of the key ES (e.g. pollination and biocontrol) derived from semi-natural habitats (SNH) for the main European cropping and farming systems. This will be achieved by identifying key SNH according to their potential to support selected ES based upon vegetation traits. The ES delivery will then be verified through field studies in 16 case studies covering the predominant European cropping systems. A case study is defined by a unique combination of region, crop species, and service. Data will parameterise spatially explicit models to determine how vegetation composition, management, shape, area, and placement of SNH in agricultural landscapes affect the distribution of invertebrate based ecosystem services from farm to landscape levels. To investigate synergies and trade-offs in ecosystem services, multi-criteria analysis will be developed to combine a suite of modules in an integrative modelling framework. The project will produce guidelines, make recommendations to local, national and EU stakeholders and provide a web-based tool for farmers to enhance exploitation of semi-natural habitats for ES provision. QuESSA is funded by European Union's Framework 7 programme.

ARABLE LANDSCAPES AND MULTIPLE ECOSYSTEM SERVICES IN THE NETHERLANDS

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Ecological intensification of agriculture requires actionable knowledge for taking effective measures to support biological control, pollination and other ecosystem services in agricultural landscapes. We use a suite of empirical and modelling approaches to collect and synthesize information on the relationship between land use, habitat management and ecosystem service delivery in landscapes. We combine information from databases on plant communities in real Dutch landscapes with information on plant-insect associations and information on resource needs and dispersal of pollinators and natural enemies of crop pests to develop dynamic maps of ecosystem service provision. Assessments will be made of costs and profits. Engagement with stakeholders in two case study regions, the Hoeksche Waard and Flevoland, is pursued to take into account the services most valued by stakeholders such as farmers, water boards, nature conservationists, provincial and municipal authorities, etc. These analyses help to identify gaps in resource provisioning in the landscape that limit the delivery of ecosystem services. Furthermore, trade-offs and synergies may be identified. Such analyses may assist stakeholders in informed decision making and negotiation on habitat management and land use.

MANIPULATING FIELD MARGINS TO INCREASE PREDATION INTENSITY IN WINTER WHEAT (*TRITICUM EASTIVUM*) FIELDS IN DENMARK

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Habitat manipulation is a well-known practice in conservation biological control in order to enhance natural enemy density, and is a valid alternative to pesticide use. However, due to the striking differences in their ecology, generalist and specialist predators may show different response to habitat manipulation interventions. Moreover, clear evidence that to higher density of predators correspond higher density of predation may be not easy to find, due to possible undesired effects (i.e. intraguild predation, cannibalism, hyperparasithism). Additionally, quantitative estimations of predation rate are difficult to obtain, as predation may remain undetectable (i.e. hidden, night). We recorded the composition of predatory arthropod guild and predation rate within and along the edges of winter wheat (*Triticum aestivum*) fields surrounded by flowery or grassy strips from May to July 2014 in Denmark. Predators were collected using pitfalls traps and a suction sampler, while predation rate on aphids was measured using various exclusion cages (open, partially excluding, and totally excluding as control), and sentinel prey made of plasticine, that allows the identification of the predator marks. Ground beetles (Carabidae), rove beetles (Staphylinidae), spiders (Aranea), and parasitoid and predatory wasps (Hymenoptera) were the most common natural enemies during the experiment. We found significantly lower number of generalist predators (but not specialists) in flower vs grass margins ($p<0.05$) from the suction samples. Activity density recorded using pitfall traps did not show significant difference in flower vs. grass margins for either specialist or generalist predators. Mean survival time of in-field aphid colonies was shorter (5.8 days) near flowery vs. grassy (9.9 days) edges. However, the Biological Control Index was not different. Forty-six % (n=756/1637) of the sentinel prey were attacked after 24 h mostly by chewing insects (88%, n=665/756 of the bites), followed by small mammals (13.2%, n=100/756), and birds (1.3%, n=10/756). Predation rate by chewing insects was higher in grass than flowery margins (48.9%, n=436/892 vs. 30.7%, n=229/745), and also higher in the edge than within field (45.3%, n=371/819 vs. 35.9%, n=294/818). In the flowery strips, predation was slightly higher within the field than in the edge (30.9%, n=115/372 vs. 30.6%, n=114/373, respectively), while in grassy ones, it was higher in the edge than within field (57.6%, n=257/446 vs. 40.1% n=179/446). Our preliminary results suggest that flowery strips enhance specialist but not generalist predator abundance in the field edges, and that a correlation between generalist predator abundance (especially of ground beetles) and predation rate on artificial sentinel prey may exist.

