Integrated pest management on strawberry production in hanging gardens in Sologne (France)

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INTEGRATED PEST MANAGEMENT ON STRAWBERRY PRODUCTION IN HANGING GARDENS IN SOLOGNE (FRANCE)

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INTEGRATED PEST MANAGEMENT ON STRAWBERRY PRODUCTION IN HANGING GARDENS IN SOLOGNE (FRANCE)

PROTECTION BIOLOGIQUE INTEGREE SUR LA CULTURE DE FRAISERS EN JARDINS SUSPENDUS EN SOLOGNE (FRANCE)

Key-words : Strawberry production, Integrated pest management, Biological control by introduction and conservation of beneficial agents, stakeholders co-working

Mots clés: Production de fraises en jardins suspendus, Protection biologique intégrée, Lutte biologique par introduction et conservation d'auxiliaires, Collaboration entre acteurs

Résumé:
Dans le contexte actuel, l'utilisation des produits phytosanitaires doit être limitée. De multiples acteurs élaborent des innovations techniques pour atteindre ce but. En Sologne, la station expérimentale 'Légumes Centres Action' travaille en collaboration avec les producteurs de fraises pour mettre en place des stratégies de Protection Biologiques Intégrées (PBI) adaptées au contexte local pour lutter contre les ravageurs. Ce projet s'est orienté sur des techniques de PBI par introduction d'auxiliaires du commerce et par conservation d'auxiliaires naturels associés à des produits phytosanitaires compatibles. Afin d'évaluer les stratégies mises en place, des suivis de populations de ravageurs et d'auxiliaires ont été réalisés pendant 5 mois sur quatre parcelles de fraises de variétés remontantes produites en jardins suspendus. Les résultats 2011 ont permis de mettre en évidence que ces stratégies doivent être adaptées à l'échelle de l'exploitation et même à l'échelle de la parcelle. D'un autre côté, un suivi plus précis a été réalisé pour mettre en avant l'impact d'éléments paysagers sur les populations de ravageurs et d'auxiliaires. De nombreux facteurs entrent en jeux dans la réussite d'une stratégie de protection biologique intégrée : facteurs de production, facteurs environnementaux, facteurs climatiques ainsi que les facteurs humains et économiques. Dans certains cas la PBI par introduction et conservation d'auxiliaires ne semble pas être suffisante (apparition de ravageurs secondaires, non installation des auxiliaires apportés, résistance de ravageurs aux produits phytosanitaires), et devrait être associés à d'autres méthodes de luttes alternatives. L'utilisation de filets 'insecte-proof', de plaques colorées collantes, de plantes pièges ou d'extrait de plantes sont des techniques qui sembleraient être intéressantes à intégrer dans la gestion des ravageurs en fraiseraies pour répondre aux nouveaux problèmes rencontrés.

Abstract:
Actually, chemical uses must be reduced. Stakeholders are elaborating innovative techniques. In Sologne, the 'Légumes Centre Actions' experimental station is working together with the producers to set up Integrated Pest Management (IPM) strategies to control pest adapted to the local context. This project is using IPM techniques by introduction or conservation of beneficial agents associated with compatible chemicals. Pest and beneficial agent populations were monitored during five months on 4 ever-bearing strawberry plots cultivated in 'hanging gardens' to evaluate IPM strategies efficiency. 2011 results show that strategies have to be adapted at the farm level and even at the plot level. In addition, impact of landscape elements on pest and beneficial agents were highlighted. Multi-factors interact on IPM strategies success: production, environmental, climatic, human and economical factors. Sometimes IPM by introduction and conservation of beneficial agents is not sufficient (secondary pest, non installation of beneficial agents releases, pest resistance) and should be associated to other alternative methods. Insect proof net, coloured sticky cards, trapped plants or plant extracts seems to be interesting techniques to manage strawberry pest in a sustainable way.

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Abbreviations

BC: Biological control

Ctifl: Centre Technique Interprofessionnel des Fruits et Légumes (French technical center of Fruits and Vegetables)

Ha: Hectare

IOBC: International Organisation of Biological Control

IPM: Integrated Pest Management

Kg: Kilogram

LCA: Légumes Centre Actions

m: meter

m²: square meter

ml: meter long

mm: millimetre

Introduction

Since the green revolution, farming and food systems evolved toward intensified systems. From the agronomical point of view farming systems are mainly based on monoculture crops and on lots of inputs like fertilizers and chemicals. From the ecological point of view, those agricultural practices have broken natural equilibriums (pests occurs and beneficial insect decreases), and exhausted natural resources (groundwater, soil fertility). From the social point of view, links between producers and consumers were broken by commercialisation distances. Producers are less and less independent in their choices, because lots of firm advisors are implicated in their production techniques. In such systems based on inputs production costs are very. Today lots of stakeholders of the farming and food system have a higher interest to improve situations toward more sustainable systems. My master thesis project is a case study around the strawberry production in Sologne area to improve the production techniques from the ecological point of view.

Strawberries are very sensitive fruits and are hard to preserve. Visual and gustative qualities are constraints that producer has to take into account every day. Even more in specialized production systems, pests and diseases occur and are commonly managed by chemicals.
Consumers are more and more concerned by their food quality, their health and the environment. In order to answer to consumer and media pressures, different agricultural stakeholders set up objectives to improve practices. The “Ecophyto 2018” plan is working in this direction. The main objective is to reduce by two the uses of chemicals in agricultural systems before 2018. Producers want to develop new techniques to answer to pest management issues.
Different stakeholders in Sologne are working together in order to set up alternative methods to control the main pests occurring in strawberry plants. The ‘Légumes Centre Actions’ experimental station and producers are working together on integrated pest management. However, the main aim of the producers is still to produce strawberries with a very good visual aspect at a moderate cost.

Firstly, the strawberry production context will be clarified the set up the purpose of the study. Then integrated pest management (IPM) and ecological principals will be developed to understand the technical topics. Next, methods used to set up and monitor strategies by introduction and by conservation of beneficial agents will be presented. The four main pests occurring in strawberry production are *Thrips sp., Tetranychid mite sp., Aphid sp.* and *Lygus sp.*

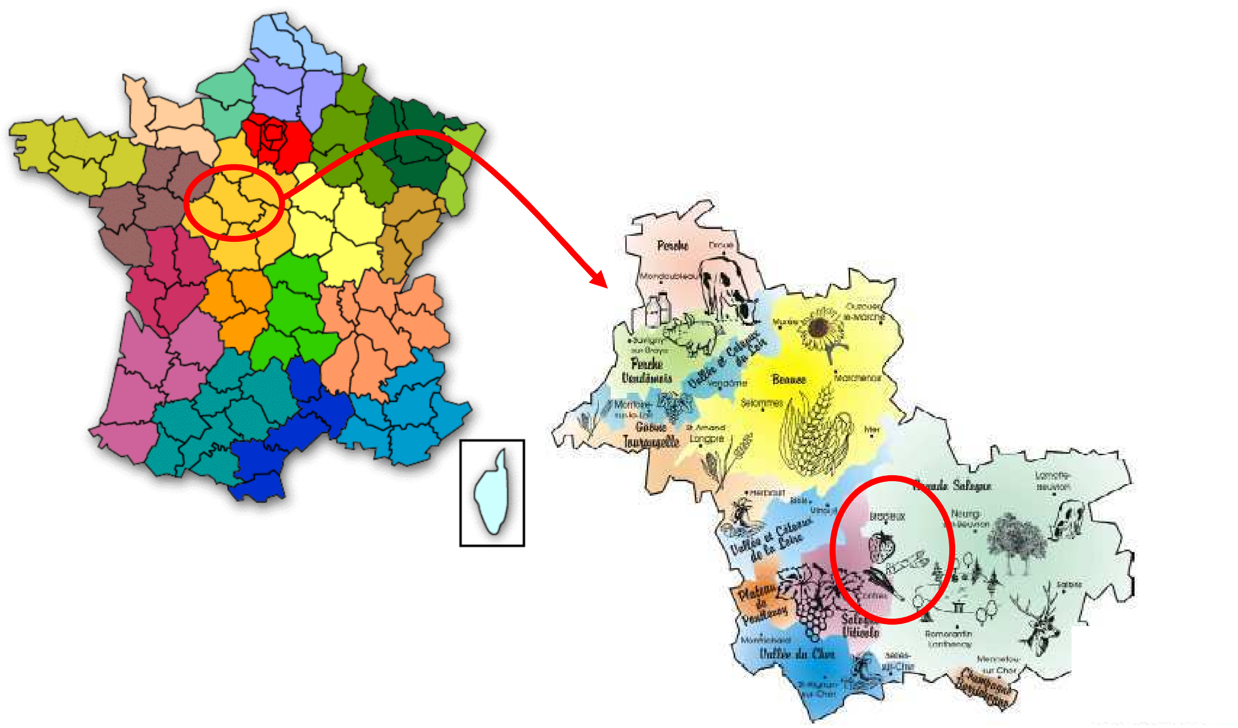
Therefore, each pest will be presented one after the other as well as beneficial insects that are part of their control. A synthesis of the previous trials at the LCA experimental station as well as the results of 2011 monitoring will enable us to set up strategies by introduction. The main factors influencing success or failure of IPM by introduction of beneficial agents will be highlighted. Then other methods including landscape elements as part of biological control method by conservation will be studied. Finally, propositions will be made to control pest in a long term objective.

1. Strawberry production system in the Sologne area

1.1. Presentation of the Sologne area

The “Loir-et-Cher” is one department of the “Centre” region and have a diversity of production.. It is divided in small territories, which are specialized in one or two agricultural productions. The Sologne area is one of them, and is located in south of the “Loire” river. This area is close to the “Chateaux de la Loire”. (Figure 1: Location of the Sologne area in France) It is flat and composed of lots of artificial ponds, which have been constructed in order to purify the marsh area. The soil is composed of clay and sand. Climate has a continental influence. It is characterized by late frost (until may) and spring and summer drought. Rainfall level is of about 600 to 750 mm per year. (CRPF, 2005) The agricultural production is nearly exclusively composed of strawberry, leek and asparagus productions. The Sologne area is known in France wide as one of the best French strawberry and asparagus production areas. The hunting activity is part of the dynamic of the area. There are lots of private hunting forests.

This year, the weather was characterized by a very warm month of may and a cold and wet summer.



(Sources http://www.gissol.fr/partenaire/partenaires_regionaux.php (left map) / http://www.loir-et-cher.chambagri.fr/documents/regions_productions.pdf (right map))

Figure 1: Location of the Sologne area in France

1.2. Strawberry production stakeholders in Sologne

1.2.1. Experimental station: "Légumes Centre Actions"

The experimental station "Légumes Centre Actions (LCA)" is specialized in fruit and vegetable experiments for the "Centre" region. This structure is a society which has about fourteen partners, included three "Chambres d'Agriculture" of three departments (Loir-et-Cher, Loiret, Eure-et-Loir), "Ctifl" and producer associations. "Chambre d'Agriculture" is the French organism which is the link between the farmers and the politicians. The "Ctifl" (Centre Technique Interprofessionnel des Fruits et Légumes) is a national organism which makes experiments on fruits and vegetables. The LCA is composed of three experimental stations: Tour-en-Sologne, Orleans and Saint-Denis-en-Val (close to Orleans).

The Tour-en-Sologne station, where I was, is constituted of 4 hectares, and of 3 000 m² of greenhouse and protected production areas (tunnels). Today the team is composed of 7 full time employees at the station. A station manager supervises the team, and is also responsible for the vegetable section at the "Chambre d'Agriculture". There are also 3 experimenters and 2 advisors. The production manager is like a farmer. He is in charge of the production job and manages the seasonal workers. The intern students are working with and for the experimenters.

Experiments are focused on strawberries, raspberries, leeks, asparagus, courgettes, onions and potatoes. Researchers are working on different topics: optimisation of irrigation, variety potential from quantity and quality point of view, fertilisation optimisation, chemical effectiveness, and integrated pest management strategies adapted to the local context. Strawberry is one of the main productions of the station. Some experiments are lead on each of the topics presented above. My project is included in the last topic. They started to work on integrated pest management on strawberries 10 years ago.

One of the objectives of the station is to link more closely experiments and advices. A part of the experiments is realized at the station and another part is realized on farmers' plots, depending of the topics. The experiments are adapted to producer needs. The project that I focus on was conducted in producers' plots. It was a monitoring of how IPM strategies are lead in different situations. The objective is to adapt some strategies in real case situations. It is more interesting to conduct them by farmers' plots and not only at the station. As the environmental contexts of farms are different, it gives different examples. My project is an action-research project. The producers are fully included in the development of the strategy.

1.2.2. Strawberry producers

Strawberry production in Sologne area started in between the two world-wars. Today in Sologne, there are about 35 strawberry farmers. 25 of them produce only strawberry in soil, and 10 of them produce mainly in hanging garden structures (Figure 2: strawberry plants in hanging garden structures) which represent 21 hectares. I choose the term ‘Hanging garden’, because hydroponic and soilless production did not seem to be appropriate to this production. The first producer started to make strawberry in hanging garden structures in the 1990th, but it did not work, because there was not enough technical knowledge around it at this time. This production system rose mainly since 2000. The main reason is that the soil is exhausted. There is no rotation. The soil is exhausted. In this context, they wanted to create a more productive system. It costs more because the whole system is based on inputs, but it produces more! Another minor reason, which is used to make this system nicer, is that seasonal worker conditions are better. The fruits are at their shoulder level, they do not need to be kneeled all day long. I asked the LCA strawberry advisor for those information.

Figure 2: Strawberry plants in hanging garden

1.2.3. Strawberry commercialization: “Cadran de Sologne”

Producers had created 30 years ago, a kind of cooperative called ‘Cadran de Sologne”. All the producers bring their strawberries daily in the pick season (in may) and three times a week in summer and autumn. 3 000 T of strawberries are produced in Sologne in one year. The mean price is about 3 € per kilogram, it can vary from 6 € to less than 2 € per kilogram. Producers bring different batches and they are sold independently. Every day or every two days, there is a market. Strawberries are sold by auction; it starts at the highest price and then decreases. About fourteen big buyers participate to the auction market, and distribute the strawberries to supermarkets all over France, and in other European countries. Producers and buyers are all grouped in the same room. And a man talks and presents the different batches and the price start to decrease on a screen. Buyers stop when they agree with the price. The producers are satisfied by this way of selling their production. They do not need to find some buyers, but they do not control the price at all. The price depends of the european strawberry market, of the season and of the fruit quality. If there is a high demand and if the production is low the price is high. The "Cadran de Sologne" is a very important stakeholder for the strawberry production in Sologne.

1.3. Strawberry production

Strawberries as lots of other fruits and vegetables are very sensitive and perishable. It needs to be stocked in cold area. The time between the picking and the selling has to be as short as possible. The consumers are very strict with the visual and the gustative quality. The strawberries need to be nice and to have a good taste (not to acid, not to sweet).

There are lots of elements to take into consideration, in order to produce strawberries, as the consumers like them. The whole strawberry system is going to be presented in order to underline the elements that characterized the project. The main elements that we are interesting on for later are going to be presented more in detail, the others one are going to be quote.

1.3.1. Hanging garden production

Strawberry production that we are interested with are hanging garden production in tunnels, every elements of the production are based on inputs. (Figure 3: Strawberry production system in Sologne) The strawberry can also be produced in the soil and Plants are bought in a nursery which is located in Sologne or somewhere else in Europe. They are planted in some substratum which can be compost or coconut fibres, which are also by to some firms. An irrigation system needs to be built up in order to bring water and fertilizer to feed plants and enable them to produce fruits. In greenhouse structure, the temperature and the humidity are automatically led by computer. Some constrains are determined by producer in order to manage the opening of the doors and the number of irrigation. In other structure, the producer has to manage him self.

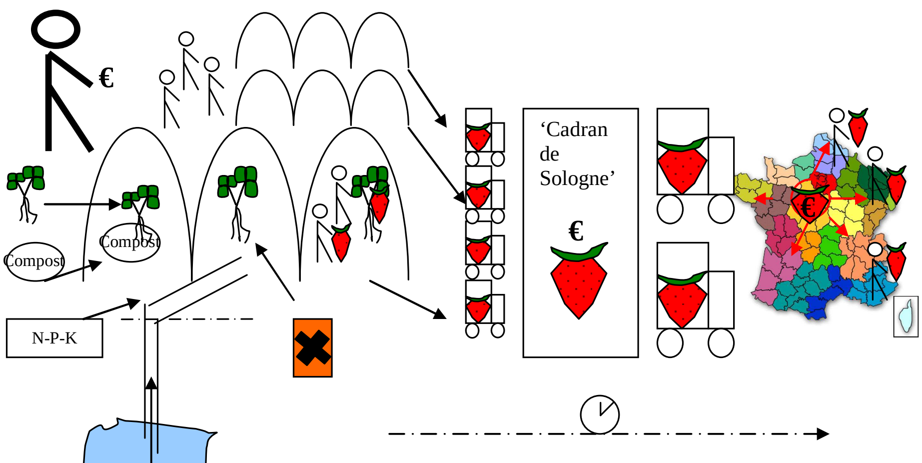


Figure 3: Strawberry production system in Sologne

One ever-bearing strawberry plant produces in mean 0,6 kg of strawberries in the season. Production cost in strawberry produce in hanging garden are of 2,6 €/kg or 10,92 €/m². The mean prize for ever-bearing strawberry is of 3 €/kg or 12,6 €/m². The mean profit is of 0,4 €/kg or 1,68 €/m².(Figure 4: Strawberry economical references) A pesticide application cost between 0,005 and 0,015 €/m².

	Yields (kg)	Production costs (€)	Selling prices (€)	Profits (€)
1 plant	0,6			
1kg		2,6	3	0,4
1 m² (7 plants)	4,2	10,92	12,6	1,68
5 000 m²	21000	54600	63000	8400

Figure 4: Strawberry economical references

1.3.2. Strawberry varieties

Strawberry varieties can be divided in three groups. (Figure 5: Comparison of the three different varieties of strawberry production) Some of them are called short-day varieties, which mean that they produce early in spring during two months in april and may. They are planted either in the middle of the summer (august) or at the beginning of a new year (January). They do not care if the days are shorts, to grow up. They do not produce later on in the summer. Most of the time, in hanging garden system, those short-day varieties are dug up at the end of may and some new plants which are ever-bearing strawberries are going to be counter-planted at the beginning of june. The second varieties which are the same as the counter-planted ones are ever-bearing strawberries. Those one are planted between january and march. They produce from may until october. They are flowering many times during one production season. The picking is done twice or three time a week, in order to have nice fruit. Some seasonal workers are hired for picking the fruits and for taking care of the plants. (They plant, they cut the stolons and the old leaves,…)

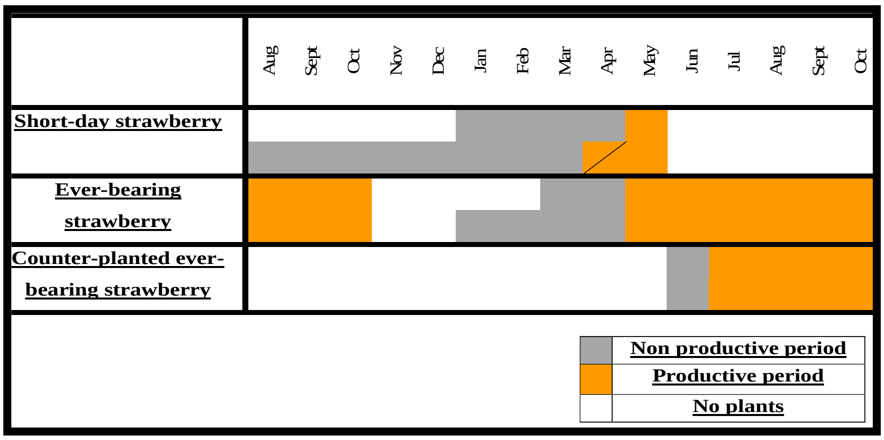


Figure 5: Comparison of the three varieties of strawberry production

1.3.3. Pest management strategies

In such intensive system, diseases and pests currently occur on plants. Three main pest species in the strawberry production: *Thrips sp.*, *Tetranychid sp.* and *Aphid sp.* are known. Some secondary ones appear in some plots led with IPM strategies: *Lygus sp.*, ... Most of the time chemicals used to combat the main pests also kill the secondary ones. But today there is more and more interest for alternative methods to improve agricultural production issues. Limits of available chemicals, consumers demand, media pressure and more knowledge are reasons to be interested in integrated pest management.

First of all, there is a reduction of active molecules, which means fewer chemicals are available to control pest species. And regulations of chemical uses are more and more restricted and adapted to each molecule: time before going into tunnels and prescribed time before harvest. There are also high risks that pests become resistant to chemicals, because they were not used correctly. (Van-Driesche and Bellow, 1996; Dubon, 2011) Constrains of pesticide applications are stricter in particular under tunnel toward the workers, and because of high temperature. The producers do not like to treat. Secondly, the pressure of the media about chemicals is very strong. The consumers ask for more healthy food and use of techniques which respects the environment. (Dubon, 2011)

During the last year there is more interest on biological control methods and more knowledge about how to use it are available. Integrated pest management is included in national political objectives about chemical uses in the future. (Dubon, 2011) Different stakeholders of the French agriculture system commit to respect and to reach the “Ecophyto 2018” plan. The general objective of this plan is to use 50% less pesticides in 2018 than they were used in 2008. (http://agriculture.gouv.fr/ecophyto-2018)

2. Integrated pest management

Agricultural system is a simplification of the natural system. With this simplification, equilibrium between insects is broken. The biological control concept is to reach again those equilibriums by anthropics methods. (Suty, 2010)

2.1. IPM definitions

The Integrated Pest Management (IPM) is defined by the International Organisation of Biological Control (IOBC) as the combination of different methods, which can be use to control pests. They need to be ecologically, economically and toxicologically satisfying. The priority is to use natural method in order to limit pest development and to respect the level of tolerance that producers accepted towards damages. Producers' level of tolerance is overtaken; when he feels that the risk for his harvest or the cost of the alternative method may exceed the earning price. Biological control is not always sufficient, and it is sometime necessary to combine it to a chemical control. Integrated methods need to be taken into consideration within the space and the time. Resistance developed by pests toward chemicals can also be developed towards beneficial insect species. Those methods are part of the "natural selection" of species: the more resistant survived by adaptation. The combination of different methods reduces the chance of species adaptations on one method. **No control method is perfect, but the combination of imperfect methods can be perfect.** (Pintureau, 2009)

2.2. Biological control

Biological control (BC) "is the use of parasitoid, predator, pathogen, antagonist or competitor population to suppress a pest population, making it less abundant and thus less damaging than it would otherwise be. […] BC may be the result of purposeful actions by man or may be results from the unassisted action of the natural forces." (Van-Driesche and Bellow, 1996)
Biological control can be defined as the use of living organisms or their products in order to combat some organisms that are considered as pest species. There are two categories, one using beneficial insect species and the second which use their products. (Pintureau, 2009) In this project biological control method will be mainly associated to beneficial insect specie uses.

2.2.1. Beneficial agents

Beneficial agents can be defined as organisms that help to maintain pest species at a low level by its way of life. They use the pest species to feed them or to reproduce (Suty, 2010). Two kinds of agents can be distinguished: microorganism and enthomophagus species. The term beneficial agent will be used when we talk about insects and mites, whereas beneficial insects only include insect species. All the pest and beneficial agents will be presented in more detail further on.

The objective of using microorganisms like virus, bacteria or fungi is to create some illness to the undesirable species, and eliminate them. (Pintureau, 2009)

The enthomophagus species can be divided in two types (Figure 6: two types of Aphid beneficial insects)

Predator species hunt preys to eat or to feed their larva. One stage or all stages are predacious, depending on species. Predators that we are most interested on are Ladybug, Staphylin, Chrysope, Bug, Aphidoletes, Syrphe….(Suty, 2010)

The parasitoid species are insects or nematodes that during at least one stage of their development take place inside or in contact to another insect called host species. The parasitoid species is smaller than its host; they caused the death of the host individual. Each larva uses one host, but one female can lay on one or more individuals. Aphidius and Aphilinus species are Aphids parasitoids, we will talk about them later. (Suty, 2010)

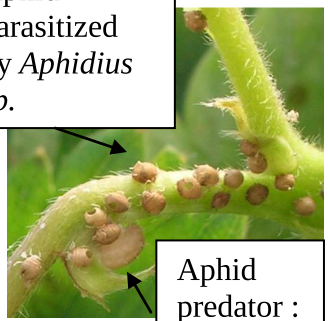


Figure 6: Two types of Aphid beneficial insects

2.2.2. Different methods of biological control

Biological control methods working with beneficial agent species can be divided in four categories:

- Conservation method is based on the preservation of beneficial indigenous species. The objective is to maintain habitats for over-wintering, for feeding natural enemy population when pests are not present, and to create favourable reproduction area by using environmental elements around the crop production area. They can be non-cultivated area such as hedgerow or cultivated area such as flowered crops. (Van-Driesche and Bellow, 1996)
- Inoculation release is used when indigenous natural enemies seem to be too restricted to control pest. The objective is to increase those indigenous populations by making some releases usually limited during to the spring period. (Van-Driesche and Bellow, 1996; Pintureau, 2009)
- Inundation release is based on massive release of populations which are not necessarily indigenous. This method can be considered as a biological treatment, because individual quantities applied are very big and application frequencies are very high. It is used when the pest insect is very difficult to be controlled. Some bio-fabrics reproduce those beneficial insects in big quantity and commercialize them. (Van-Driesche and Bellow, 1996; Pintureau, 2009)
- Acclimation method is based on introduction of new natural enemies in order to fight against new invasive pest species. Those species are coming from another geographical area. Pest species were introduced accidentally in a new area.

(Pintureau, 2009) The conditions of establishment are studied so that the objective is to install them for a long term period. Those populations need to be well studies in order to know the perfect quantities, the safety, and their impact on other organisms. (Van-Driesche and Bellow, 1996)

- We will use the term IPM by introduction, which the last three methods.

2.2.3. Difficulties to work with living organisms

Introduction method costs are high and not always effectiveness. As we work with living organisms, many factors influence their capacity to leave and to reproduce in a new environment: transport condition and storage before the implementation (temperature and time), release conditions (temperature, wind, humidity), and the global environment of the production plots.

2.2.4. Some ecological concepts about dynamic of populations

It is not that easy to work with beneficial agents, it is important to aware of some basic concepts of dynamic of population.

2.2.4.1. Food chain

Food chain is based on a linear succession of trophic species. It starts with plants (strawberry plants) called producers are getting their energy from the sun, from organic and mineral components. Those elements become accessible thanks to the decomposers work. Herbivorous species (pest species) eat plants. Carnivore I (predator species) only eat herbivorous species, whereas carnivore II (predator species) also called super-carnivore eat carnivorous species. (Suty, 2010) (Figure 7: Food chain including strawberry-pest-predator)

Food web is a complex food chain, which include multiple consumers interacting in the same habitat. This concept is difficult to take into consideration in biological control methods.

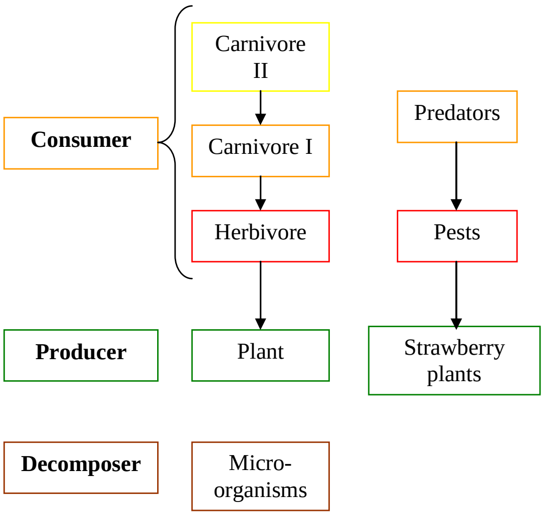
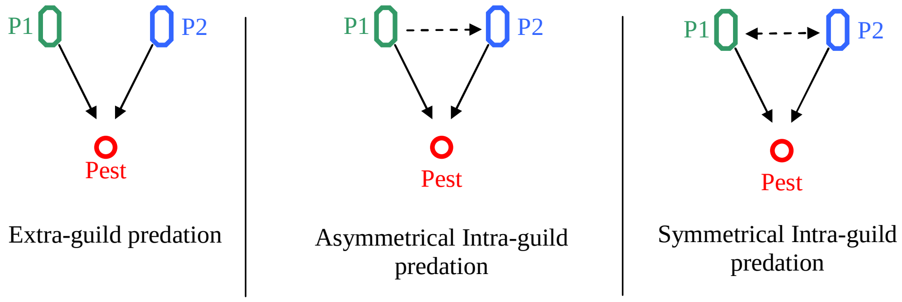


Figure 7: Food chain including strawberry-pest-predator

2.2.4.2. Intra-guild predation

To simplify this phenomenon, the term predation use in this part takes into account predators and parasitoids. The intra-guild predation concept is important to be aware of, because relationship between pest and beneficial agents are not linear. In one hand, extra-guild predation is for example, two different predators (P1 and P2) that eat the same prey. (Figure 8: Representation of different types of predation systems) The intra-guild predation is a more complex system. In addition to the extra-guild system, the intra-guild predation takes into account that one of the two predators (P1) of a pest could be the predator of the second predator (P2).



Adapted from (Suty, 2010)

Figure 8: Representation of different types of predation systems

We can speak of asymmetrical intra-guild predation when the predation is only in one side and of symmetrical intra guild predation when the predation is mutual. This means that if one predator is introduced whereas the second one is indigenous, the effect of the introduced one will not been observable. And the predation by P1 is no more sufficient to control the pest. This phenomenon has to be known to set an IPM program. (Suty, 2010)

2.3. Different methods that use products or components of beneficial insects

Other methods of biological control can be used; they are not based on beneficial insects. (Pintureau, 2009)

- Extract of plant can control some pest species, because of their toxicity.
- Varietal or genetic control consists in selecting the most resistant plants to a pest species. The first method selects the varieties and the second one inserts genes from another species to the plant genome to defence himself some defence against pests.
- Sexual confusion is based on saturating the area with pest species pheromones. This method interferes with the couple meeting and fecundation.

- Autocid control consists on introducing not fecund individual into the pest species, so the population will degenerate within the generation.

2.4. Use of pesticides

Pesticides destroy organism by using synthetic molecules to eliminate pest species. This technique has a negative impact on human health, on environment and on insect biodiversity. In order to combine biological and chemical methods, it is important to use pesticides in a sustainable way: to use it when it is really needed, without exceeding the stated doses. Chemicals should be choosing as the most specific for the aimed pest, the less toxic for the environment and the one with the shortest persistence. (Pintureau, 2009)

2.5. Prophylactic methods

Prophylactic methods consist on limiting pest arrival in a crop. They are mainly based on physical methods. Create harmful climatic conditions under tunnels to killed insect populations (high temperature or high humidity). Insect proof net and trap coloured sticky cards can be used to limit and to prevent outside infestations. (Pintureau, 2009)

3. Problematic

Politicians, consumers and producers share the same aim for decreasing chemical uses. Restrictions on chemical uses and constrains of utilisation are more and more strict. As tunnels create a closed environment, these restrictions are especially pointed out. Resistance phenomena of pests against chemicals appear in Sologne area. Then, producers feel more and more concerned about new pest management systems.

On one hand the LCA station have been working for 10 years on integrated pest management by introduction and conservation of beneficial insects. An objective of this experimental station is to use innovative methods and to make them accessible to producers. Years after years, experimenters by their trials accumulate knowledge and references linked to different conditions of production: weather and practices. (Figure 9: Stakeholder needs, base of my project)

On the other hand strawberry production in Sologne is a highly specialized system. Most of the Sologne producers manage pest issues by using chemicals. However, some producers started to use integrated pest management by introduction and conservation on their plots but they have difficulties to get successful results with these alternative methods.

Training are offered by the "Chambre d'Agriculture" and organised by the LCA station aim to increase awareness and knowledge of producers around IPM topics. Producers do not have the same knowledge and sensibility about this topic. Trainings enable them to recognise and to learn more about beneficial insect species. In addition to this training, producers using already this method would like to go further. So, they asked the LCA strawberry experimenter to work with them to set up methods adapted to the local context of Sologne.

As integrated pest management is the association of different methods used to manage pests, the main objectives today are biological control methods associated with compatible chemicals. A longer term aim could be to manage pests with biological control methods, by introduction or by conservation of beneficial agents and with other non-chemical techniques.

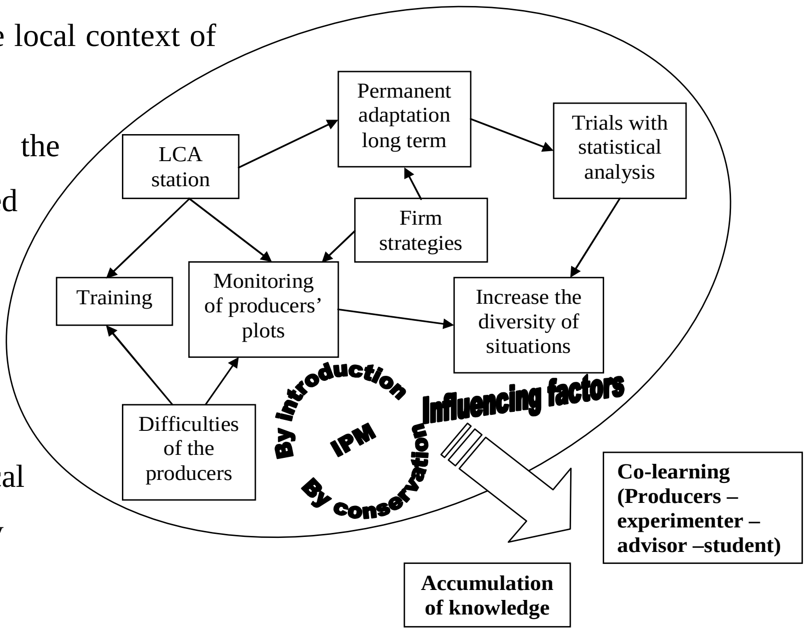


Figure 9: Stakholder needs, base of my project

The aim of my master thesis was to set up adapted strategies to the local context. As my work placement lasted over 6 months, we decided to make IPM on ever-bearing strawberry produced in hanging gardens, which start to produce at the end of march and stop in october. The objectives of my project could be divided in two parts.

On one hand the objective is to set up some IPM strategies on ever-bearing strawberries produced in hanging garden for each pest species, by introducing beneficial insect species. IPM strategies were set up with two firms that commercialize beneficial insect species. Four plots were monitored, one at the station and three on producer plots, in order to compare strategies in four situations. Strategies are based on IPM by introduction of beneficial agents: evolution of pest and beneficial agent populations were monitored during four to five months. **Can the introduction of beneficial insects solve all the problems? Which factors influence the success of IPM strategies? What are the perspectives on IPM for the next years?**

On the other hand, we would like to evaluate the impact of the landscape elements on conservation of indigenous beneficial insects to manage strawberry pests. Landscape elements such as edges are habitats for natural enemies of pests. **How do those beneficial insects on those landscape elements can move towards strawberry plants in hanging gardens? Are grass strips under strawberry plants efficient to fight pest species?** This was implemented by an experiment on the LCA station.

Finally different stakeholders are working together with producers to elaborate innovative methods and allow them to be more independent from firm advisors. **How this technical project is included in an action-research project, where different stakeholders are part of innovative techniques?**

4. Material and method

In this part I will present the different steps of the project. It is divided on two parts, the first one is based on IPM by introduction strategies and the second one is based on IPM by conservation.

4.1. Set up IPM strategy on ever-bearing strawberries in hanging garden structure

4.1.1. Synthesis of previous monitoring led at the station

First of all, a synthesis of the different experiments was realized for each pest. As it was impossible to characterize strategies, the main evolution points are presented. Not enough detail around factor that influences failure or success. I choose to take into account evolution of pest population after beneficial insect introduction, pest intensity at the end of the season and strategy cost. As IPM is the combination of beneficial insects and of chemicals, sometime it is difficult to say which action were successful. As each year strategies and weather conditions are different, there were not much information in the report, it was difficult to interpret. But I succeed to highlight the general evolution of strategies throughout the years. And some elements helped to set up future strategies. Another limit of this part is that IPM strategy on strawberry has most of the time been lead on short-day strawberry or on counter-planted ever-bearing strawberry. Those productions are shorter than the one we are interested with, but it still give us some elements that we were not sure this year. They strengthen the conclusions of this year.

4.1.2. Plots monitoring in 2011

The analysis of the previous year strategies has been realized while the strategy of this year was already set up. I manage to stand out previous strategies, when I experience it by my selves and I made some readings.

4.1.2.1. Presentation of the four plots monitored

The situation of the four plots is different, beside the fact that it is ever-bearing strawberry plants cultivated on hanging garden structure. (Figure 10: Characteristics of the four plots monitored) The variety of strawberries is different in one producer plot. The plot leads by the producers are bigger than the one at the station. The date of plantation is different from one plot to another (from January to march). Moreover producer 2 planted 5 tunnels every 2 weeks. So, the plantation spread on one month and a half. Tunnel doors are managed differently. In two plots, tunnels are never closed. The two others use their doors. One has an automatically system, that manage the doors according to temperature, humidity, and wind orientation. The other one opens and closes the door manually, when the temperature is low and when the wind is strong. The age of compost bags are also different. The plot environments are different from one plot to the other: presence of landscape elements, or cultivated crops closed to strawberry plots. At the station and the producer 2 have less than 2 ha of strawberry, whereas the two others have more than 3 ha. IPM strategies by the producers are set up by a Koppert advisor, a company that produce and commercialized beneficial insects. IPM strategies are conducted against *Thrips sp.* and *Tetranychid mites sp.*. At the station, it is Syngenta Bioline that commercialized beneficial insects. Strategies were set up against *Aphid sp., Thrips sp.* and *Tetranychid mite sp.* Lots of factors are different from one plot to the other. Even if strategies are similar, situations are different. Some other like fertilization, irrigation and action on plant (cut old leaves, cut stolon,…) have not been compared.

	Producer 1	**Producer 2**	**Producer 3**	**LCA station**
Ever-bearing strawberry variety	Charlotte	Charlotte	Anabelle	Mainly Charlotte
Size of the plot lead with IPM strategy (m²)	3 600	5 000	3 600	630
Plantation period	Beginning of march	Between beginning of february until the end of march	End of january	Middle of march
Age of compost bags	2nd year	1st and 2nd year	3rd year	1st year
Door management	Not used	Manual	Automatic	No doors
Other productions close to the plot	Cereals	Leeks	/	Cereals, courgettes, leeks, asparagus, potatoes
Landscape elements close to the plot	Hedgerow, follow, sylvan pine forest	Forest	Fallow and hedgerow but far away	Natural grass-strip, young hedgerow, and in one part clover-strip under hanging gardens
IPM strategy for	Thrips and Tetranychid mites (Koppert)	Thrips and Tetranychid mites (Koppert)	Thrips and Tetranychid mites (Koppert)	Aphids, Thrips and Tetranychid mites (Syngenta)

Figure 10: Characteristics of the four plots monitored

4.1.2.2.Monitoring method

During my stay in LCA, I monitor insect population evolutions in time on different kind of strawberry plots: short-day, counter-planted and ever-bearing strawberries. All of them were produce on hanging gardens. I will direct my results only around ever-bearing strawberries.

Four plots of ever-bearing strawberry were monitored weekly, in order to follow pest and beneficial agent population evolutions. In each plot, thirty plants were observed each time. They were chosen at random. This mode of sampling was set up nationally by a working group composed of experimenters working on IPM strategies on strawberries. By the producer, we choose the LCA experimenter and me to follow 10 plants in three tunnels, because lots of tunnels were managing with IPM strategies. I always looked at the same tunnels to see an evolution of pest and beneficial insects within the time. At the station, I look at 4 to 5 plants in each tunnel, because tunnels were fewer and smaller. The following observations were realized on each plant. (Figure 11: IPM monitoring methods on strawberry plants). Two leaves are observed with a hand-lens. *Aphid sp*. and *Tetranychid mite sp.* were observed on the underside leaves and notated with a class system. (Class 0: when there is no individual, class 1: between 1 and 3 individuals, class 2: between 4 and 10, class 3: between 11 and 30, class 4: between 31 and 100, class 5: between 101 and 300, class 6: more than 300). The number beneficial insect individuals by species are counted. Then the heart and a floral stalk are observed to determine the presence of *Aphid sp*. and of beneficial insects. Then a flower is shook to count the number of thrips in it.

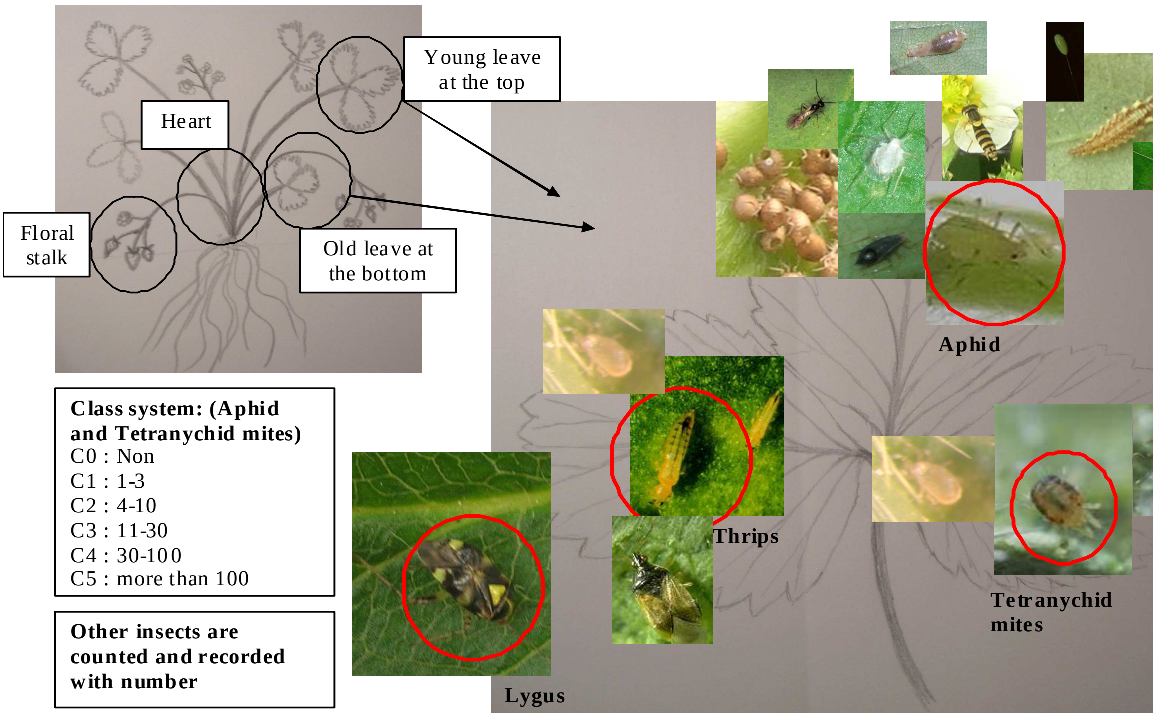


Figure 11: IPM monitoring methods on strawberry plants

As ever-bearing strawberry flowering is cyclic, I counted the number of mature flowers present on the plant that I observed. This is realized in order to calculate the number of thrips per m²: (Thrips /m² = (x thrips / 10 flowers observed) * ((number of mature flowers / 10 plants) * (number of plants / m²)).