BIODIVERSITY OF HOVERFLIES (DIPTERA: SYRPHIDAE) AND SEASONAL VARIATION IN VINEYARDS OF DOURO WINE REGION, PORTUGAL

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Syrphids provide important ecosystem services and have been indicated as useful ecological indicators, largely due to the diversity of species with different range of behavior and habitat. Some species are important biological control agents, particularly those from subfamily Syrphinae, whose larvae prey essentially on soft-bodied Hemiptera, although they may include also, on their diet, other insects such as Lepidoptera, Coleoptera, Neuroptera, other Diptera, Acari and Thysanoptera; on the other hand, the larva of the subfamily Eristalinae includes feeding modes as diverse as phytophagy, saprophagy, mycophagy and predation. In addition, adults of syrphids are flower visitors, where they look for food (pollen and nectar), having an important role in the pollination. In this work, developed under the project EcoVitis " Maximizing ecosystem services in Douro Demarcated Region vineyards" it was intended to study the composition of hoverfly communities in vineyards, as well as their fluctuation thought the growing season. The insects were monitored between April and December 2013 using white sticky traps that were checked weekly. On the basis of the collected sample 11 species from two subfamilies, Syrphinae and Eristalinae were identified. Syrphinae was the most abundant, being represented by nine species and totalizing 97.7% of the captures. *Sphaerophoria scripta* (Linnaeus 1758), *Eupeodes corolla* (Fabricius 1794), *Melanostoma scalare* (Fabricius 1794) and *Episyrphus balteatus* (De Geer 1776) were the most abundant species, representing almost 88% of the total captures. Two periods of activity were observed. The first period occurred during the spring, between the beginning of April and the end of June, coinciding with the period of spring floral abundance and blooming of spontaneous plants; the captures in this period represented about 72.8% of the total. The second period started in the middle of October and held until the end of sampling. Eristalinae only was captured in the autumn, between the end of October and the middle of November. The abundance of syrphids was higher at the end of May, while the richness was higher in the begging of November, when eight different species were captured. The Syrphidae family is an important functional group of arthropoda that in vineyards might play a role as a potential predator of grapevine pests, such as the grapevine mealybug, *Planococcus ficus* and the European grapevine moth, *Lobesia botrana.* Additionally, within Ecovitis project, it can give information about the impact of some practices of habitat conservation that are being implemented, playing a role as bioindicators.

WHICH IS THE ROLE OF NON-CROP HABITATS ON BIODIVERSITY OF GROUND-DWELLING SPIDERS IN VINEYARDS OF DOURO DEMARCATED REGION, PORTUGAL?