To present the results I did not took into account the class: density of pest, % of plants occupied by the plants are already sufficient to highlight the main interesting point. Graphs are explained in Appendix 1. **This appendix needs to be kept open for all the report.**

In addition to those observations, some *Aphid sp.* and *Thrips sp*. are sampled and identified by specialists. The aim of *Aphids sp.* identification is to adapt parasitoid releases to *Aphid species*. They are sent to the INRA of Rennes for identification. The *Thrips sp.* was for the first year identified in order to see if species are the same in the different plots and to know their damages. They are determined for at the plant health laboratory in Montpellier.

4.1.2.3. Additional monitoring

On a plot, *Lygus sp.* presence limited of the IPM success. The general monitoring method does not take into account the *Lygus sp.*. When a producer observed the first *Lygus sp.* on his plot, we decided to make an additional observation from june to august on each plot. 90 plants are shook over a yellow bowl, the falling Lygus are counted.

In another plot, an additional trial was realized in order to evaluate blue sticky card potentiality, on thrips population. Sticky cards are used to detect and to catch insects. The yellow and the blue are used to attract thrips, whereas the yellow ones also catch beneficial insects. They are used at a density of 1 card per 100 m², in order to detect the first thrips and their evolution.

Blue sticky-cards are hung in three tunnels at a density of four cards per 100 square meters (12 blue sticky cards / tunnel). The cards have liquid glue on each side; they are 20 cm large and 25 cm long. This card density was recommended by Koppert commercial advisor, when used as a control method. The middle tunnel was monitored weekly, as well as one without blue sticky cards. I counted thrips number in 30 flowers per tunnel, and counted the flower number on 30 plants. In addition to those observations, I counted the thrips number caught in a week on one side of 4 sticky cards. Blues cards are changed every week in the monitored tunnel.

4.1.2.4. <u>Co-decision of IPM strategies by beneficial insect introduction</u>

A first meeting was organised in mid April to set up strategies by producers' for 2011. Producers, Koppert advisor, LCA experimenter and advisor and me were present. The LCA experimenter and me went and saw producer plots before this meeting. We did not want to take part firstly in the strategy decisions. Koppert advisor suggested his strategies without a first observation of the plots. Producers refused to use blue sticky cards. And they did not want a strategy against *Aphid sp.*. Within those constrains strategies against *Thrips sp.* and *Tetranychid mite sp.* were set up. Dates of beneficial insect implementations were choose. The first meetings with Koppert advisor on the plots were organised 3 weeks later, after the first implementation to see the population evolution. He came back three other times. Every week, I realized my monitoring. Producers came nearly every time during my monitoring to see the evolution of pest and beneficial insect populations. Then I updated the data, with the LCA experimenter and sometimes the LCA advisor. If needed, we predicted new treatments or beneficial insect releases, by setting them with Koppert advisor and with the producer concerned. Sometime the producer did not take the advices into account. During all the monitoring, elements were kept out to improve next year strategies.

For the station plot, the strategy was not set up in advance. I started my monitoring, each week a report with charts was sent to the Syngenta Bioline advisor. When pest populations started to rose up, she came and decided of which beneficial insects should be released and at which density. She decided according to pest and beneficial insect present at the moment and with the accord of the LCA experimenter. She came four times during the season.

4.1.3. Strategy in process with producers

All the different steps will enable us to set up a strategy by pest adapted to the local area. In addition to that I realized a technical support on the compatibility of chemicals with beneficial agents (Appendix 2). I compiled information from different sources, in order to create a table which can be easily used by the farmers. I presented 2011 results to the producers enrolled in the IPM training. This power-point makes reminds about pest characteristics, beneficial insects available to control this pest and 2011 results. Other methods are presented for the future to improve the failing points of IPM by introduction of beneficial agents. Those methods were discussed with the producers concerned by the monitoring, across all my visits. During this meeting we also made a point about what does the monitoring bring to them, if they want to go further on, what does it brings to the others.

4.2. Evaluate impacts of landscape elements on pest and beneficial insect species

The second topic of my project is to evaluate the impact of the landscape elements on the pests and beneficial insect species on strawberries. The monitoring has been realized at the station. The plot is composed of 7 tunnels of 20 meters long. The strawberries are produced on hanging garden under tunnels. There are 3 rows of strawberry plants in each tunnels and the density of plantation is 7 plants per m². One limit of this trial is that we are not going to observe only the indigenous enemies of pests, because it is on the same plot previously presented to set up the IPM strategy at the station. Some beneficial insects are released during the season.

4.2.1. Condition of the trial

Three types of landscape elements have been set up during the previous years: (Figure
Figure 12: Pictures of the different landscape elements)

At two meters beside the last tunnel, a hedgerow has been planted in 2008. It is composed of small trees and bushes.

At the end of the tunnels, there is a natural grass-strip. It is about three meters large.

Clover-strip under two tunnels is composed of clover (60%), of fescue (15%) and perennial ryegrass (25%). The sawing was realized last summer, with a density of 20 kg/ha. Strawberry plants are in hanging garden. Those two tunnels are the closest ones of the hedgerow. The ground under the five other tunnels is covered with a tarp: a woven dark sick fabric.

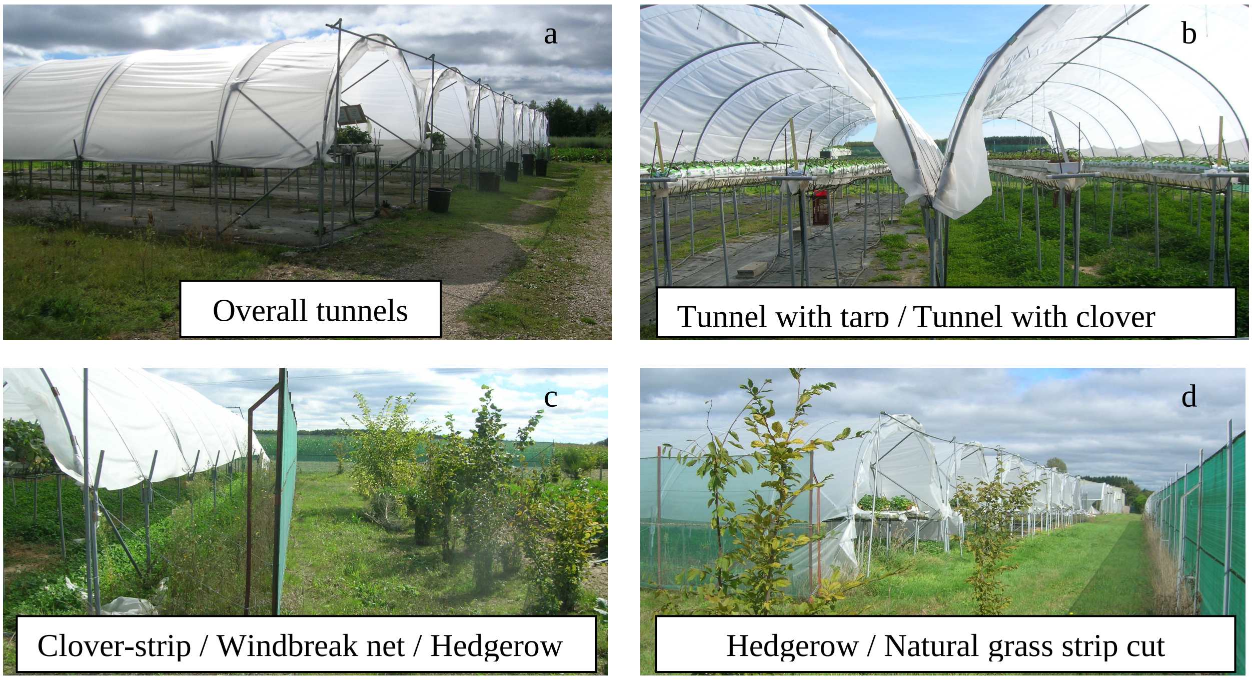


Figure 12: Pictures of the different landscape elements

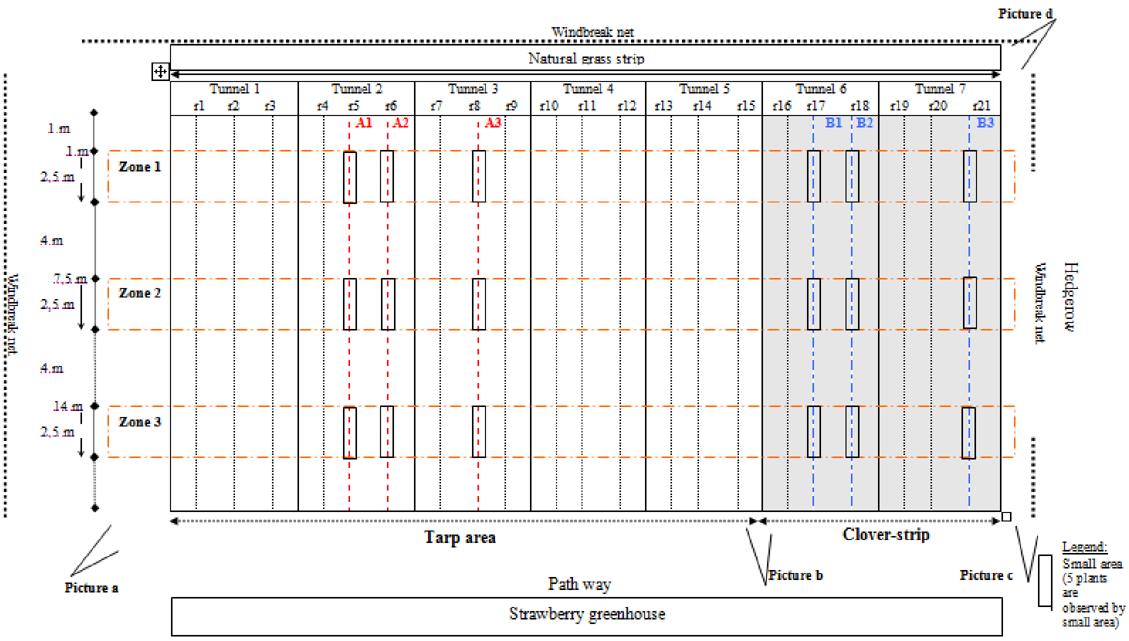


Figure 13: Trial plot plan

4.2.2. Experimental protocol

Last year these kinds of monitoring were already led, but the results were not significant. There were no repetitions. This year the objective is to lead the observation with repetitions in order to have more significant results. (Figure 12: Pictures of the different landscape elements and Figure 13: Trial plot plan)

In order to make a more significant targeting, I took ideas in the Ferré experiments working on the impact of beneficial flower-plants including on the cultivated-non-flower-plants. (Ferre, 2011)

Firstly, the objective is to see the influence of the ground structure. Two different ground structures will be compared:

Area A: tarp

Area B: clover-strip which can not be dissociated of the effect of the hedgerow because of its localization.

Secondly, the objective is to highlight the impact of the natural grass-strip at the end of the tunnels. The distance between the plants and the grass-strip could have an impact on pest and beneficial insect populations present on strawberry plants. We distinguished 3 zones, based on the distance to the natural grass-strip:

Zone 1: 1 m away from the natural grass-strip

Zone 2: 7,5 m away from the natural grass-strip

Zone 3: 14 m away from the natural grass-strip

When we combine those 2 factors, 6 small areas are obtained. Each small area will be repeated in three different rows to have a more significant monitoring and to eliminate the row factor influence. We finally obtain 18 small areas to observe. For example, the area A3-Z1 is in the tarp area and close to the natural grass-strip and it is the 3 third repetition of the small area. There are other trials on this plot about variety, substrate and plant care; we choose six rows that have the closest production management. The variety is Charlotte an ever-bearing strawberry, the compost-substratum comes from the same company, and the care of the plants is the lowest one, only the oldest leaves (nearly dead) are removed.

Those small areas are 2,5 meters long. There are 25 plants in each area. For each small area, 5 plants have been chosen with a random draw method, in order to follow the evolution of the insects and mites populations on always the same plants. They are marked with a piece of wool. This precaution eliminates the plant effect. It would be even better to take more than 5 plants, but it would not be feasible for the monitoring. The monitoring was realized weekly from the middle of march until the end of july. It took me between two and six hours weekly to monitor this plot. The lenght depends on pest and beneficial agent populations present on the strawberry plants. Pest and beneficial agent populations are examined on two leaves, the heart and the floral-stalk as presented on a previous part § 4.1.2.2.

In addition to this monitoring, I follow the insect and mite populations in the clover-strip. I took a square frame of 0,25 m². I counted the number of individual of each beneficial insect species that I observed inside the frame. And I counted the number of tetranychid mites on the underside of 10 clover leaves present in the frame. This has been carried out in the three zones characterized by the distance to the natural grass-strip. Those followed has been realized according to what was feasible.

4.2.3. Data processing

All the observations are registered on Excel® sheets by pest species, at each date of observation. For the beneficial insects they are entered independently and then number beneficial insects per pest is calculated. I calculated the mean between the results of the 5 plots.

Then some statistics are carried out in order to make obvious conclusions. First of all an ANOVA analysis with two factors is realized at each date and for each pest and group of beneficial agents by pest. The two factors taking into account are the ground structure factor and the distance to the natural grass-strip factor. The combination of the two factors is also made by the analysis. The combination of these analysis and of some chart, distinguished the evolution of the pest populations in different periods. I will present the main results.

5. Set up IPM strategies adapted to the local context of Sologne

There are three main pests on hanging garden production in Sologne: Thrips, Tetranychid mites, and Aphids. Lygus, Aleurodes, Cicadelles and Anthonomes are secondary pests. Results are oriented on the three main pests and also on Lygus. First of all, the pest will be presented as well as its beneficial agents. It is important to better know pest species characteristics to control them. (Greer and Diver, 2000) Secondly, IPM strategy evolutions at the station will be highlighted. Thirdly, 2011 results will be presented in details; plot by plot. Finally a comparison of the four situations will enable us to conclude on IPM strategies adapted to situations. Other solutions will be quoted to associate to IPM strategies when necessary. A global approach of IPM on strawberries will be presented in the last part.

5.1. Thrips management by insect introductions

The *Thrips sp.* is one of the most difficult pests to control under tunnels. They cause important damages that have a strong repercussion on the quality of the fruits, and indirectly on strawberry selling price. (Jones *et al.*, 2005)

5.1.1. Thrips characteristics

Thrips sp. is parts of the Thripidae family. Those 2 mm long insects have a very short life cycle. There are between 8 and 15 generations per year. Climate conditions under tunnels are favourable to their development. They like to go in very tiny place. (Greer and Diver, 2000) This insect, like lots of other insects, can reproduce themselves by parthenogenesis, which means that a female alone can induce eggs without fecundation. Thrips life cycle is composed of 6 stages. (Figure 14: Thrips life cycle) Eggs are laid in leave cells or inside flower cells. The two first larva stages are fulfilled close to the lay area. Then larva falls in the soil to realize the nymph stage.

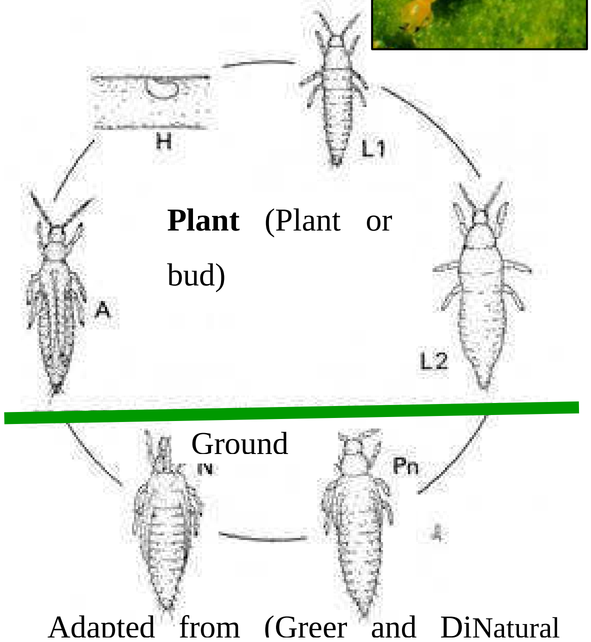


Figure 14: Thrips life cycle

In hanging garden, this stage can happen in substratum bags or under leaves. It is mainly larva stages that induce damages. *Thrips sp.* spends the winter 20 centimetres depth in the soil. Adults come back when the temperature become higher in spring (mean day temperature of 12°C). (Greer and Diver, 2000) Thrips are very difficult to control because they like to go in tiny areas and their life cycle is very short. (Stracey and Fellowes, 2002) The three main Thrips species occurring in Sologne strawberry plants are *Frankliniella occidentalis*, *Frankliniella intonsa* and *Thrips major.*

Larva and adults feed on flowers and leaves. They suck flower cells during flower mature stage, which caused damage on fruits. Fruits become tarnish. When the attack is even more severe, fruits are also deformed (Cloyd, 2009). Damages might be caused before flower opening (Murai, 2000). They can also induce viruses on some plants like tomatoes. No viruses are known yet on strawberry plants. IPM tolerance levels defined by Koppert and Syngenta are 1 thrips per flower or 20 thrips per m².

Some factors influence thrips development. Warm and dry weather are favourable to thrips proliferation. Wind is their way of transport; they have very small wings, so they are just bared by wind. That is the reason why the producers speak about thrips flights. (Greer and Diver, 2000) Pollen presence increases egg production and adult life duration. (Murai, 2000) Optimal conditions of thrips development are 55% of relative humidity and 22 °C. When the temperature increases, thrips life cycle is shorter.

5.1.2. Thrips beneficial agents

There are three mains agents that are sold by commercial firms to control thrips in strawberry production plots. A fourth one can be find naturally in the field, in spring and at the beginning of the summer.

5.1.2.1. Orius sp.

Orius sp. is a small bug. Larva and adult stages are thrips predators. They can be used against *Frankliniella occidentalis.* They fly and like to go in cultivated and non-cultivated plants. They do not have very specific habitat, they like cereals, sun-flowers, alfalfas and maize as host plants. (Veres *et al.*, 2010) They can eat between 5 and 20 thrips per day. The quantity implemented are between 0,8 and 1 Orius per m², repeated 2 or 3 times (2 weeks in between). When they do not have any prey, they can also eat pollen. The most commonly used in Europe is the *Orius leavigatus. (Lenteren, 2003)* They can be observable about 30 days after the release, when the second generation appears.

5.1.2.2. <u>Amblyseius cucumeris</u>

Amblyseius cucumeris is a mite, which is predator of thrips. They eat eggs and larva. (Lenteren, 2003) They can be applied in small bags, which are hanging in strawberries leaves, one every 2 linear meters. This can be renewable a second time. They can also be deposed on the plants, without a bag, and they will go directly in the flowers, and attack their prey. The relative humidity should not be too low (around 75%). The mean temperature should be around 12°C with some peaks at 20°C. They eat between 1 and 10 young thrips larva per day. They also eat some kind of mites. (Greer and Diver, 2000)

5.1.2.3. <u>Amblyseius swirskii</u>

Amblyseius swirskii has mainly the same characteristics than *Amblyseius cucumeris*. The different Amblyseius species can not be identified in the field, with a hand lens. Those Amblyseius also eat aleurode. (Malais and revensberg, 2008)

5.1.2.4. <u>Aeolothrips sp.</u>

Aeolothrips sp. is a white and black predacious thrips. They are indigenous natural enemies. Larva and female adults are predator. They are mainly present in may and june. Their predatory activity is not well known. There is between 3 and 4 generations per year. The life cycle last about 15 days in may and 20 in june. They have an important role in thrips management in association with other beneficial agents. (Conti, 2009)

5.1.3. Syntheses of IPM strategy trials at the station in the previous years

Most of the records show that biological methods work. There is lots of variation from one year to the others. The pressure of thrips were most of the time under 0,5 thrips by flowers, only some peaks were recorded at about 1,5 thrips by flower. The main trends over these 10 years can be highlighted. (LCA station internal reports)

For day neutral strawberries, only *Amblyseius sp.* were used in 2009 and 2010. Thrips pressure in the spring is low, the production is short. Beneficial insects have difficulties to set up, because the temperature is low. It is not very interesting to set up IPM strategies for day neutral varieties.

Until 2009, beneficial agent releases were realized only on counter-planted strawberries. During the first years, chemicals were included in the strategies. Before 2005, only Orius were used. Whereas most of the time, since 2005 some *Amblyseius cucumeris or swirskii* were associated with Orius. They are applied in small bags, one every two meters of strawberry plants. In 2008 and 2009 blue sticky cards were added to the strategy. All strategies were different form one another: number of Orius implemented, frequency and date of releases, association with other beneficial agents, use of blue sticky cards, and its density. Results analysis show that all strategies tested work. Cost of each strategy was. When 2 or 3 releases of Orius (2,2 and 0,8 individual per m^2 are implemented), the global cost of the strategy against thrips can raise up to 0,3 €/m^2 (Chemical costs are lower than 0,05 €/m^2 / Whereas benefits are 1,68€/m^2). The blue cards are cheaper (0,03 €/m^2). They have been introduced at 1 to 4 cards per 100 m^2.

5.1.4. 2011 results

IPM strategy by introduction to control thrips was the same for the 3 producers. 3 *Orius leavigatus* implementations and once of *Amblyseius swirskii* were released. (Figure 15: IPM strategy costs against thrips in producers' plots and at the station) But it was different at the station; some *Amblyseius cucumeris* were released as well as some *Orius leavigatus*. Situations and success on the four plots were very. Results will be presented from the best to the worst.

By producers		cost/m^2
27-apr	***Orius laevigatus*** **(1 ind/m^2)**	0,07
27-apr	***Amblyselius swirskii*** **(1 bag / 2m)**	0,1
12-may	***Orius laevigatus*** **(1 ind/m^2)**	0,07
27-may	***Orius laevigatus*** **(1 ind/m^2)**	0,07
Totale thrips		**0,31**

At the station		cost/m^2
12-may	***Orius leavigatus (0,8 ind/m^2)***	0,0538
12-may	***Amblyseius cucumeris (1 bag / 2 m)***	0,0504
28-may	***Orius leavigatus (0,8 ind/m^2)***	0,0538
17-june	*Success*	0,0080
1-july	***Amblyseius cucumeris (1 bag / 2 m)***	0,0504
1-july	***Amblyseius cucumeris (120 ind /m^2)***	0,0667
Totale thrips		**0,2831**

Figure 15: IPM strategy costs against thrips in producers' plots and at the station

5.1.4.1. Producer 2: a successful biological control program

The first graph (Figure 16: Producer 2: Evolution of Thrips population: comparison of the 3 tunnel cases) shows that thrips populations were different in each tunnel. The tunnel T18 was more attacked than the two others. The peak thrips population were of 4 thrips / flower, and higher than the tolerable level (represented with the doted line). This tunnel was planted one month later than the other ones. So the plant stages, when beneficial insects were released, were different. The quantity of pollen could be different and influence beneficial agent installations.

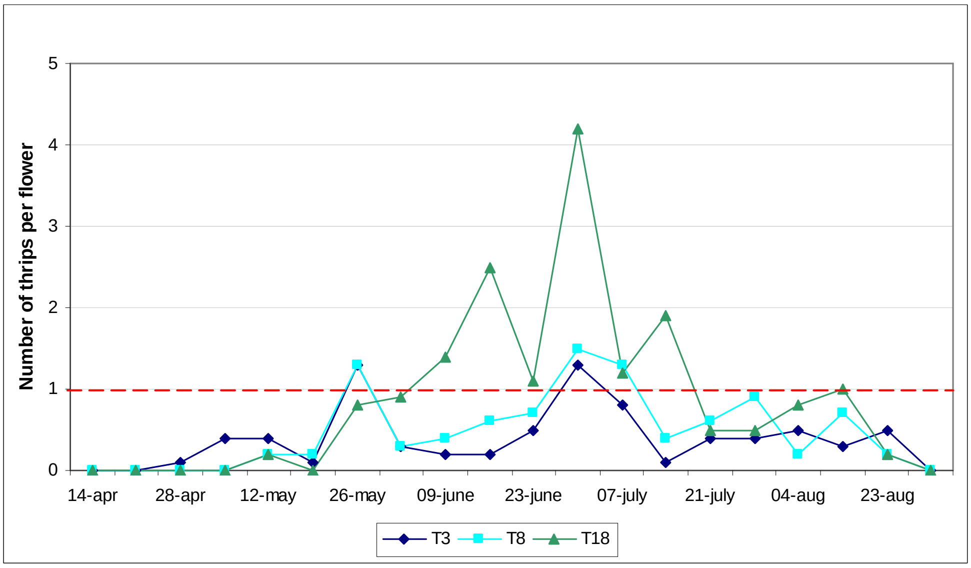
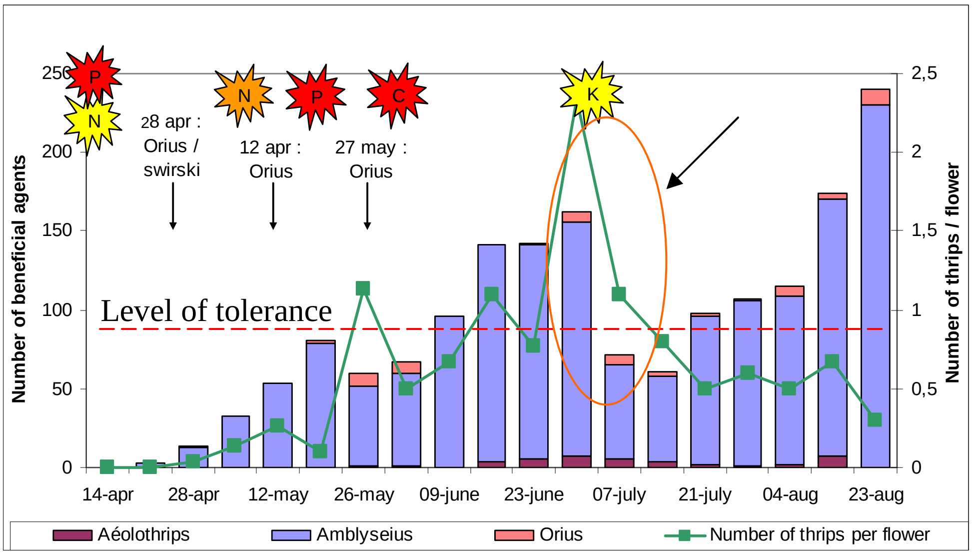


Figure 16: Producer 2: Evolution of Thrips population: comparison of the 3 tunnel cases

The second graph which is a mean of the 3 tunnels represents the number of thrips per flower, as well as the number of the three beneficial agents of thrips. (Figure 17: Producer 2: Evolution of the thrips and beneficial agent populations) It shows that the *Amblyseius* were found directly after their introduction. The first *Orius* were already found three weeks after the first introduction.



See appendix 1 : for the star legends

Figure 17: Producer 2: Evolution of the Thrips and beneficial agent populations

And we did not found any during 3 weeks just after the Calypso (C) application. This chemical is harmful to Orius, but it is the only Aphid pesticide usable during the harvest. The producer has to wait only three days before the next picking, whereas the one which is less toxic for the beneficial have to be used 15 days before the harvest. The Karathane (K) is an anti-odium chemical. According to the observations, we could have thought that the Karathane treatment had an impact on pest and beneficial insects. Thanks to its mode of action, we can say that it does not have a significant impact on insects. The brutal diminution by two of thrips populations could be link to the emergence of Orius at a high level at the beginning of july (1 Orius every two flowers, in the tunnel 18). No new releases were realized since the end of may. This could be related to a high level of Orius in the tunnels closed to the IPM one. The Orius could have flied from this plot when thrips populations increased in our tunnels. As the Amblyseius population also decreased, some other factors could have an impact. The temperature in july was lower than in may and june. Workers cleaned the strawberry plants: the old bottom leaves are removed and are left on the ground. Most of the time there were more pest and beneficial insects on the bottom leaves. The size of Orius and Amblyseius populations are not comparable. The thrips were maintained at a low level until the end of august. No productive damages were observed. The *Amblyseius swirskii* are not distinguishable from the *Amblyseius californicus*, with a hand lens. Thrips were sampled at the beginning of july and the thrips present on this plot were the *Thrips major* and the *Frankliniella intonsa.* We can conclude that the global strategy against thrips by the **producer 2** works well, the Amblyseius and Orius release are mainly part of this success, but other factors could have an impact.

5.1.4.2. At the station: a successful IPM strategy including chemicals

Like in the previous case, we had a thrips peak at 4 thrips per flower that were managed. (Figure 18: Station: Evolution of thrips and of their beneficial agent populations) Around the middle of may the first peak of thrips appears, but at the same time the first release of beneficial insects were implemented. The peak decreased by half at the beginning of the next week and then increased again.

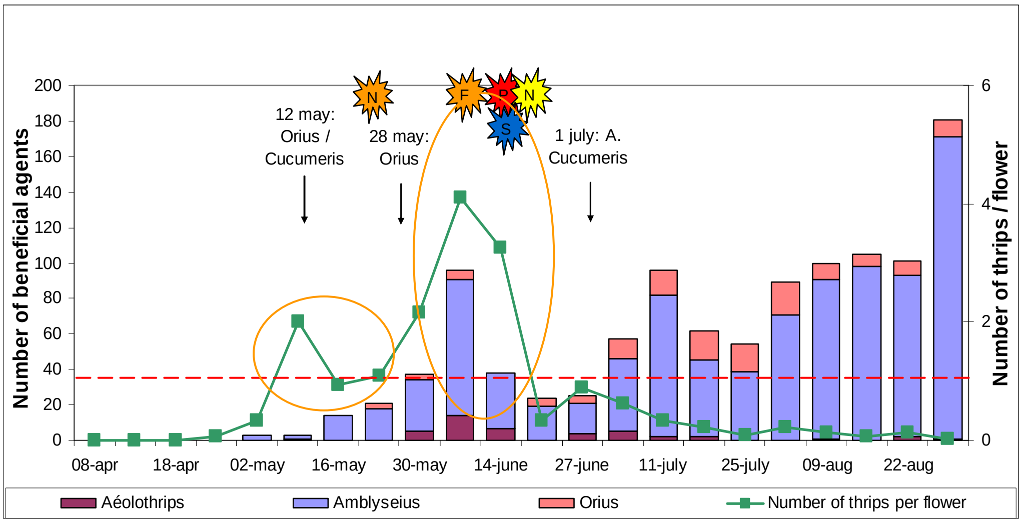


Figure 18: Station: Evolution of Thrips and of their beneficial agent populations

In the middle of june the firm advisor come and told us to treat because the thrips population was four times higher than the economical level of tolerance. The Success (S) is a harmful chemical for Orius larva and maybe for the *Amblyseius cucumeris*. In the middle of june many different chemicals were applied because of pest population explosions. Just before the Success, the population seemed to decrease a little bit. Just after the treatment, the thrips population fell down, with a small increase a week later. Some new *Amblyseius cucumeris* were implemented in two different ways: one like the other time and the second one in loose, to put down on the strawberry plants. This strategy maintained the populations at a low level until the end of august with very high populations of Orius and Amblyseius. Aeolothrips were quite numerous in the middle of the season; they might help to maintain thrips populations. The thrips identified at the beginning of july were the same as those of the producer 2: *Thrips major* and *Frankliniella intonsa*.. The thrips species before the treatment could have been different than the ones in july. And we could imagine that the last release of Amblyseius could have been realized earlier instead of the treatment. Would they have succeeded to manage the peak of thrips and keep the plot clean until the end of august?

5.1.4.3.<u>Producer 3: high population of thrips without damages</u>

There were some natural Orius in this plot, since mid april. (Figure 19: Producer 3: Evolution of thrips and their beneficial agent populations) Thrips populations stayed low until the middle of june. A Calypso (C) was used to control the Lygus, (this issue will be develop later on) and the Orius population was reduced by the chemical. Since this first application, thrips populations started to grow up. Amblyseius sp. set up very well (some peaks reach more than 10 Amblyseius on 2 leaves), but we did not know which species it was.

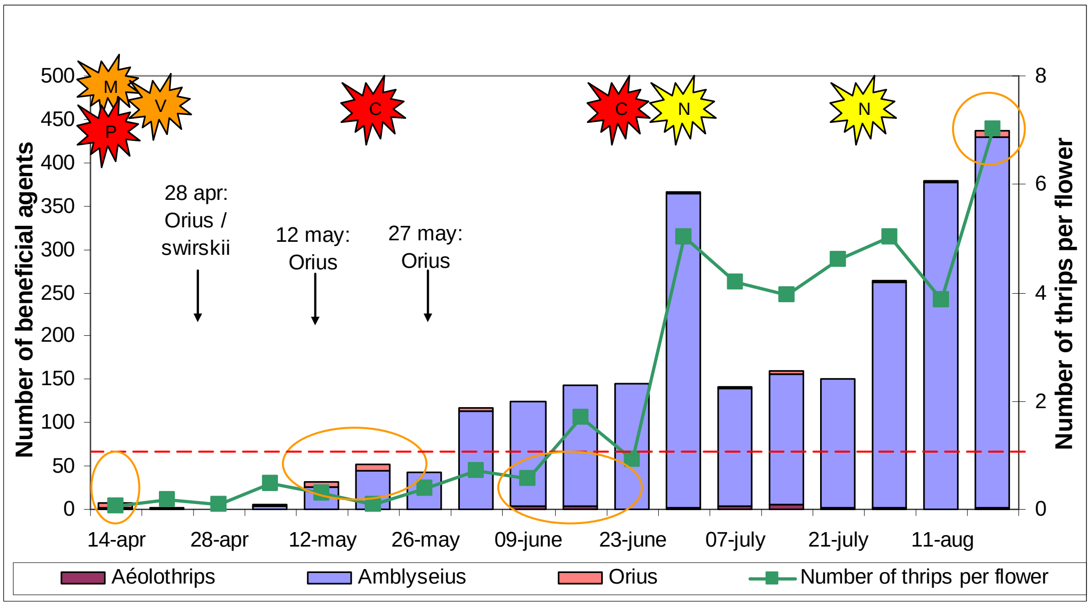
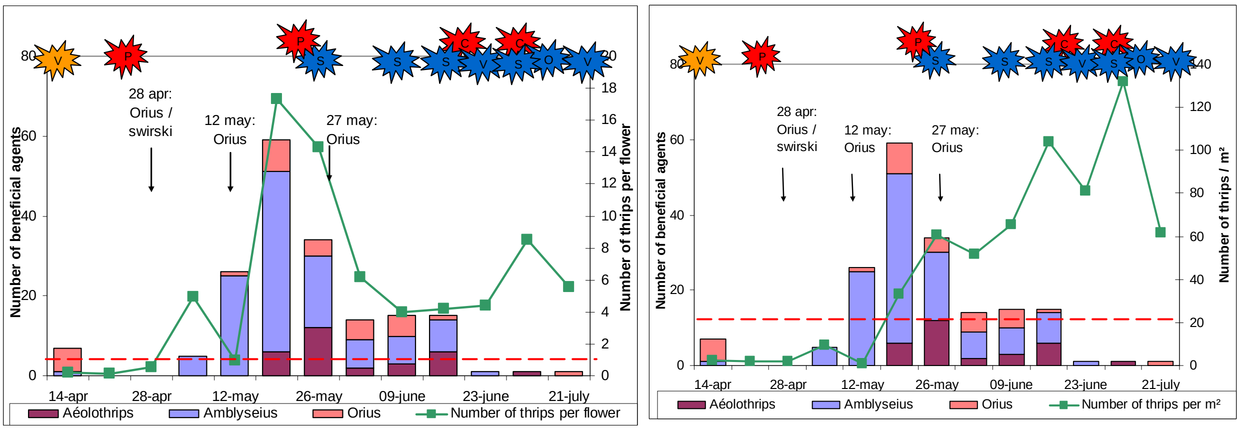


Figure 19: **Producer 3: Evolution of thrips and their beneficial agent populations**

In the beginning of july thrips population exploded from about one thrips per flowers to a mean of 5 thrips per flower in one week. This seems to be a flight. Then they stayed at this level during one month and a half. Some Orius and Aeolothrips were observed regularly. Amblyseius grew up with the time. No significant damages were recorded, according to the producer feeling. The thrips present on this field are the *Frankliniella occidentalis* and the *Frankliniella intonsa*. The Amblyseius seems to works, because they eat thrips larva. During the last observation the population grew up again. **One of the limits of the IPM strategy on his plot to fight against the thrips is the absence of beneficial insects available to control Lygus.** This point will be dig up later. Even if the number of thrips is high, there was ne economically damages. But the situation is risky.

5.1.4.4.Producer 1: failure of thrips management, with IPM and chemical strategies

The two graphs presented for the results of the strategy by the producer 1 are complementary. (Figure 20: Producer 1: Evolution of thrips and of their beneficial agent populations (two units)) For the beneficial insects it is the same whereas the thrips are presented into two different units. The first one is the same unit than the previous results (number of thrips per flower); it is more understandable by the producers. But the second one takes into account the number of flower per plant (number of thrips per m²).



Number of thrips / flower   Number of thrips / m²

Figure 20: Evolution of the thrips and their beneficial agent population (two units)

The first one shows that we had a big peak at the end of may, (20 thrips / flower), which is unbelievable. The Orius as well as the Amblyseius are present between the middle of may and the middle of june. And the producer told me that there was fewer thrips larva on the IPM tunnels than on the other ones. At the peak, we get afraid and the advisor advices him to treat with a Success. It works a little because thrips population dropped down to 6 thrips per flower and stayed at this level until the end of june. But if we look at the number of thrips per m², the thrips populations still goes up and stay high until the end of june. Strawberries started to be marked by the thrips and maybe the pollination was reduced due to the treatments. The highest issues were in july, lots of strawberries were not sold. The producer continued to treat, and there were no more beneficial insects visible. So we decided that the monitoring of this plot end up at the end of june. And we wanted to find the origin of such high populations, but we failed. Even the chemical method did not work.

For this plot it would have been interesting to monitor some tunnels with the IPM methods and some tunnels with a chemical method. I monitored at two dates in july IPM tunnels and conventional tunnels, and it appears that the IPM tunnel (6 thrips / flowers) has 3 times less thrips per flower than conventional ones (20 thrips / flower). This shows that IPM strategy has maybe not failed. We might have tried to go further and to release some new beneficial insects, and not to treat. But when I observed it on my data, it was too late. The thrips present on this field are the *Frankliniella occidentalis* and the *Frankliniella intonsa*.

We try to find some other methods; two of them have been tested: blue sticky cards and juice of garlic extract. At the beginning of july I installed blues sticky cards on 3 tunnels, in order to see their impacts. The producers do not like them, because they think that they are not easy to use and to install and that they fall down, because of the wind. They are installed at 4 cards per 100 m², at 30 cm up to the top of the strawberries plants.

We observed that in tunnels that have sticky cards, there were less thrips than in the other ones. (Figure 21: Producer 1: Evolution of thrips populations in tunnels with blues sticky cards and without them)

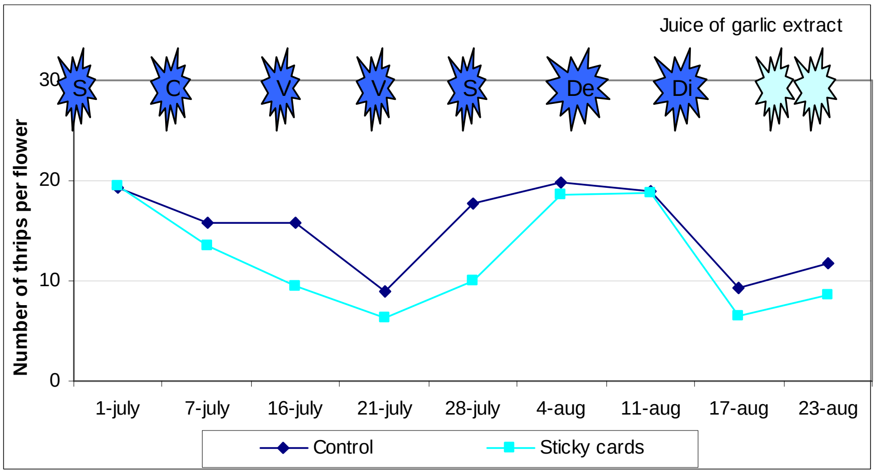
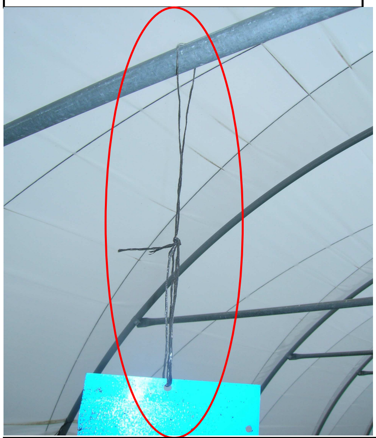


Figure 21: Producer 1: Evolution of thrips populations in tunnels with blues sticky cards and without them

But the producer did not see any difference on the fruit quality. This trial was too small to be significant. All his tunnels, which means between 2 and 4 hectares of strawberry are infested by thrips. (This producer is the biggest one of the four plots) The thrips are all over the farm, and the 3 tunnels with sticky cards are exposed to the thrips that come with the wind. The trial started too late, it would have been better to install them at the same times as the release of beneficial insects, when the population of thrips was smaller. During all the period of monitoring some chemicals against thrips has been applied every week, without any positive results. Any they could also have reduced the pollination. The thrips seems to have created resistances against the molecules used. The chemical was neither a solution.

The blues cards should be install just at the top of the strawberries plants. Producers do not like the blue sticky cards because the fall down due to the wind. I tied the cards with three different techniques: at the main structure of the tunnels with an iron piece, with binder-twine, and the last one to a chain that support the hanging garden with binder-twine. The two that were hung with binder-twine did not fall down, and the card perforated hole did not break. This method does not cost much, beside the labour cost. The cards can be hung at least for two months. (Figure 22: a blue sticky card after two months and a good hanging method)

A blue sticky card after 2 months



Best hanging metod

Figure 22: A blue sticky card after two months and a good hanging method

At the beginning of august, I call some other advisors on strawberry productions, a method using some juice of garlic extract is found. The garlic is known as an insect repulsive. This extract is pulverised likes a chemical on the strawberry plants. But there is not any restriction about it, and it does not give any bad taste to the strawberries. As he applied it before my last monitoring I could not see the impact, in the long term. This method is more a preventive method than a curative method.

5.1.4.5. Synthesis of the four plots monitored this year

In conclusion of the thrips monitoring this year, we can distinguish two mains groups based on success and failure of the strategy. At the station and for the producer 2, strategies worked. And the plot end up clean at the august end from the thrips point of view. A peak was managed with only beneficial insects, or with the help of a chemical. On those two plots the Thrips *Frankliniella occidentalis* were not present, whereas in the two others, they were. By the producer 3, thrips density was high, but there were no fruit damages. Maybe one treatment with a release of *Amblyseius cucumeris* would have been successful. In the last plot, it was unbelievable; it was the first time in the area that there was a such high thrips density per flower. An objective for the future is to limit the thrips arrival and set up. The high pressure of thrips could be kinked to the size of the strawberry farm, the two with high thrips pressure at the two biggest one of the monitoring. In such infested plot, other alternative methods need to be associated to beneficial agent introduction.