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Spiders are generalist predators that play a key role on the biological control of arthropod pests. Due to their ability to feed on a wide range of preys they can remain in the crop, even with low density of pest population; moreover, they can move from other nearby habitats and prevent pest outbreaks, early in the season, when specialized natural enemies are not yet available. Under the project EcoVitis "Maximizing ecosystem services in Douro Demarcated Region (DDR) vineyards" it was intended to demonstrate that biodiversity conservation, through the maintenance or/ and implementation of surrounding natural vegetation can result in benefits to winegrowers by enhancing conservation biological control of arthropod pests. The specific objective of this work was to study the composition of ground-dwelling spider communities in vineyards from DDR as well as to evaluate the influence of an adjacent area of natural (woodland) or semi-natural vegetation (abandoned almond grove) in the crop colonization by spiders through the season. With this objective, spiders were monitored in five vineyards, between April and October 2013 using pitfall traps. Monitoring was done along three transects in three different distances (5, 50 and 100 m) from the natural vegetation area, during three periods: mid-April to mid-June, mid-June to mid-August and mid-August to end of September. The collected sample allowed the identification of 19 families and 41 genera, from which 43 species were identified. The most abundant families were Zodariidae (25.8%), Gnaphosidae (21.5%), Lycosidae (10.8%), Thomisidae (8.9%) and Agelenidae (6.8%). For species, the most abundant were *Zodarion styliferum* (18.6%) followed by *Alopecosa albofasciata* (4.6%), *Tegenaria feminea* (3.9%) and *Xysticus bufo* (3.1%). Two species (*T. feminea* and *Z. styliferum)* were present in all farms, suggesting that they are well adapted to the region; conversely about 47% occurred in only in one of the farms. The relative abundance of 71.4% of the taxa was lower than 1%. While, there were no significant differences between farms in the richness and diversity of spiders, their abundance was significantly different. Although, apparently, in the early period, the abundance and diversity of spiders tended to be higher in 5 m than in both 50 and 100 m distance, these differences were not statistically significant. Likewise, while these indices were apparently higher

inside the vineyard during the vegetative cycle (middle and late periods of sampling) the differences were not statistically significant. These results could be related to the fact that the soil of all vineyards was covered with natural vegetation, mowed during the spring and summer but whose residues were maintained in the soil. These could represent, himself, a habitat for ground-dwelling spiders, that does not need to move to other places.

ENHANCING THE SOIL FOOD WEB TO HELP CONTROL SOIL DWELLING PESTS OF FIELD VEGETABLES

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With changing EU legislation and consumer pressure leading to a reduction in the use of pesticides, new sustainable solutions are urgently needed to control the effects of field vegetable pests. Evidence suggests that soils with long and complex food webs, with more trophic links and more abundant predatory fauna, can effectively suppress plant pathogenic organisms. The project aim is to test this hypothesis for the damaging Brassica pest *Delia radicum* (cabbage root fly, CabRF) at two established fully factorial field trials, in Kinsealy (Ireland) and Newcastle (UK). At both sites the soil food web will be quantified over at least a two year period and key soil parameters also determined. The abundance of entomopathogenic fungi, nematodes, predators and parasitoids will be specifically monitored and abundance and damage from CabRF will be assessed on site. First growing season data in Kinsealy indicates that agronomic practices such as soil fertility and crop protection treatments, as well as variety choice, clearly influence soil biology and impact the target pest at different life stages. Soil respiration is affected by crop protection methods, with soils sampled from organic crop protection plots (OP) respiring more than soils from the conventional crop protection (CP) soils (on log scale, CP=1.39±0.039, OP=1.46±0.035, F=13.44, p=0.035). Soil fertility treatments affect nematode community composition, as organically fertilised soil communities are less disturbed than the conventionally fertilised (maturity index OS=1.66±0.16, CS=1.27±0.15, p<0.001). This constitutes the first indication of agronomic practices having an impact on the soil food web in this study. Field monitoring data show that at the beginning of the season more eggs can be found in the organically fertilised plots (OS=8.53±0.78 eggs per 40mL soil sample, CS=5.05±0.56 eggs per 40mL soil sample, F=27.11, p<0.001), however the 2nd generation egg count seems to be more affected by the type of crop protection used than the soil fertility treatments (OP=9.01±0.72, CP=12.21±0.87, F=12.55, p<0.001), hinting at possibly different influences of practices over the growing season . Pupae count and feeding damage at the end of the 1st generation are mainly influenced by protection treatments, but crop variety choice also matters. Invertebrate activity and parasitism data are being analysed to determine possible impacts of those practices on natural enemies. Detailed laboratory experiments will consequently be designed to determine the effects of different soil food web complexity on the cabbage root fly egg laying, growth and development in soils taken from field sites. Experimental results, together with input from growers to better understand the interactions between soil and pest, could lead to enhanced control field conditions.