5.1.5. Strategies in process with the producers towards the future

Some literature elements will justify and complete observations in the field. And some other methods are presented in order to test them in this area in the future.

5.1.5.1. *Frankliniella occidentalis* and its resistance to the chemical molecules

Thrips pressure could be linked to the species of thrips present on the plot. At the station and by the producer 2 the pressure was lower than for the two other producers. One species (*Frankliniella intonsa*) was the same in the four plots. But in the first one there were the T*hrips major*, which is a not-very harmful thrips on protected cultures (Stracey and Fellowes, 2002) compared to the *Frankliniella occidentalis* This thrips is originated from the west-cost of the United-States that is why it's commonly called the californian thrips in France. It was introduced in Europe in the 1980. It is since considerate as a major pest of greenhouse cultures. (Stracey and Fellowes, 2002; Cloyd, 2009)

The Success which is a chemical that can be used against thrips, works well the first years of its authorization of use. But today some resistances are developed mainly by the *Frankliniella occidentalis*. This chemical is efficient on immature and adults thrips. It does not eliminate all the stages. (Murai, 2000) This product is not too toxic again the *Amblyseius cucumeris* and a little toxic against the *Orius*. It is better to wait a week after a treatment with Success, before introducing some *Orius* in a field. (Jones *et al.*, 2005) The chemicals are not always well used by the farmers, and the molecules become inefficient. The pests get used to the chemical. (Martin *et al.*, 2005)

The thrips and especially the *Frankliniella occidentalis* are known to develop easily some resistance against chemicals, because they high reproduction capacity (more than 10 generation per year / and short life cycle). Optimization of chemical uses is important in order to limit the risk of resistance. The failure of a treatment should not be automatically associated to the resistance phenomena. (Martin *et al.*, 2005) One key of the chemical thrips control is too treat early, when they are not too numerous. It is important to use different molecules of pesticides with different modes of action. This will increase the life of the products. The rotation of pesticide molecules should be used with a period of 3-4 weeks, the length of a life cycle. (Murai, 2000; Jones *et al.*, 2005; Martin *et al.*, 2005)

5.1.5.2. Efficiency of Orius in the area

The Orius present in july might come from the release, but they can also be indigenous. As we do not know where they come from, it could be interesting to conserve the indigenous one instead of introducing some, that cost a lot and which may not set up correctly.

The size of the strawberry farm could explain that we do not find them where we implemented them in a high quantity. As they flight they could have gone under other tunnels. 1 Orius / m² plan for 3 500 m² can not manage thrips population of 3 or more hectares, that is obvious. In order to see their real impact insect proof net could be installed.

Veres *et al. (2010)* noticed that cereals are host plants for Orius. (Veres *et al.*, 2010) This information can joint lots of remarks that I heard from different persons, the presence of cereal increase the presence of thrips. The producer that has lots of issues with thrips has more than 5 hectares of wheat close to the tunnels. The explanation might be that the thrips beneficial agents can not manage the cereal thrips of the cereals as well as the strawberry thrips at the same time. As we presented previously, the thrips are not the same in the two cultures according to our sampling, and specialists' determination. It may also explain that the Orius introduce in the tunnels have not been found after the release.

Producer 3 managed Lygus with pesticides which are harmful to Orius. Then if he can not stop pesticide uses, he should work with *Amblyseius sp*. to control his Thrips. *The Amblyseius cucumeris* have shown their efficiency associated with a Success treatment at the station. They are two times less expensive than the swirskii ones (*A. cucumeris*: 0,05€/m² (Syngenta) against 0,1€/m²for the *A. swirskii* (Koppert)), and their difference of efficiency is not much known.

5.1.5.3.Other alternative methods

For the plots where the IPM strategy by introduction does not seemed to be sufficient for a good management, some other alternative methods could be associated to introduction of beneficial agents.

First of all the sticky blues cards as presented before is one method used to monitor thrips arrival, or as a trapped method depending on the density. At a high density: 4 cards (20 cm * 25 cm) per 100 m² they can help to reduce thrips population by catching the adults. They need to be installed just at the top of the strawberry plants. One way to hang them is to use some binder-twine (see §5.1.4.4). And they do not fall down; they can stay up to 2 months. The cost for 4 cards per 100 m² is of 0,03 € / m². The costs of the workers that install them need to be taken into consideration. Even if the installation is not easy, because it is sticky and it takes time, it would be interesting to use them in addition to the IPM strategy.

Some insect-proof net could be installed at the entrance of the tunnels. The size of the link need to be very small and to be proof to thrips, the BIOThrips® fabric is one of them. This method might be expensive, but it would reduce consequently the population of thrips on strawberries.

The juice of garlic extract should be tested at a lower thrips pressure, than the test realized this year by producer 1. The garlic is a repulsive of insects and especially of thrips. The dilution need to be realised at 5% if there is lots of thrips and of 2% if the density is low. A producer of juice of garlic extract is based in the Dordogne area in the south-western part of France, at an affordable cost, (0,015 €/m² by application) not more expensive than a chemical. Some producers there already use this technique. This method could be associated with yellow sticky cards, if there are not any beneficial insects. It does not give any bad taste to the strawberries. (www.f'ort'ich.com)

Some producers in the Nederland plant directly some garlic in the greenhouse, at the density of 3 plants of garlic per 100 m². (Greer and Diver, 2000)

A nematode named *Steinerma feltiae* is used in some area to combat the thrips. Some articles show that it works well on thrips, whereas in some other cases it did not work. The humidity should be high and the mean temperature by day should be upper than 12°C. (Greer and Diver, 2000) They are applied by pulverisation, the humidity of the plants need to be kept high during 2 hours. Those nematodes live in symbiosis with a bacterium. In contact with the thrips, the nematode goes inside the thrips by the natural orifices. When it is in the stomach, the bacteria are release and became actives. The bacteria are the cause of the death of the thrips. They do not have negative effect on beneficial insects and on human. It is sold by the beneficial insect firms (Koppert / Syngenta). There is no constraint of application, like the chemicals. (Cloyd, 2009)

5.1.5.4. Proposition of strategies for next year

This year the pressure of thrips seems to be high compared to the previous years. In plots with low thrips pressure and low damages (smallest strawberry production farm), the strategy could be lightened. Some *Amblyseius cucumeris* could be brought (1 bag for 2 meters) at the end of april or at the beginning of may. The *Amblyseius cucumeris* are cheaper than the *Amblyseius swirskii*. The use of blue sticky cards should be tried again at a high density in the plots with issues. *Orius leavigatus* could be release a little later at one or twice release at 0,8 Orius per m². In the plots that have Lygus issues, it might not be necessary. A second *Amblyseius cucumeris* release could be implemented, when there is a peak of thrips. This could be one Success treatment, one week before the second release of *Amblyseius cucumeris*. Long term objectives are to optimize the IPM program in order to decrease its cost. (less than 0,3 €/m²)

By the producer that had the most issues with Thrips, it could be interesting to buy some thrips proof net and to try the different methods proposed higher: juice of garlic extract, nematodes, and introduction of beneficial insects propose for the other producers. A tight monitoring will enable the producer to compare the different methods, in order to see the one that is the most efficient, the costless and the easiest to use.

It could be interesting to make sampling of thrips at different periods of the strawberry production. This would enable to make some correlation between the species and the thrips pressure.

5.2. Tetranychid mite management by introducing beneficial agents

Another pest of the strawberry plants is the *Tetranycus urticae.*

5.2.1. Tetranycus urticae characteristics

Tetranycus urticae more commonly called the two-spotted spider mites, are small spider mites of less than 0,5 mm long. On their abdomen they have two long spots. If temperat ure increases life cycle become shorter, and percentage of death increases. The life cycle is composed of five stages. There are between five and eight generations of two-spotted spider mites per year. A female can produce between 50 and 100 eggs. (Malais and revensberg, 2008) They live on the underside of the leaves. They suck the liquid inside the cells. Their eggs are very small and transparent but they are visible with a hand lens. When females enter in dormancy in winter, they become reddish. They start to be active, at the end of the winter when temperatures are higher. They do not like humid conditions. They have a lot of host plants. They can be transported by the wind. In favourable condition (warm temperature higher than 20°C and dry weather) their life cycle is very fast (Strand, 2008).

They make indirect damage. A high population of tetranychid mites can reduce the potentiality of the plants to produce. The fruits can be smaller. When the attack is very strong, the plant leaves become purple and some webs appear. Then the plants start to dry and die.

5.2.2. Beneficial agents available to control tetranychid mites

There are different beneficial agents that can be used to protect the strawberry plants against the two-spotted spider mites. Some need to be introduced and some other ones are indigenous.

5.2.2.1. Phytoseiulus persimilis

Phytoseiulus persimilis is a red mite, which is a predator of two-spotted spider mites. They are very mobile in order to feed themselves. They are curative predators, which mean that they can be introduced only if there are some two-spotted spider mites. When they do not have enough food, they can become cannibal and can not survive more than 2 days. They are introduced in the field at a density of 5 to 10 specimen per m². Their capacity of reproduction is higher than the two-spotted spider mites, which can explain why they can be good predators. As they eat several spider-mites per day, they will reduce the quantity of tetranychid mites and bring the population under the damage level. They will died or go in another crop, when the populations of two-spotted spider mites are low, but they do not exterminate the population. Many releases could be necessary in order to keep the pest populations at a low level. Optimal temperature for the *Phytoseiulus persimilis* populations are between 15°C and 27°C. They could not live if the temperature is above 38°C. (Malais and revensberg, 2008; Strand, 2008)

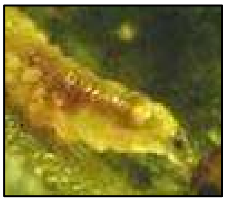
5.2.2.2. Amblyseius californicus and Amblyseius andersonii

Amblyseius californicus and *Amblyseius andersonii* are transparent predacious mites. They have to be introduced before development of tetranychid mite populations (under 10% of occupied leaves). If there is no spider mite they can survive eating pollen or other preys. Both species have the same role, but they are sold by different firms. They are mainly sold in small bags, where they have some food. They stay inside the bag until outside conditions are good. The quantities planed by the firms are one bag for two meters of plants. (Malais and revensberg, 2008; Strand, 2008)

5.2.2.3. Feltiella acarisuga.

Feltiella acarisuga is dipteran, their larva stage is predator. They eat tetranychid mites. They are found naturally, but can also be introduce. Adults search actively two-spotted spider mites, and lay their eggs close to them. The pupa stage is easy to observe, they are on the underside of leaves and they are in white cocoons. (Reboulet, 1999; Malais and revensberg, 2008)

5.2.2.4. Staphylin sp.



Staphylin sp. is a coleopteran, long and usually black. The Oligota species are one of them. Their tail straights up, when they walk. They are present naturally between may and july. They need a high hygrometry. Larva and adults are polyphagous. In spring and in summer, they eat two-spotted spider mites. (Reboulet, 1999)

5.2.2.5. Stethorus sp.

Stethorus sp. is a small, black coleopteran. There is one to three generations per year. They can be indigenous, and they spend the winter at the adult stage close to the culture. They eat actively and preferentially tetranychid mites. (Reboulet, 1999)

5.2.3. Syntheses of the IPM strategy trials in Sologne in the previous years.

The first experiments of IPM at the station started 10 years ago. (LCA station internal reports) Koppert uses the same beneficial agents since the beginning, but strategies were evolved. Most of the time, *Phytoseiulus persimilis* and *Amblyseius californicus* are used together. The quantity releases are different. *Phytoseiulus persimilis* is often associated to Nissorun, a chemical that kills tetranychid mite eggs. Release densities varied from 2 to 15 *Phytoseiulus persimilis* per m². *Amblyseius californicus* packaging and quantities evolved within the years. Until 2007, *Amblyseius californicus* were released at a rate of 2 individuals per m², whereas today they are released in small paper bags (contained 1000 individuals each). The density is one bag for two meter length of strawberry plants (500 individuals / m²).

Between 2005 and 2007, some *Feltiella sp.* were released. For some strategies, chemicals such as Vertimec killing adults and larva, are applied before harvest and before beneficial agent introduction. Syngenta strategies are closed to those of Koppert. One point differs: they used *Amblyseius andersonii* instead of *Amblyseius californicus*. Lots of factors have an impact on IPM strategies efficiency, so it is difficult to make a classification. No very important damages were recorded over these years, but some could be define as more successful than others. This can be defined by comparing beneficial insect effectiveness, strategy costs and tetranychid mite density at the end of the season.

5.2.4. 2011 results

In all producers' plots, some bags of *Amblyseius californicus* were implemented at the end of april. At the station, some *Amblyseius andersonii* were released at the end of may. Some *Phytoseiulus persimilis* were released when tetranychid mite population grew up. For some of them they treated early in the season, before introducing beneficial agents. (Figure 23: Comparison of the three IPM strategies against tetranychid mites)

Producer 1 and 3		cost/m²
05-apr	Vertimec	0,015
28-apr	***Amblyselius californicus (1bag / 2ml)***	0,110
Totale		**0,125**

Producer 2		cost/m² T3 & 8	cost/m² T18
07-apr	Vertimec	0,015	
28-apr	***Amblyselius californicus (1 bag/ 2ml)***	0,11	0,11
11-may	Nissorun	0,01	
12-may	***Phytoseilius persimilis* (10 ind/m²)**	0,09	
Totale		**0,225**	**0,11**

Station		cost/m²
12-may	***Amblyseius andersonii (40 ind/m²)***	0,0985
23-may	Nissorun	0,0100
28-may	***Phytoseius persimilis (5 ind/m²)***	0,0579
3-june	***Phytoseius persimilis (5 ind/m²)***	0,0579
9-june	Floramite	0,0170
01-july	***Amblyseius cucumeris (1 bag/ ml + 120 ind / m²)***	0,1172
Totale		**0,2244**

Figure 23: Comparison of the three IPM strategies against tetranychid mites

5.2.4.1.Producers 3 and 1: no tetranychid mites

For producers 3 and 1 strategy and situation are very close. A treatment was applied during the month before the *Amblyseius californicus* release. Vertimec treatment is not compatible with tetranychid mite beneficial agents. Amblyseius were released while there were no tetranychid mites on strawberry plants. Two-spotted spider mite population stayed at a very low level during all the season: lower than 10% of plants occupied by tetranychid mites. The cost of their strategy was accessible (0,125 €/m²). (Figure 24: Producer 1 and producer 3: Evolution of tetranychid mite and their beneficial agent populations)

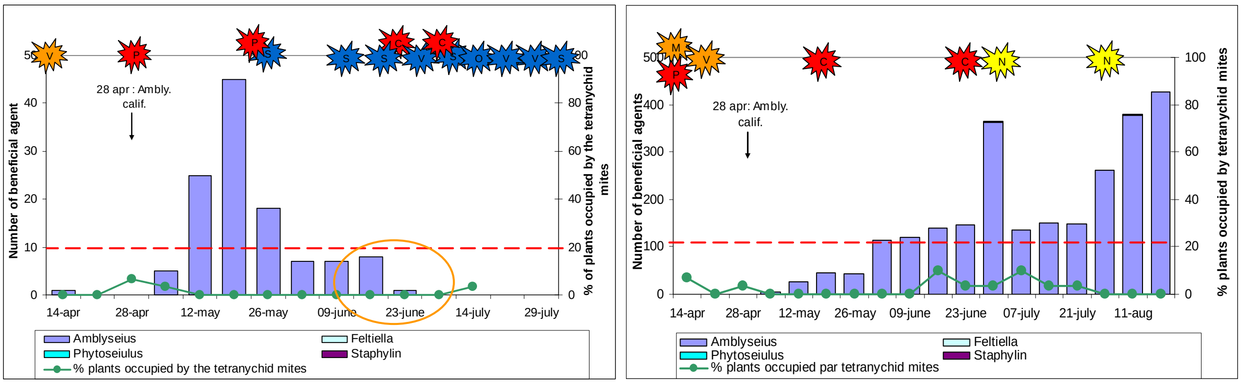


Figure 24: Producer 1(left chart) and producer 3 (right chart): Evolution of tetranychid mite and their beneficial agent populations

On producer 1 plot, some treatments applied in june against thrips are also harmful to tetranychid mites and to their beneficial agents. By this producer, pest management ended up with chemicals. A common point of those two plots is that the present thrips are omnivores. In addition to other thrips diets, *Frankliniella occidentalis* also eats *Tetranychus urticae* eggs. In presence of tetranychid mites, *Frankliniella occidentalis* eat twice less plants tissues. (Agrawal *et al.*, 1999) Therefore, they could help to manage tetranychid mite populations. This is an observation, but it is not at all a solution to control tetranychid mites. But the strategies could be lightened. This information could be an explanation for the absence of tetranychid mites in some plots. Until the end of may, Amblyseius population was the same (we do not know if they are californicus or swirskii as we could not differentiates them with a hand lens. Samples were send to Koppert in order to be determine, but it is not done right now). But at the beginning of june the Amblyseius population increases in the producer 3 plot, while they decrease in producer 1 plot, because of all the treatments against the thrips.

5.2.4.2.Producer 2: 2 cases one successful and one risky

For producer 2, we have again two situations. (Figure 25: Producer 2: 2 cases of evolution of tetranychid mite and their beneficial agent populations)

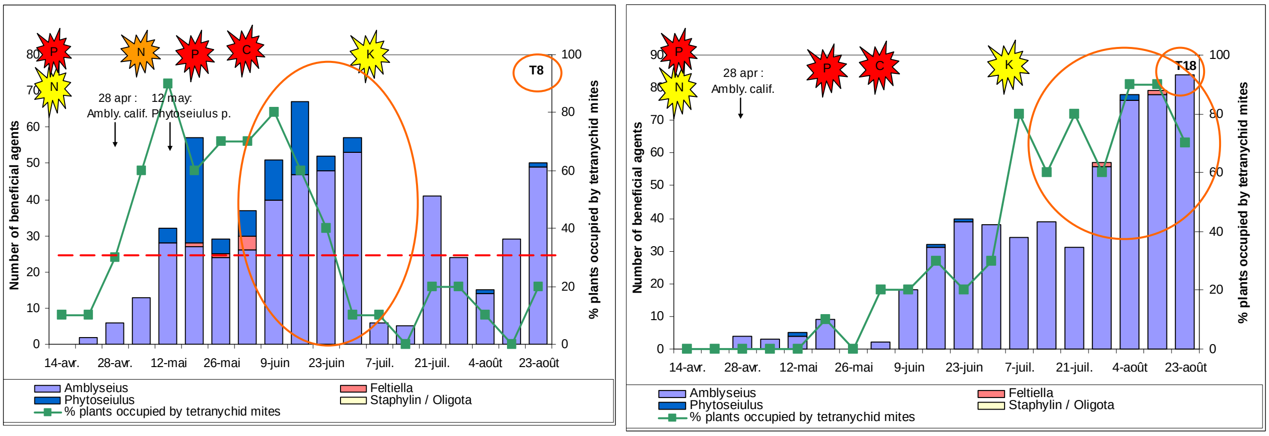


Figure 25: Producer 2: 2 cases of evolution of tetranychid : mite and of their beneficial agent populations

The two first tunnels monitored are quite the same. I will present the results of only one of them the tunnel 8 (chart on the left). Those two tunnels were planted in second year bags at the beginning of february A Vertimec treatment against tetranychid mites was applied in the first tunnels, in mid april. When I started the monitoring, tetranychid mite population was quite low, but they exploded (50% of plants occupied by the two-spotted spider mites) at the end of april, when *Amblyseius californicus* were implemented. As those beneficial agents work in preventive, they should be implemented when the tetranychid mite population is low (under 20% of plants occupied). They could not be effective against a very high population. *Phytoseiulus persimilis* were released at a 10 individuals per m² density. Nissorun was applied just a day before. This pesticide only killed mite eggs, but they do not have a negative impact on the beneficial insects. After those two actions, the tetranychid mite population decrease a little in the short term, but in the long term, it was successful. In may and june, *Amblyseius spp*. and *Phytoseiulus persimilis* settled. When tetranychid mite population decreases significantly, beneficial agent population was the highest. Since the middle of july, two-spotted spider mites population was very low. The strategy works and costs 0,22 €/m². To conclude, the strategy in those tunnels worked well, even if there were a risky period in may. But one thing to keep in mind is that when some beneficial agents such as *Phytoseiulus persimilis* are implemented, producer has to wait until an equilibrium between pest and its beneficial agents is reached. The producers have to be patients, because they work with living organisms and not chemicals, which need time to settle.

On the last tunnel (the left chart), the case is completely different. The plants were planted a month later in new compost bags. The Amblyseius californicus has been applied, while the tetranychid mites were not yet present. The populations of pests and beneficial mites stay low until the beginning of june. At the beginning of june, tetranychid mites starts to raise up, and the Amblyseius make the same. When tetranychid mites raise a lot, Amblyseius are not able to rise as much because pesticides (Calypso) seem to have a negative impact on them. At the end of the monitoring, nearly all the plants were occupied, but with a very low number of individual per leaf. The density of Amblyseius is very high too. The situation is quite risky, but as it is at the end of the summer, the length of the day goes down, and the risk decrease.

A release of *Phytoseiulus persimilis* in july might could been interesting, in order to limit the increase of the populations.

5.2.4.3. Station: Good integrated pest management against tetranychid mites

At the station, the strategy is close to the situation of the producer 2 (T3 and 8) Some *Amblyseius andersonii* were applied in the middle of may while the populations of tetranychid was between 20 and 40% of plants occupied. (Figure 26: Station: Evolution of tetranychid mite and of their beneficial agent populations)

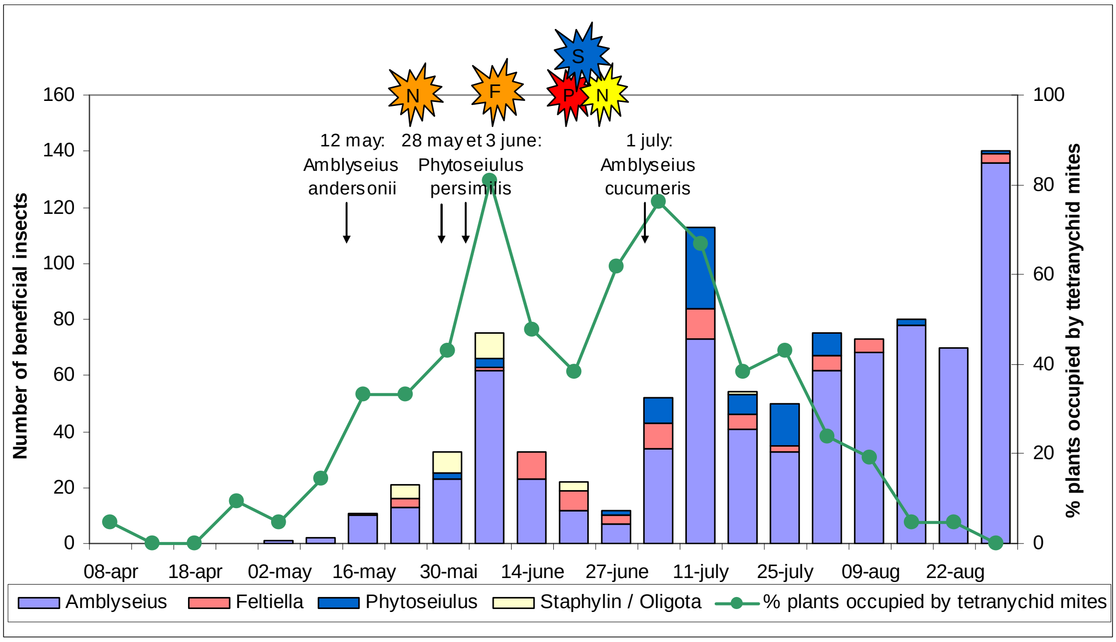


Figure 26: Station: Evolution of tetranychid mite and their beneficial agent populations

The Amblyseius went out of the bags, directly, and so were present at the density of one individual by leaf, at the beginning of june. But the situation seems to be risky so a pesticide killing mite eggs was applied, and two releases of *Phytoseiulus persimilis* (5 individual per m²) had succeed around the beginning of june. As the population of tetranychid mites was still going up, a last pesticide was applied. Floramite kills the adults, and also affects *Phytoseiulus persimilis*. Those four actions were very close, so it is difficult to know the real impact of each of them. The populations were present on 80% of the plants whereas after the Floramite the populations had cut by half after two weeks. It also reduced the populations of beneficial insects by more than half. *Phytoseiulus persimilis* were not present any more during three weeks after the treatment. The experiment by the producer 2 shows that we should have waited, until the Phytoseiulus do their work.

At the beginning of july, the populations of tetranychid mites started to grow up again. At the same time, some *Amblyseius cucumeris* were released, in order to manage the thrips populations, but the thrips were not present any more at a high density at this time. They seem to be interested in the two-spotted mites. Since this date the populations of Amblyseius increase and the *Phytoseiulus persimilis* appear again at the same time. In the middle of july, beneficial insect populations were the highest whereas tetranychid mite population decreases. They disappeared after a month and a half. At the end of august they were not present any more. The populations of Amblyseius stay high until the end.

5.2.5. 2011 results synthesis and propositions for the future

Amblyseius californicus or *andersonii* are efficient when implemented before the first tetranychid mite arrival. Two solutions are possible when tetranychid mites are present: a chemical treatment can be applied at least two weeks before the *Amblyseius californicus* or *andersonii* releases. *Phytoseiulus persimilis* can be implemented in association with an egg killer chemical, when tetranychid mite density is higher than 20% of plants occupied. (Nissorun can be applied few days before the release / Floramite is not recommended when *Phytoseiulus persimilis* are used) The Amblyseius maintain tetranychid mite population at a low level. Phytoseiulus are used when tetranychid population exploded. Those two beneficial agents are complementary. Producers have to be patient in order to see the decrease of tetranychid mite population.

The link between no tetranychid mites and the presence of *Frankliniella occidentalis* need to be check on more plots. Sampling should be realized at different time during the production period, and should be extended to other producers farms.

5.3. Aphids sp. management by introducing beneficial insects

5.3.1. Aphid characteristics

Macrosiphum euphorbiae

Rhodobium porosum

Aphids are one of the main pest species in strawberry production. There are about 8-10 species observable in strawberry plants. Resistance phenomena against chemical appeared, in some situations. It is why it is interesting to find alternative way to control them. Their high potential of reproduction is their strength (between 12 and 20 generations per years). They have two ways to reproduce themselves: sexual and asexual ways. In autumn female eggs are fecundated by males. The eggs are laid and stayed until the spring on leaves. Then viviparous females can generate lots of small aphids within a short time. A female can produce between 4 to 10 young aphids in one day, and so between 100 and 400 young aphids in their life. (Dedryver, 2010; Lascaux, 2010) Population development is linked to the food availability. A plant with an excess of nitrogen is more likely to be touched by aphid populations. Slough skin can be observable on strawberry leaves at each development stage. (Lascaux, 2010) When there is not enough food on leaves, aphids get winged and fly elsewhere in the culture. Dry and warm weather are favourable for their development. (Malais and revensberg, 2008)

They suck cell components of the strawberry plants. It slows down the plant development. They also produce a sugary product: honeydew, which make the plants sticky. This reduces the quality of strawberries even not be marketable. Honeydew promotes development of some mould. (Strand, 2008)

5.3.2. Beneficial insects available to control aphids

Two different kinds of beneficial agents are used to control aphid populations: parasitoids and predators.

5.3.2.1. Parasitoid species

Aphid parasitoids are small wasps. There are different aphid parasitoid species. It is important to determinate aphid species present in plots in order to use the more specific parasitoids for this species. (Appendix 3: Complementarities between aphid species and parasitoid species) Parasitoids lay eggs in aphid bodies. The parasitoid larva get develop inside the aphid bodies, the aphid become mummify. There is a delay before parasitoids spread up and control aphid population. In a week a female can parasite between 100 to 200 aphids. (Suty, 2010) There is two packaging: some include only one parasitoid species and the other is a mix of parasitoids. They can contain from 2 to 6 parasitoid species. (Figure 27: Aphids parasitized by different species). The aphid species need to be determined in order to choose the right parasitoid species to introduce. Recently a mix of 6 parasitoids has been commercialized by Viridaxis (another beneficial agent firm). They are introduced, and an observation can determined the more present ones. The observed species could be introduced again at a higher rate. Parasitoid forms and colours are characteristics of parasitoid species. Some of them can be mix up, because they look the same. We just differenced the *Aphilinus sp*., the *Aphidus sp*., and the *Praon sp.*

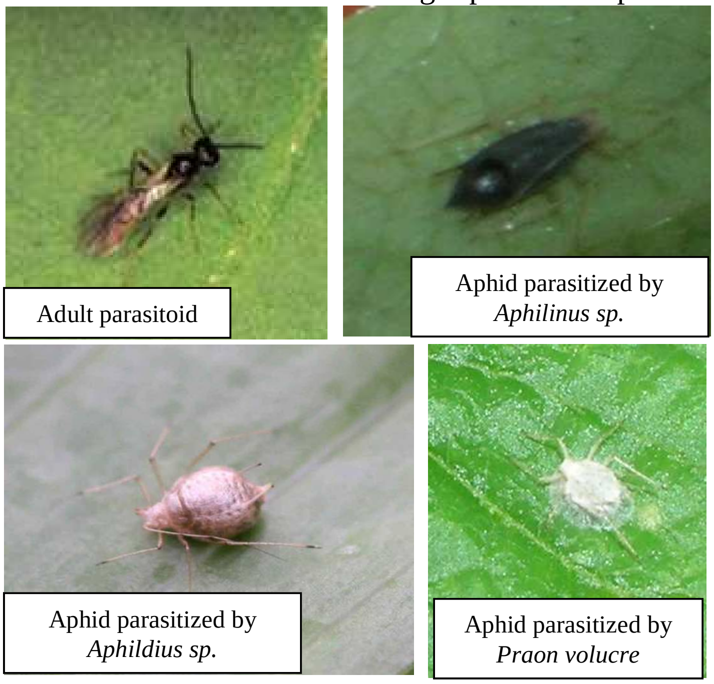


Figure 27: Aphid parasitized by different species

5.3.2.2. Chrysope sp.

Chrysope sp. is a polyphagous insect at the larva stage: it does not eat a specified prey. They are part of the neuropteran order. They can have between 2 to 4 generations per year. The female lay eggs at the end of a stalk fixed on the underside of a leaf or on the stalk of a leave. Koppert and Syngenta advisors recommend them to control aphid populations. A larva can eat 500 aphids or 10 000 tetranychid mites during the larva stage period, which last 15 days. Chrysope spend winter at the adult stage in sheds or at the larva stage in cocoons in the crop. They are actives from june until septembre. They are sold by firms. (Reboulet, 1999)

5.3.2.3. Syrphe sp.

Syrphe sp. is an aphid predator at the larva stage of the diptera order. They are naturally presents in the environment. There are several generations per year, and they spend the winter at the larva or nymph stage. The larva stage last 10 days, during this period a larva can eat between 400 and 700 of aphids. They eat all the specimen of a colony. They suck the inside of the aphids. The adults fly and feed on pollen and on nectar. This food enables the female to generate eggs. Eggs visible under leaves close to colonies, are white, small and long. (Reboulet, 1999) They are difficult to be observed.

5.3.2.4. Aphidoletes aphidimyza

Aphidoletes aphidimyza is a gall midge, an aphid predator. They are part of the diptera order. The larva stage can eat between 5 to 10 aphids a day. They can kill more aphids than they eat. They can also be introduced in spring but they are more active in summer and in autumn. (Reboulet, 1999)

5.3.3. IPM strategy synthesis in Sologne in the previous year

This synthesis only takes into account the last four years. Beneficial insects used are much diversified, as well as the strategy itself. In 2008 and 2007, the strategies were based on *Aphidoletes aphidimyza* releases with *Aphidius sp.* parasitoids. About three releases were made, with a density of 3 insects per m².

In spring, there is a gap between indigenous beneficial insect and pest arrivals. On short day varieties, some *Chrysopes sp.* were introduced in autumn in order to find them earlier in the strawberry plants in spring. The method failed: Chrysope were not found at all the next spring.

Between 5 to 6 aphids species are recurrently found in strawberry plants in Sologne. New beneficial insects were tested in order to see their efficiency. *Hemerobes sp*., which is close to chrysope species and a parasitoid not yet tried: *Ephedrus cerasicola* were tried one year. *Hemerobe sp*. and *Ephedrus cerasicola* were not found in the plot afterwards. Those trials have not been carried out again.

The last two years on counter-planted ever-bearing strawberries, some chrysopes were released three times at a density of 1 to 1,5 larva per m². When chrysopes are introduced before the aphid arrival, this strategy seems to control the aphid population in the summer, but there are issues at the end of October. The aphid populations explode. And the Chrysope might not be active any more.

IPM strategies against aphids are expensive. The strategies need to be optimizing in order to be more economically accessible to producers.

5.3.4. 2011 results

Some beneficial insects were only release at the station. For the producers, not any beneficial insect were implemented; it was a chemical management associated to indigenous beneficial insect in some plots.

5.3.4.1. <u>Producer 3: Good biological aphid management in summer thanks to indigenous beneficial insects</u>

This producer made a chemical application before my first observation. (Figure 28: Producer 3: Evolution of aphid and their beneficial insect populations) Pirimor is the most compatible chemical with IPM used against aphids. No aphids were observable in the tunnels I monitored until the end of may. The number and the diversity of beneficial insects were also low, during this first period. He made two applications of Calypso, even if there were no aphids. The objective was to kill the Lygus present on the plot. Since the middle of june some Syrphes were present. Parasitoids and chrysopes started to be observable in the strawberry plants at the beginning of july. Some aphids were present in a low density since the beginning of june. Since this same period beneficial insect numbers rose up and maintain the aphids at a reasonable level. The aphids in july and august were controlled by indigenous beneficial species.

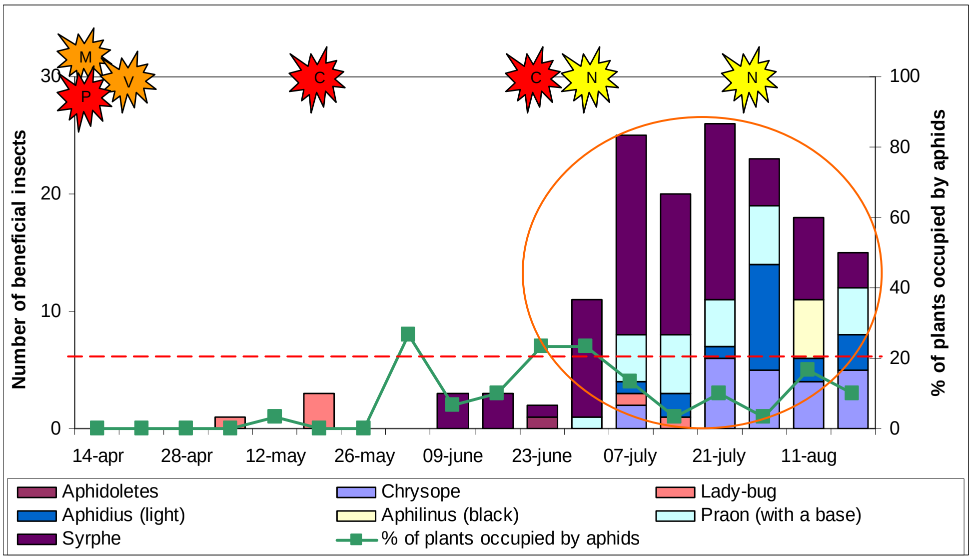


Figure 28: Producer 3: Evolution of aphid and their beneficial insect populations

5.3.4.2. <u>At the station: IPM strategy including releases and chemical</u>

At the station, the season started and ended clean. Some beneficial insects were implemented at three dates. (Figure 29: Station: Evolution of aphid and their beneficial insect populations) The evolution of aphid population can be divided in four periods. From the plantation until the beginning of may the aphids were present at a very low level. The beneficial insects were implemented when the aphid population started to rise up. Some parasitoids and chrysopes were released in the middle of may. The next release was realised two weeks later, the same parasitoids are introduced, as well as some Aphidoletes. At the beginning of june Chrysope and Aphidoletes are introduced. I thought that the population was beginning to decrease, but the advisor and the experimenter told me that the situation was too risky. *Chaetosiphon fragaefolii, Macrosiphum euphorbiae*, *Aphis forbesi*, *Rhodobium porosum*, *Acyrthosiphon pisum* were the aphid species present on this plot. A Pirimor treatment is realized in the middle of june. The treatment is compatible with beneficial insects. The treatment helped to clean the aphids.

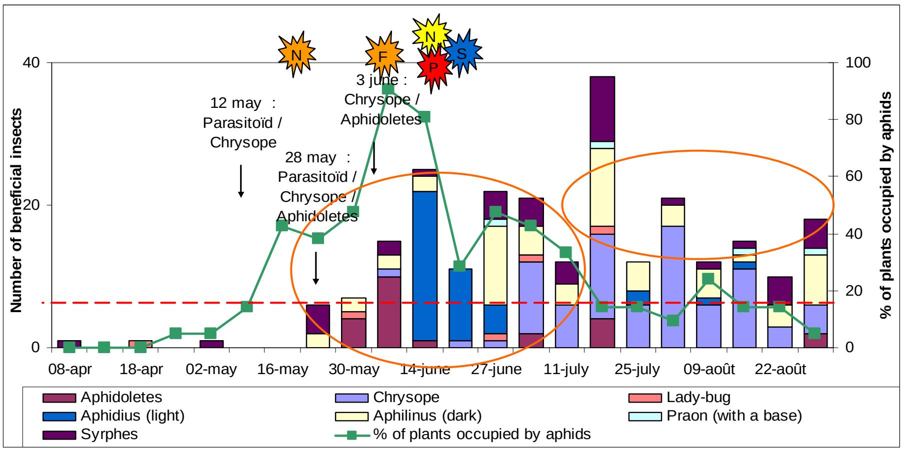


Figure 29: Station: Evolution of Aphid and their beneficial insects

Then the beneficial insects were able to manage and reduce aphid populations to a tolerable level, in the middle of july. Aphidoletes are found mostly just after their first release. We can observe that the Chrysope started to be present at the end of june, and they are present until the end. Parasitoids were observed during all the summer period: in the second part of june, there were more Aphidius parasitoids than Aphilinus one, since the beginning of july it was the opposite. This is directly linked to the aphid species present. There were not the same species repartitions along all the season. In conclusion, this strategy is quite positive. The release could have started earlier. The peak period in the middle of may and june, could have be manage by the beneficial insects, if we would have been patient. The chemical worked well this year, in association with the beneficial insects. Some years it was not very efficient. The only important negative point is the price. It cost 0,75 €/m². (Figure 30: Station: Description and cost of the IPM) This is not affordable by a producer, in addition to the cost of the other beneficial agents used to control the other pests.

Station		cost/m²
12-may	***Aphidius ervi et colemani (1,6 ind/m²)***	0,1112
12-may	***Chrysoperla carenea (1,5 ind/m²)***	0,0591
28-may	***Aphidius ervi et colemani (1,6 ind/m²)***	0,1112
28-may	***Aphidoletes aphidimyza***	0,0575
28-may	***Chrysoperla carenea (3 ind/m²)***	0,1182
3-june	***Aphidoletes aphidimyza***	0,0575
3-june	***Chrysoperla carenea (3 ind/m²)***	0,1182
17-june	Pirimor G	0,0040
1-july	***Aphidius ervi et colemani et Aphilinus***	0,1112
Totale		**0,7481**

Figure 30: Station: Description and cost of the IPM

5.3.4.3.Producer 2:

As for the other pests the 3 tunnels situations are different, so I choose again to present the results in two of those tunnels for this producer. (Figure 31: Producer 2: Evolution of aphid and their beneficial insects populations: Comparison of the 3 tunnels) In the tunnels 3, there was a very strong peak in the second part of may, so a chemical was applied at the beginning of june. The aphid populations increase slowly until the end of the monitoring. The aphid population in tunnel 8 increased gradually during all the season. It started at 0% of plants occupied and it end up at 100% of plant occupied. On the last tunnel planted T18, we can see a first aphid peak, which was managed by the chemical. We can say that the Calypso application at the end of may had a strong effect on the short term. But two weeks later, aphid populations started to increase again. The Pirimor treatment did not seem to work.

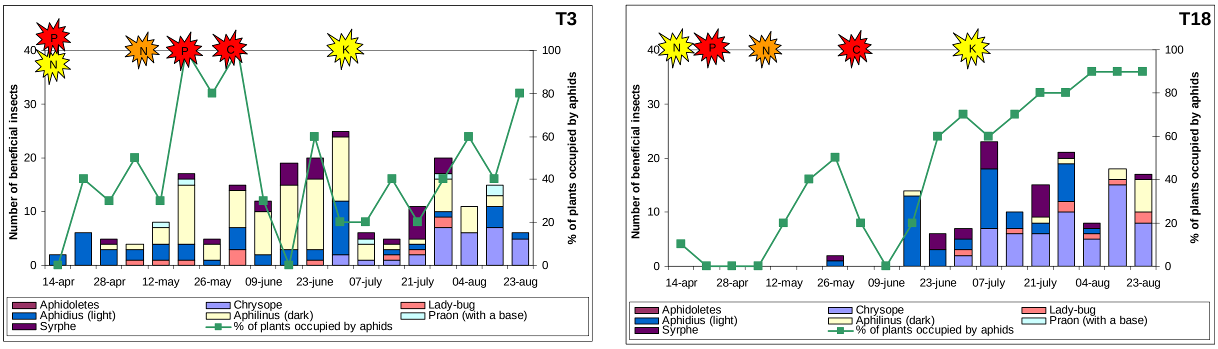


Figure 31: Producer 2: Evolution of aphid and beneficial insect populations

On the tunnel 3 beneficial insects were present since the beginning. They increased and became highly diversified in a short time. In the tunnel 18 the beneficial insect populations arrived at the beginning of june. The equilibrium between beneficial insect species was different from one tunnel to the other. The aphilius were the first one found in every tunnel. In the tunnel 3 the aphilinus were quite numerous between the middle of may and the end of june. In the three tunnels the syrphes were present from the middle of june to the end of july, whereas chrysopes were present during the two last months. The chemical applications did not seem to have a negative impact on beneficial insects. At the beginning of july, there were a real decrease of aphid and beneficial insect populations. This could be due to the cleaning of the plants: the old leaves were removed and the cold and wet weather in july could also be an explanation.

5.3.5. Further propositions for the following years to specify the strategy

The situations of producer 2 and 3 are very positives. They managed to maintain the aphids at a tolerable rate, by letting indigenous beneficial insects working during the summer. They arrive before the end of june. The beginning of the season and the end of the season are quite difficult to manage for the producer 2. The beneficial insect introduction at the station showed that they have a long term impact on the aphid populations. Chemicals could be associated to biological control, in order to break aphid development, they only have shock impact in the short term, it decreases the populations but it did not maintain the populations at a low level. But a biological control by introduction is not yet enough reliable compared to the cost.