LANDSCAPE AND CROP COMPOSITION TO PROMOTE GENERALIST PREDATORS IN AN ARABLE SYSTEM

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It is well known that landscape composition and structure effect biodiversity including important functional groups in managed lands. Many studies highlight the positive relationship between landscape complexity and ecosystem services agents such as natural enemies. Semi-natural habitat has been considered the main determinant of complexity in agricultural landscapes. However, this approach frequently does not consider different types of semi-natural habitat while also omitting any consideration of the crops being grown, neglecting possible monoculture/polyculture effects. As a response, this study aimed to reveal detail elements of the landscape composition that favour generalist predators and to distinguish the most important drivers amongst them.

To test this, pitfall traps were placed in the margin and within the crop of 40 fields in the east of Scotland to sample the population of three main groups of generalist predators (Carabidae, Araneae and Staphylinidae). To assess the relative importance of landscape composition, we used a multi-model analysis approach taking into consideration local, boundary and landscape characteristics. Landscape composition was characterized in three ways and at several scales (500 m to 5 km radius), from a simple differentiation of habitat structure (arable, semi-natural, woodland) to more detailed characterisations, one differentiating the most abundant semi-natural and woodland types and the other directed to describe more precisely the arable land by the most common crops considering their differences on management intensity, ecological functionality and habitat structure.

In this study we found that landscape composition has a significant effect on population of predators, and in some cases was of greater importance than local variables. As a general trend, our results show that the generalist predators considered respond positively to broadleaf woodland and heath, and mainly at larger scales. The response to crop composition tended to be less consistent between the different groups, although a significant effect of crop composition was found for each group. We also found different responses to local and landscape variables between margin and crop populations, suggesting that they may respond to different drivers.

These findings add to our understanding of the influence of the agricultural landscape on important ecosystem services agents of the cropping systems, contributing to the assessment and development of the land management policies.

AGBIOSCAPE: COMPUTER SIMULATION SOFTWARE FOR MODELLING THE DYNAMICS OF POPULATIONS IN FARMED LANDSCAPES

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The movement and dispersal of organisms across farmland exposes them to a range of habitats within the agricultural landscape. The effect of this is on natural populations is demonstrable with a wide range of taxa including weeds, insects showing responses in both diversity and abundance to a variety of landscape characteristics. Though empirical studies have been important in demonstrating landscape scale effects and have even begun to unravel some the underlying mechanisms, appropriate modelling strategies have a number of important advantages. These include:

- Addressing spatial and temporal scale beyond the practical limits of any empirical study.
- Addressing a wide range of landscapes, cropping systems, and taxa.
- Simulation of novel landscapes and landscape management strategies for which no examples currently exist.
- Addressing complex multi-trophic systems.
- Provide results within a short-time frame.

With these benefits in mind we have developed AgBioscape, computer simulation software designed for the implementation of spatially explicit population models within farmed landscapes.

The AgBioscape modelling system couples discrete time population models with an explicit representation of the farmed landscape using two primary software modules: the landscape mosaic generator and population process module.

The land use mosaic generator works by continually subdividing a 2-d space to produce a network of rectangular land parcels, the size, shape and clustering of which can be controlled. After generating a mosaic of fields, a series of land uses is assigned to each, allowing users to specify how the landscape changes over time in response to crop rotation or other land use changes.

The population process module uses a matrix population model approach to simulate the population dynamics of each local population. Local populations are arranged spatially on regular grids, one grid for each species being modelled, which are overlaid on the land use mosaic. Each grid-cell holds a numerical vector representing the stage structure of a local population, while transition matrices are used to specify the demographic changes in stage structure that occur over time as a function of intra- and inter-specific interactions, as well as the prevailing habitat and environmental conditions that are derived from the land use mosaic.

Dispersal between local populations is modelled empirically using dispersal kernels. These can be extended to represent complex dispersal processes by combining kernels, either in single or multi-stage dispersal events, or by the inclusion of attraction or repulsion responses to represent active dispersal.

The development of several models in AgBioscape has confirmed the utility of this approach and shown it to be capable of representing a wide range of pests, crops and landscapes.