The objective in the future is to find IPM methods that could help to manage the aphids early in spring and are less expensive. So, it is necessary to go on with the trials at the station until a cost-effective strategy is done. Landscape elements could be a method that enables the insects to winter close to the strawberries plots. They will be ready to go earlier on the plots in spring. This point will be developed further on in §6.

5.4. Lygus sp.: a limit of IPM success

5.4.1. Lygus sp. characteristics

Lygus sp. also called tarnish bug is a secondary pest species on strawberry plants. While the pests are chemically managed, they are not visible, because they are killed by aphid chemicals. But with integrated pest management system, Lygus tend to appear and to cause damages. They lay their eggs in the plant tissue mostly in dicotyledonous plants, when the temperature rose up to 20°C. Females lay about 5 eggs per day during ten to thirty days. They have between 2 and 3 generations per year between april and november. (Swezey, 2004)

They spend winter at adult stage in weedy area. They like to go on lots of different uncultivated and cultivated plants. Alfalfa is one of their preferred hosts and can be used as trapped plants. In spring they will be close to strawberry plants and will be attracted when the strawberry will be at flowering and fruiting stages. Late flowering tend to give more damage on fruits because the damaging lygus stage will arrive at the same time as the fruiting. It is the larva stage that makes most damages, because they stay on the same floral stalk. Larva look like aphids, but they run faster. They mostly stay on the same plant. Lygus bug larva eats on immature strawberry fruits. They generate small fruits and can even also deform them. This deformation is called 'cat-facing'. (Swezey, 2004)

Some studies about lygus egg parasitism were realised in Canada in order to see they efficiency. Three main parasites are found: *Anaphes spp., Telenomus spp*. and *Polynema spp.*. (Carcamo *et al.*, 2008) Only few eggs are parasitized, but it needs to be more studied. This method needs to be associated to other methods to be efficient. In other trials, they introduce Peristenus spp, which is a parasitoid imported from Western Europe (France and Spain) into North America. (Hoelmer *et al.*, 2008) This might be found as indigenous species in French area. Some predators are eating lygus, like *Geocoris spp.,* but they are not enough sufficient to limit lygus damages. Not any efficient beneficial insects are available in France to fight against Lygus spp. (Swezey, 2004)

5.4.2. 2011 results

During the monitoring four main species were observed in three plots. (Figure 32: Different Lygus sp. observed) Only one of them was identified: *Liocoris tristipulatus* which is the one that seems to make more damages.

The producer 3 detected the first Lygus in his plots, in the second half of may. His strategy is to treat as soon as he sees one Lygus, with a Calypso treatment. He thought that Lygus damages are important. He treated one time at the end of may and one time at the end of june. The Lygus that I observed were *Liocoris tristipulatus.* They were found at the highest rate at 3 *Liocoris tristipulatus* per 30 plant shakings.

The producer 2 also had some Lygus spp. At the end of may he also had some *Liocoris tristipulatus.* A Calypso treatment was applied at the end of may in order to control aphid populations and it also killed this Lygus. In june and july an other Lygus was present at a high density. For 30 plant shakings, I commonly observed 14 individuals. The producer did not feel that he needed to treat; he told me that damages were low and acceptable.

At the station 3 or 4 Lygus species were observed from the end of may to august. The damages were also estimated low, no treatments were applied to fight against them.

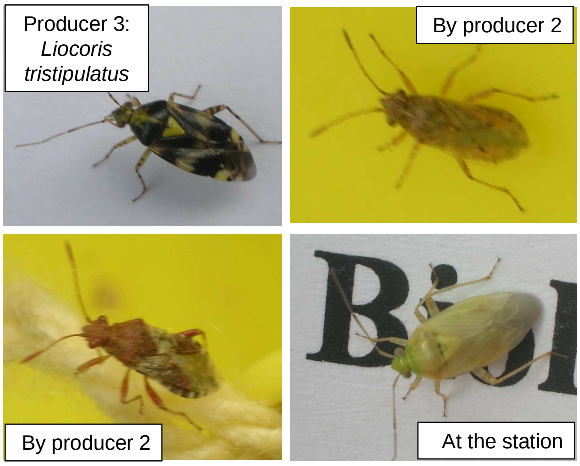


Figure 32: Different Lygus sp. observed

5.4.3. New trial perspectives for next year to control Lygus sp.

As there are neither indigenous beneficial insect neither introduced beneficial insect available in France that are really efficient to control Lygus, I will present an alternative method set up by a Suisse researcher: Fischer.

I found his method on a presentation document realized at a working group about integrated pest management on strawberry plot. In order to get more information, I called him. During his trial, he used alfalfa as a trap crop. In another trial in North America, 3 trap crops were compared to the strawberry plant attraction. It appears that more lygus were found on Alfalfa, than on radish, mustard and strawberry. (Swezey, 2004) The Suisse researcher sow Alfalfa in between two tunnels. The detection of lygus on trap plants is important, in order to be able to detect their arrival and to make treatment on trap plants to kill them. The movement of Lygus between a trap plant and a cultivated crop can be detected by using sticky cards. (Blackmer *et al.*, 2008) Plant shaking over a yellow bowl can also be a method of detection. In organic strawberry production in North America, some trials were realised by using a vacuum on a tractor in order to catch the lygus bugs. The results show that it is even more relevant to do it on alfalfa trap than on strawberries plants. On alfalfa trap, the lygus population are reduce up to 70% (Swezey, 2004)

This method seems to suit to the producer 3, the one that made treatment against Lygus. As by the producer it does not seems to be possible to sow alfalfa in between two tunnels, an alfalfa band of two meter wide all around the tunnel plot will be sown this autumn. (Figure 33: Map for the Alfalfa trial) In spring a good monitoring need to be realized early. Sticky card could be added in between the alfalfa band and the strawberry plants in order to observe their movement. Observation might have to be realized by shaking plants. A vacuum trial could be realized in alfalfa as a control method against lygus. Species identifications would be interesting to better understand the difference of damage on strawberry fruits. This could be an axis for further researches.

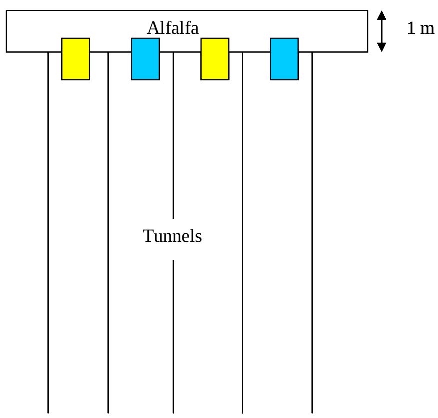


Figure 33: Map for the Alfalfa trial

5.5. Synthesis of pest issues and beneficial insects in the four plots

The objective of this part is to make a global view of what happened in the different plots and to make a comparison of the beneficial insect diversity and quantity. (Figure 34: Comparison of quantity and diversity of beneficial insects in the four plots (in spring and in summer))

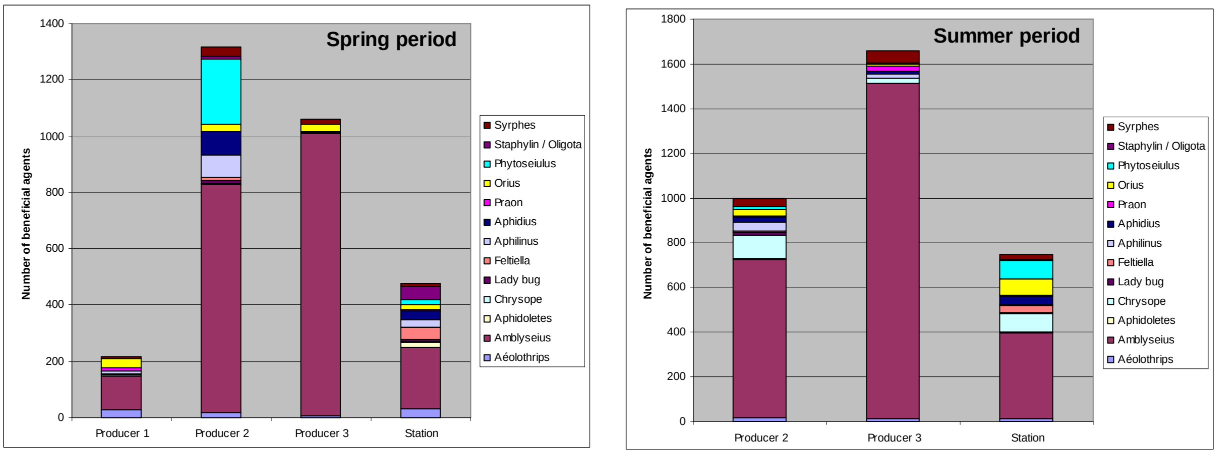


Figure 34: Comparison of quantity and diversity of beneficial insects in the four plots

In producer 1 plot the major pest is the Thrips. The IPM strategy was not successful, neither the chemical management. The beneficial agents introduced started to set up before the use of the first chemicals. But they stayed in a low quantity.

Producer 2 plot was interesting because within the same farm, production factors were variable. We see that for the four pests as well as the beneficial insects, the populations were different from one tunnel to the others. This situation shows us that IPM strategy can be successful, with a presence of pest, when lots of beneficial insect are naturally present, especially for the Aphids. The necessary to be patient show the efficiency of the method. His strawberry production surface is smaller that the two other producers.

Producer 3: The main pests are Thrips and Lygus. The Amblyseius settled very well, whereas the Orius disappeared because of chemical applications. In spring the beneficial insects where very high in quantity and low in diversity. In summer Indigenous beneficial insects controlling aphids appeared in high diversity and high quantity.

At the station, the four pests were present. A high diversity of beneficial agents was implemented. The quantity of beneficial insects is lower than in producers' plot.

The interaction between the different beneficial agents should be more took into consideration. The efficacy of the beneficial insects introduced can be low, because some more general indigenous beneficial insects are in competition against the same pests, which is the intra-guild predation. Most of the pests are present before the beneficial insects. The minimal temperature for the development of pests is lower than for the beneficial insects.

By the producers, the size of the plot monitored with IPM does not represent a high part of their total strawberry surface. As tunnels are open areas, flying insects can fly from a plot to another one. Chrysope and Orius are two examples. The insect density released is based on the plot size manage with IPM method. As they can move to other tunnels, beneficial insect number released are not sufficient to control the species in all the tunnels.

6. Evaluate the impact of landscape element on pest management

IPM method cost is higher than chemical control. But it is interesting in order to protect workers, consumers and environment health. More knowledge about the trophic links between banker plants, pest insects and beneficial insects are needed, to set up more adapted system of pest management. (Suty, 2010)

6.1. Syntheses of previous years trials at the station

In 2008, floral fallow trials were made. Three kinds of floral fallows were sown this year close to the plot. Pest and beneficial species were monitored in floral fallows as well as in the hedge. This hedge composed of 9 tree species, is still there. One of the floral fallows composed of 12 different plants was evaluated as interesting for beneficial insects controlling strawberry pests. Beneficial insect species on this floral fallow and in the hedge were diversified and numerous.
Small boxes for chrysopes were installed at the end of the summer. Chrysope which had spent the winter in those boxes were counted at the beginning of march. There were not a lot of chrysopes present. The objective of those chrysope boxes is to keep the chrysopes close to strawberries plants: they will go directly on the strawberry plants, when appropriate temperature is reached in spring. (LCA station internal report)

In 2009, insect populations were sampled in the hedge and in natural grass-strips in order to evaluate their potentiality of biological control by conservation. The beneficial insects were also observed in the strawberries plants. The sampling was realised with the help of vacuum and of a catching insect net. The insects were identified: they mostly observed aphid beneficial insects. But it was difficult to find them in the strawberry plants. Landscape elements are a great potential to be taken into account, because lots of beneficial insects are present in the environment. Two hypotheses were made: the beneficial insects had difficulties to reach strawberry plants (about 1m20 high) or the sampling method was not adapted for beneficial insect observation.
There was a limit mentioned in trial: no repetition was made, samplings were only realized on one tunnel.

The objective for the following years was to set up new landscape elements, which would help to make a way for beneficial insects to move from present landscape elements to strawberry plants. In 2010, a clover-strip was installed under two tunnels. Pest population monitoring was realised on 30 plants. Tetranychid mite populations rose up higher under the clover-stripped tunnels than under tunnels with tarp. This monitoring did not unable them to conclude on clover-strip effectiveness. *Phytoseiulus persimilis* were introduced in the strawberries but they were not found on the clover-strip tunnels.

The clover-strip was sown in july, so it did not take into account spring time. One limit of those results was that they were no repetitions. At each monitoring different plants were observed. There is always a high variability from one plant to the other one.

6.2. 2011 results

In order to answer to the limits of the 2010 trial, the plants observed were marked to observe always the same one. As I presented it in the §4.2., two factors were evaluated. Firstly the impact of the clover-strip under the strawberry rows was compared to black tarp on the ground. The clover-strips are banker-plants. Secondly we wanted to see if the distance from the natural grass-strip has an impact on pest and beneficial insect populations.

The main trends are highlighted. Results are based on ANOVA analysis. The dates with significant results are represented with an oval shape on the graphs. The full lines represent the percentage of plant occupied by the pests and the dot lines represent the percentage of leaves occupied. On each plant two leaves were observed. The trends are quite the same. The result analyses are quite different (plants and leaves data); I used both of them to justify trends. I would like to remind one point: this plot (the plot station) is the same as one of the four plots used for the strategy comparison in §5. Some beneficial agents were introduced, between the middle of may and the middle of june. The monitoring stopped at the end of july, because I needed to do the analysis.

6.2.1. Influence of the ground cover

In this part we will see pest and beneficial agent evolutions within time. General trends will be highlighted in order to see the ground structure impact on insect populations.

6.2.1.1. Aphids and their beneficial insects

Two trends can be highlighted on **aphid evolution** within the time. The bridge date between the two periods is at the beginning of june. The first period which is the month of may is characterized by highest aphid population in the clover grass area, than in the tarp area. (Figure 35: Influence of the ground cover on aphid populations) The 16th of may aphid populations are significantly different in the two areas at the rate of 5%. The second period corresponds to the months of june and july. During this period, three dates appeared to have significant results. The aphid populations are higher in the tarp area than in the clover-strip area.

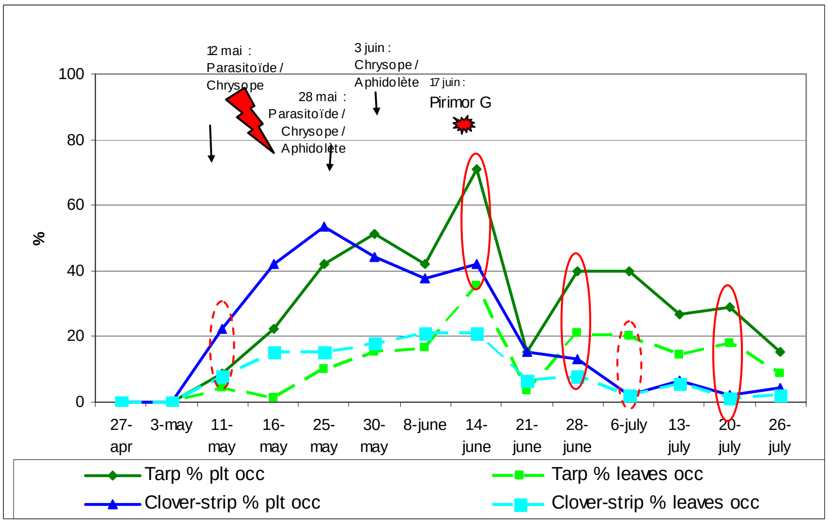


Figure 35: Influence of the ground cover on aphid populations

Beneficial insect numbers were increasing during all the period. (Figure 36: Influence of the ground cover on aphid beneficial agent populations) General trends of the two charts evolved in parallel. But it appears that more aphid beneficial insects were present in the tunnels with clover-strip than under tarp tunnels. On the 8th and 15th of june, beneficial insect numbers were significantly higher in the clover-stripped tunnels than in the tarp one. Beneficial insects introduced were the same in all tunnels. In the clover-strip, during the first period lots of parasitized aphids and lots of syrphe eggs were found.

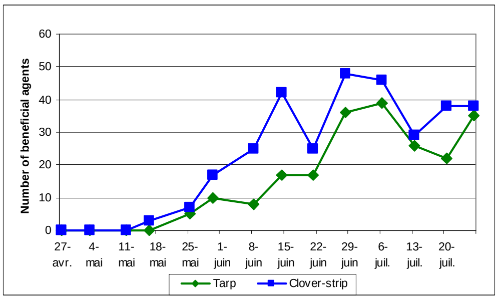


Figure 36: Influence of ground cover on aphid beneficial agent populations

An equilibrium between aphid and beneficial insect seemed to be more easily reached in clover-striped tunnels than in tarp tunnels. The Pirimor treatment might not have been necessary in clover-striped tunnels. After the Pirimor treatment, the aphid populations stayed low in the clover-strip tunnel, whereas in the other one the population rise up again just after the treatment.

In conclusion in 2011 trial conditions, the clover-strip under the hanging garden seems to be favourable to biological control of aphids.

6.2.1.2. Tetranychid mites and their beneficial agents

Two trends can also be highlighted, but are less visible. (Figure 37: Influence of the ground cover on tetranychid mite populations) Those observations are based on result analysis. The first period is until the middle of june. During this period, **tetranychid mite populations** were higher in the clover-stripped tunnels than in tunnels with tarp.

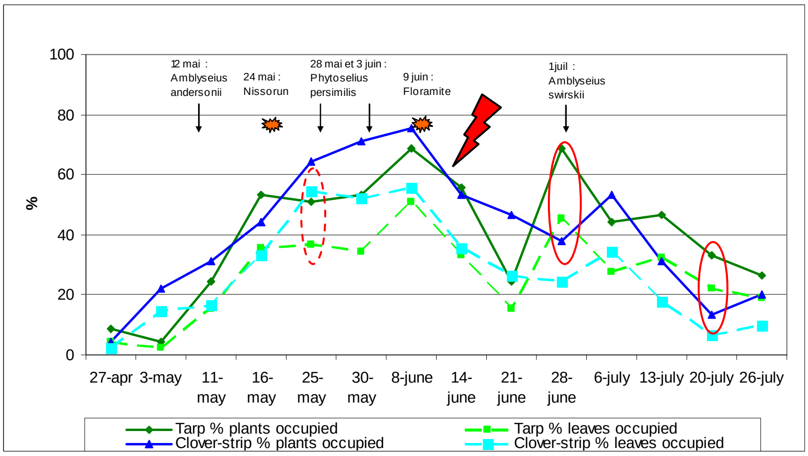


Figure 37: Influence of the ground cover on tetranychid mite populations

In addition, tetranychid mite population presents in the clover-strip were very high during this period. They were also present on the water sprinklers that were 50 m high. (Figure 38: Clover-strip watering system infested by tetranychid mites) Two treatments on strawberry plants and two waterings of the clover-strip had decreased the tetranychid mite populations. In the second half of the monitoring, the chart trends to be the opposites: on the 29th of june and on the 20th of july the population were significantly higher in tunnels with tarp than in those with clovers at the rate of 5%.

Figure 38: Clover-strip watering system infested by tetranychid mites

Beneficial agent trends were nearly the same in the two cases. (Figure 39: Influence of the ground cover on tetranychid beneficial agent populations) During the three last weeks of monitoring, tetranychid mite beneficial agents started to be different from one case to the other.

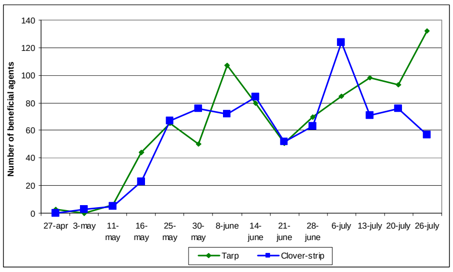


Figure 39: Influence of the ground cover on beneficial agents

In tunnels with tarps, the populations were higher than in the clover-stripped tunnels. On the 26th of july the population was significantly twice higher in tarp tunnels than in clover-stripped tunnels at the rate of 5%.

Phytoseiulus persimilis quantity implemented at the end of may were twice higher in the clover-stripped tunnels. After the Floramite treatment the tetranychid mites decrease more smoothly in the clover-stripped tunnels. Beneficial agents were touched by the Floramite. Koppert estimates that the Floramite killed between 50 and 75% of *Phytoseiulus persimilis*.

Even if tetranychid mite populations were high in the clover, it did not seem that the clover had a so negative impact that we thought in june, when the clover and the water sprinklers were full of tetranychid mites. In the future, maybe two waterings are enough to limit tetranychid mite development in the clover.

6.2.1.3. Thrips and their beneficial agents

The general trend of the charts is globally going up and down at the same time. (Figure 40: Influence of the ground structure on the evolution of thrips populations) But we can see and the statistic told us that there are more **thrips** in tunnels with tarp than in clover-stripped tunnels. At two dates there are significant differences: on the 14th of june and on he 6th of july. Thrips population seems to be managed earlier in clover-stripped tunnels. The thrips population stayed also at a lower rate in clover-stripped tunnels. Only on the 8th of june, the thrips population went higher than the level of tolerance, but it was already lower than it when the Success treatment were realized.

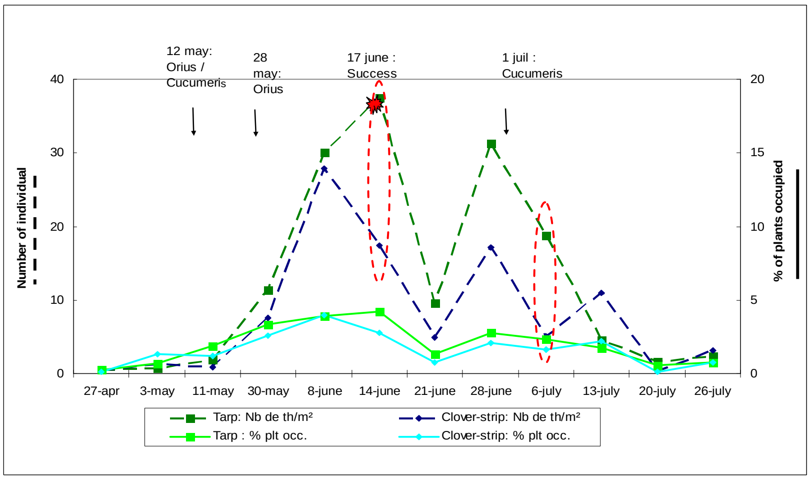


Figure 40: Influence of the ground cover on the evolution of thrips populations

Beneficial agent populations are globally the same. (Figure 41: Influence of the ground cover on thrips beneficial agent populations) Their evolutions under the tunnels with tarp are higher, whereas it is lower in clover-stripped tunnels. As we could not differentiate the two Amblyseius spp. introduced into the tunnels, they are included in the beneficial agents against tetranychid mites and against thrips. This is one limit o the monitoring.

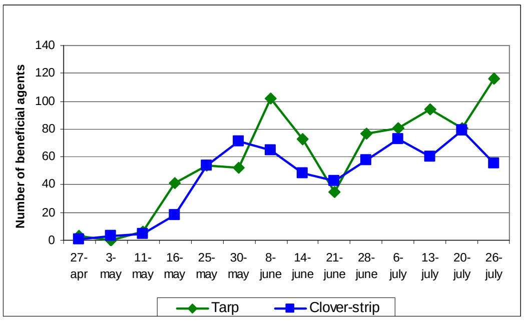


Figure 41: Influence of the ground structure on thrips beneficial agent populations

The clover strip seems to have a positive impact on thrips population. But some other factors that we did not recorded could also have an impact.

6.2.2. Influence of the distance to the natural grass-strip

The distance factor is not significant. We can highlight that in the zone 3, which is the furthest from the natural grass-strip, there are less pest and beneficial insects, than in the two other zones. The two other zones have about the same insect numbers, during all the season.
No results are effective because too much factors could have interacted with the distance factor. One hypothesis could be that the tunnels at the station are short (They are about twice or three times shorter than the producers' one) Distances from one zone to the other one are short and could not be long enough to see the influence. The zone 3 is quite far from the grass-strip, but is closed to the other side of the tunnel and to the grit way. So they are also influenced by the tunnel side factor as well as the weather factors. The wind usually arrived from this side.

6.2.3. Limits of the trial

Other limits of this trial, is that others trials are realized on this plot. Even if we manage to choose strawberry rows with the closest conditions, there were differences that we could not quantify. The climate under tunnels could be influenced by results of other trials. On clover-stripped tunnels, there were substratum trials. Those trials did not work very well so the strawberries plants were smaller. For me this factor could influence pest pressure and beneficial insect food.

We could not dissociate the factor clover-strip from the factor hedge. The results comparing clover stripped tunnels to tunnels with tarp could not be the same if we suppress the hedge.

A higher number of plants observed could give more reliable results. But a higher number would not be realizable by an observer. It is better when all the observation are realised on the same day in order to limits other factors (like the weather). Observations of 90 plants were already a lot in one day. I realized that I did not pay the same attention for the first plants than for the last ones. As I realized the observation always in the same way, I think that I minimized the error factors.

Another limit of this trial to see indigenous species coming from landscape area is that some beneficial insects were implemented. We could not really see if those we observed were due to introduction or conservation method. Without beneficial agent introduction the results would be different.

6.3. Further propositions for the future: management of the landscape elements

In 2011 trial conditions, the clover-strip under the hanging garden seems to be favorable to biological control of aphids. Their beneficial insects are presents in the clover early in the spring. The first objective of the clover strip was to get aphid beneficial insects earlier in the strawberries. 2011 results reach this objective. The thrips population management seemed to be also easier in the clover-stripped tunnels. When 2010 and 2011 results are compared, we can see that the tetranychid mites could be the limit of the clover-strip. Tetranychid mite populations on the clover can go high and could be a source of strawberry infestation. The clover watering should more study in order to see the results.

Trial conditions did not unable us to conclude on the natural strip influence on pest and beneficial agent populations. To see the influence of landscape element like grass-strip at the end of tunnels or of hedges seems for me to be more relevant in producer plots.

7. Discussion

7.1. Factors influencing IPM strategy effectiveness

Integrated pest management in strawberry production in hanging gardens is not so easy. During all the project lots of elements that seem to influence pests and beneficial insect presences were highlighted. Five main topics are outlined and have to be included in IPM strategies: production, environmental, human, economical, climatic and. (Figure 42: Factors influencing IPM strategy effectiveness)

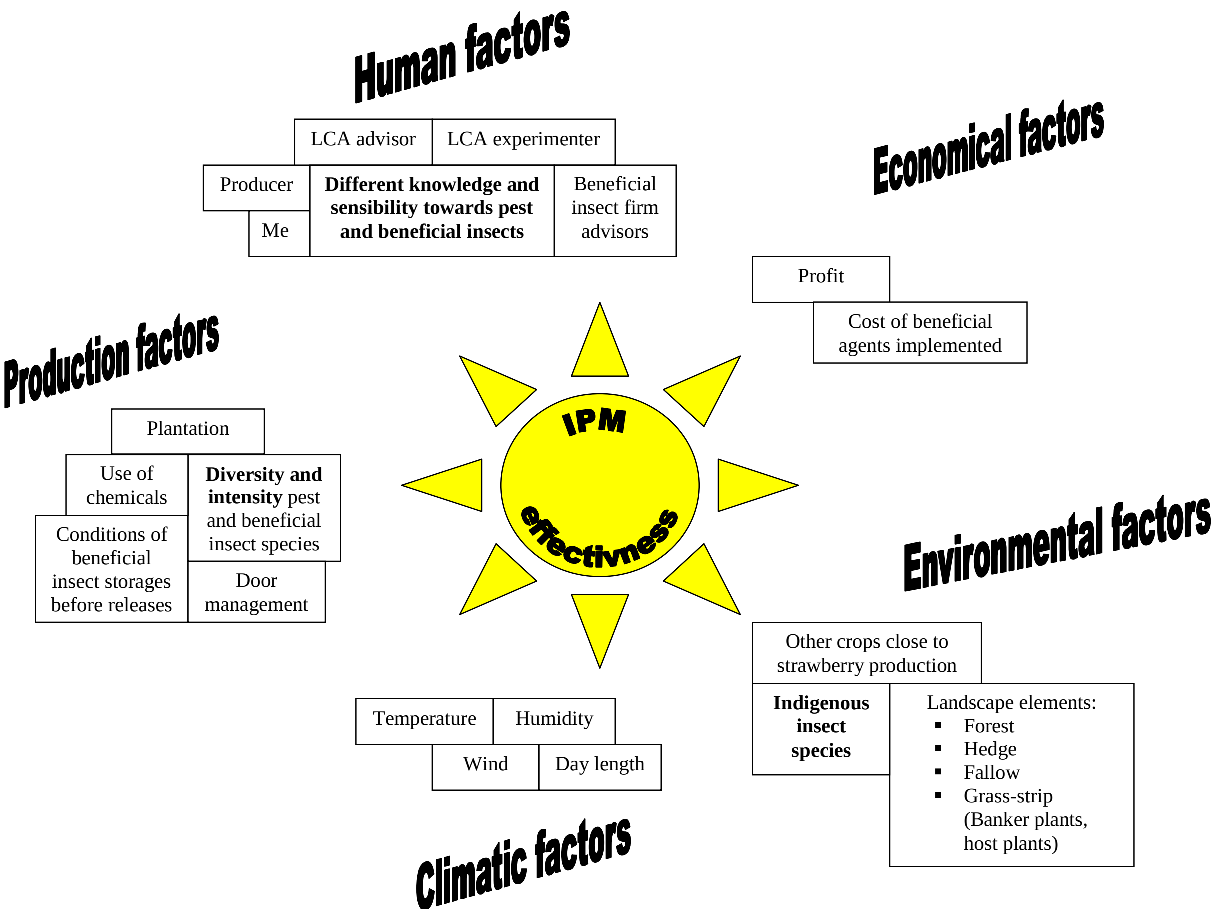


Figure 42: Factors influencing IPM strategies effectiveness

Lots of **production factors** seem to be linked to pest management.

Plantation characteristics seem to have an impact on pest and beneficial insect arrival dates. Producer 2 plot gives lots of information. We observed that pest and beneficial insect populations were different from one tunnel to the others. Ages of the bag seem to have an impact. Second year bags are more likely to be exposed to pest presence, when pests were already occurring the previous year. They spend the winter inside the bags. An interesting point is that this producer changes half of his bags every two years. And he always starts to plant from the same side. This year, the first strawberry plants were planted at the beginning of february, in second year bags. Next year, he will change those bags and start to plant also from this side, because those "tunnels are protected by the forest". If monitoring will be realized next year, they might be able to see if any highest pest pressures and higher number of beneficial insects are due to bag ages, plantation dates or the forest proximity. To optimize integrated pest management by introduction, the link between strawberry plant stage, intensity of pest and date of beneficial insect release need to be more study in next years.

Tunnel doors are managed differently. At the station and by the producer 1, there were no doors. Producer 2 has some doors that he opens and closes manually. He closes the doors, when he releases some beneficial agents, or when it was windy or cold. The producer 3 has automatic doors. The doors are opened and closed, when the appropriate climate inside the tunnel (temperature, humidity and wind under the tunnels) is not adapted to his goals. He also closed the doors when he released beneficial agents.

Pesticide effects have to be taken into account in order to optimize IPM strategies. Some chemicals can be harmful to beneficial insects but not to all of them. I create a technical sheet for the producers, which will be useful for them. This table crosses information from three different sources. (http://www.biobest.be/neveneffecten/2/none/ ; http://actions-secondaires.koppert.nl /; http://e-phy.agriculture.gouv.fr/). Non desirable effects of pesticide are classified for each beneficial insect from the less harmful to the more harmful (Appendix 2). A technique that is used in IPM strategies is to make a chemical application late in autumn or early in spring, before planting or just after the plantation. This has a cleaning effect; this is one of the strategy point which differs between the producers 1 and 3 and between the station and the producer 2. The two first one have made treatments early in march especially against tetranychid mites and the seconds did not.

IPM program should be though more global. An IPM strategy against thrips can not work with *Aphid sp*. and *Lygus sp.* chemical strategies. The only pesticide (Calypso) that can be use during the harvest against aphids and lygus is harmful to *Orius sp*..

Release conditions need to be optimized. Storage temperatures are written on beneficial insect packages. Storage time is about one or two days, after reception. But the fastest they are released the best it is. Beneficial agents should be implemented as far as possible from a chemical or from strawberry cleaning plant actions. The different actions have to realize on plants before the reception of beneficial agents. For example, if stolons or old leaves need to be cut, it would be preferable to do it before the releases. The removal of old leaves seems to have an impact on pest and beneficial insect populations as we saw it in the plots of the producer 2 and 3, at the beginning of july. The anti-oïdium treatments did not seem to have a real impact on insect populations, because of their modes of action. In the middle of july the Nimerod treatment by the producer 3 did not have any impact on them. Beneficial agent activity and healthiness should be controlled at the reception of the package. Two producers closed their doors when they release the beneficial insects. It seems to be a good point because in the Sologne area in spring there is a lot of wind and for beneficial insects like *Chrysope sp.* and *Orius sp.* could go with the wind. The larva stage could fall down and can not go up again, and the adults could go in another culture. Producers have to wait after releases that beneficial agents are reaching the level to manage the insects. If they are not able to wait for an equilibrium to be reached, they should not work with IPM by introduction.

E**nvironmental factors:** landscape elements like forest, hedgerow, fallow and grass-strip as well as crop productions close to strawberry plots are habitats for indigenous pest and beneficial insects. The real dynamic of population is difficult to be taken into account. Management of landscape elements needs to be more invested. With the landscape element trial we saw that landscape elements can be strengths for some pest control (*Aphid sp*. and *Thrips sp*. with the clover-strip) and weaknesses for others (*Tetranychid mite sp.* with the clover strip) Associating crops could be interesting to study later on.

Human factors are link to knowledge and sensibility of the different stakeholders of IPM strategies. Producers, advisors, experimenter and me, we saw pest and beneficial agents from a different point of view linked to our experiences and back ground.

Through all my discussions with producers, it appears to me that their motivations were a little different. I think IPM success or at least their level of tolerance is partly due to their motivations. The producer 1 already has some issues with the thrips. He has reached an impasse with chemicals, because they do not work any more on his farm. For him, he was expecting that the beneficial agents were going to work very well. It seems that he could have some bad practices with chemicals. Molecules that should be used once or twice a season were applied 6 or 7 times. The Success treatment is the best example, and some resistance phenomena appeared. He expected a lot from this IPM but he is disappointed. The producer 2 is tired of taking time under his mask in order to treat. He spends 5 hours to treat all his strawberries. He does not like it, so he wants to decrease treatment numbers. He is ready to use beneficial agents even if it is more expensive. He told me that this year, he applied between two times less pesticides than last year. He was very positive of this year results, in his plot. The producer 3 started to make IPM about 6 or 7 years ago, he told that sometimes it works and some other times it fails. His weakness is the Lygus, which appears, after few years of IPM. He wants to become more independent from pesticides. And he always wants to be at the technical innovative top.

The level of tolerance is different from one producer to the other one. Their level of tolerance can evolve within the years or in a same season. Producer 3 is a good example, when he started to use IPM method, he did not accept to have 1 thrips per flower whereas this year he accepted for a long season a mean of 5 thrips / m² and no damages were observable. This year, at the beginning of the season, the same producer told me that he used to treat Lygus as soon as he sees one specimen. In july, he told me that he preferred to conserve his Orius instead of suppressing his Lygus. The feeling and knowledge change with experience and might be linked to the season period. At the beginning of the season, pest management needs to be stricter because less beneficial insects are present. If pest occurs early in the season, it could have a negative impact on the production season. A risk for having bigger pest population could increase with climatic factors. For example, if producer 2 accepted higher level of *Aphid sp.* his can be linked it is because he knows that he has indigenous beneficial insect against *Aphid sp.*

During the restitution time, they express the fact that they are not ready to take as much time as I did to monitor weekly the evolution of pests and beneficial insect populations. For next year, they would like to do again the monitoring in collaboration with the LCA station. They improve their knowledge within the years. Using a technical method on their own plots, bring them much more than coming at the station in order to look at the results. This is even more right because the IPM strategy is influenced by lots of factors. Plot environments, as well as producer sensibility toward tolerable pest level are factors that influence the IPM effectiveness. Participatory action is a good way in order to set up strategies within the years.

Other producers were present during the restitution time. They laugh, when we spoke about secondary pests species. They say, "it costs more and your have new issues…". The other producers are not ready to use IPM strategies. The main reason is the high cost of IPM strategies by introduction. Another reason is that beneficial agents are less reactive as chemical: it takes more time to see the effect and is a safer method for them.

Koppert advisors define the strategy before the season. Some adaptation can be added when it was needed. Syngenta advisor seems to adapt beneficial insect introductions to the evolution of the pests. Delivery delay is usually shorter with Koppert than with Syngenta. Both of the two firms have strengths and weaknesses.

A tighter relation should be created between the producer and the advisor, because it happens that the producers made some treatments which were not compatible to beneficial insects before they received beneficial insect. Implementations have to be taken it into account when they organize their planning. Producers should write on their calendar dates of releases. As the beneficial insects by introduction are expensive, implementation conditions should be the best for them. The strategies should be more adapted, when some non predicted treatments are made. For example producer 3, needed to treat with a Calypso at the end of may and the *Orius sp.* arrived at the same time.

My experience as pest and beneficial insect observer give me information about what to do or not to do. Limits of my observation, and also to all new observers are that I learn to identify beneficial insects within the time, when I found them. Some time there were one or two weeks between the first time I saw a new insect and the day I started to register it.
At the beginning I make my observation at any time of the day. But one day I made it in the middle of a warm afternoon I thought there were fewer insects than when I did it in the morning. Since this day I try to do my observation in mornings.
Each week on thursday I did my observation by producers, I always did my observation on the same sides. (Producer 1 in the morning, then the second one and the last one in the middle of the after noon) It was easier and it limits day time impact.

Each people have his own way of observation, and his own sensibility to this and to this pest or beneficial insect. For example the producer 3 has his own way to detect the presence of *Lygus sp.*. He searched for deformed fruits with ‘cat head’ and then he sees the *Lygus sp.*. I was shaking plants to make the *Lygus sp*. fall into a yellow bowl.

As it was the first time that I follow pest species in a culture, I think that I was less afraid of quite high pest populations. I did not see before real negative effect on the strawberry qualities, beside the thrips pest by the producer 1.

Economical factors are linked to beneficial agent cost, compared to the strawberry production profit. As we saw it earlier, the profit is of about 1,68 €/m². IPM strategies by introduction for thrips and tetranychid mites cost about 0,5 €/m² when aphid strategies are included we are above 1 €/m². It means that the profit decrease of 30% when IPM strategies cost about 0,5 €/m² and of 60% when IPM strategies are above 1 €/m². (They are based on mean prices) The effectiveness of IPM strategies are linked to beneficial agents cost.

Climatic factors influence pest and beneficial insect population intensity and diversity. Insect life cycles are link to day length, temperature and humidity. The wind is a factor that influence insect repartitions in the environment. The weather had an influence on my observation. I think that on very warm day, on rainy day or on cold and windy day, I observed fewer insects. We registered the temperature, but we have not been able to link it to other factors.

All those factors show the importance to **adapt the strategies to producers and even to the smaller plots** characterized by production factors. Some other factors that are not quoted could have impact on IPM method efficiency, but our results did not highlight them.

7.2. <u>Limits of a specialized production from a sustainable point of view</u>

Strawberry production in hanging gardens is a very specific production. Most of the producers only produce strawberries on their farms. Investments for such structures (tunnel material and irrigation systems) are very expensive and high inputs are needed every year from strawberry plants, to compost bags, chemicals and fertilizers. Therefore production costs are very high ad profits per kilo of fruit is low. All their productions are sold on the global strawberry market in one place. Even if they do not control their selling prices, their products would be sold in nearly

every case without having to find buyers. Their systems are working quite well and they don't want question them. They are part of the global food system.
In a more diversified system, producers need to have knowledge on lots of topics, but they are less specialized on each production. Most of the times, they need to find buyers in different places, which takes a lot of time. However, one of the main advantages of this diversification is the possibility of crop rotations which is a good mean to control some pests and diseases with various practices.
The introduction of beneficial insects is not very sustainable. They need to be implemented each year. Equilibrium will be difficult for reaching such an artificial production system. We do not know impacts of introduced insects on the other indigenous insects. In one hand they want to solve their solutions, and in another hand they might induce new issues.

7.3. What does this project brought me for my learning process?

When I started the project, I had very small knowledge about insects: pests and beneficial agents. In this project I go back and forth from the theory to the practice. When I read some think I could not make it mine until I saw it. Observations are completed by readings. I increase my awareness about pest issues and beneficial insects in an agricultural system. To work with insects is not that easy. As we are working with living organisms, lots of factors have an impact on them. The human being is not neutral, each people has his own back ground, his own knowledge and his own feelings. As the way of working is not the same, it is sometimes hard to work together. Communication is not so easy, in a working group. To work with four real cases situations in order to improve producers issues are very rich, and show the complexity of dealing with living organisms in an agroecosystem. Lots of people to who I presented my project spoke about a paradox situation: working with beneficial agents in a such intensified system.
For me their issues are at the bases of their production system. The system should be thought more globally. But in such highly intensified or industrialized system, it is hard to improve their bases because the production is based on input material. The farm is just a support of production. They could produce at the top of a supermarket; it will not be much different !

My project can be presented as a first step toward co-working process, between experimenters, advisors and producers. The monitoring in producer field as well as at the station are fulfilling the gaps between knowledge and real production situation.

Conclusion

Nothing is better for such a thematic than to work directly in real situations: on producer plots. Parallel monitoring of plots in 4 different farms enables us to highlight factors that seem to have an impact on IPM strategy effectiveness. Trials on several years can differ because of climatic conditions. Seasons are different from one year to the other one. It makes it difficult to compare different strategies under different weather conditions. With 4 plots weather factor was eliminated and other factors could be highlighted.

Stakholders wanted to set up IPM strategies adapted to the Sologne area. Production, environment and climate factors need to be taken into account, in order to set up strategies adapted to producer willingness. The human factor is important, because knowledge and sensibility is different depending on previous experiences. This project shows that the strategies have to be adapted at the farm level and sometimes even at homogenous production plot level. IPM needs a close monitoring, in order to set up strategies adapted to each case. This project is part of a longer term project. For each pest issues in each producer context some propositions are made, in order to improve their method of pest management for the year to come. To reduce pesticide uses other IPM methods than introduction or conservation of beneficial insects are available to be tried as insect proof net, juice of garlic extract, trapped plants,... Landscape elements have an impact on pest and beneficial population bringing the first one or the others in strawberry plants. So this topic needs to be studied further. IPM by conservation could be a more sustainable biological control system from the economical and ecological point of view, but the main limit of IPM by introduction is the cost.

When natural elements of ecosystem have to be taken into account, we are dealing with compexity. Dealing with agroecosystem is a challenge, one issue can not be answered by one solution, a group of issues can be improved by association of small solutions.

Aim such as reducing pesticide uses have to be a complex association of different methods. Different stakeholders bringing their own knowledge and feelings need to work together, when dealing with such innovative techniques. Integrated pest management needs to be experimented, improved within the years, by taking into account pest issue evolutions.

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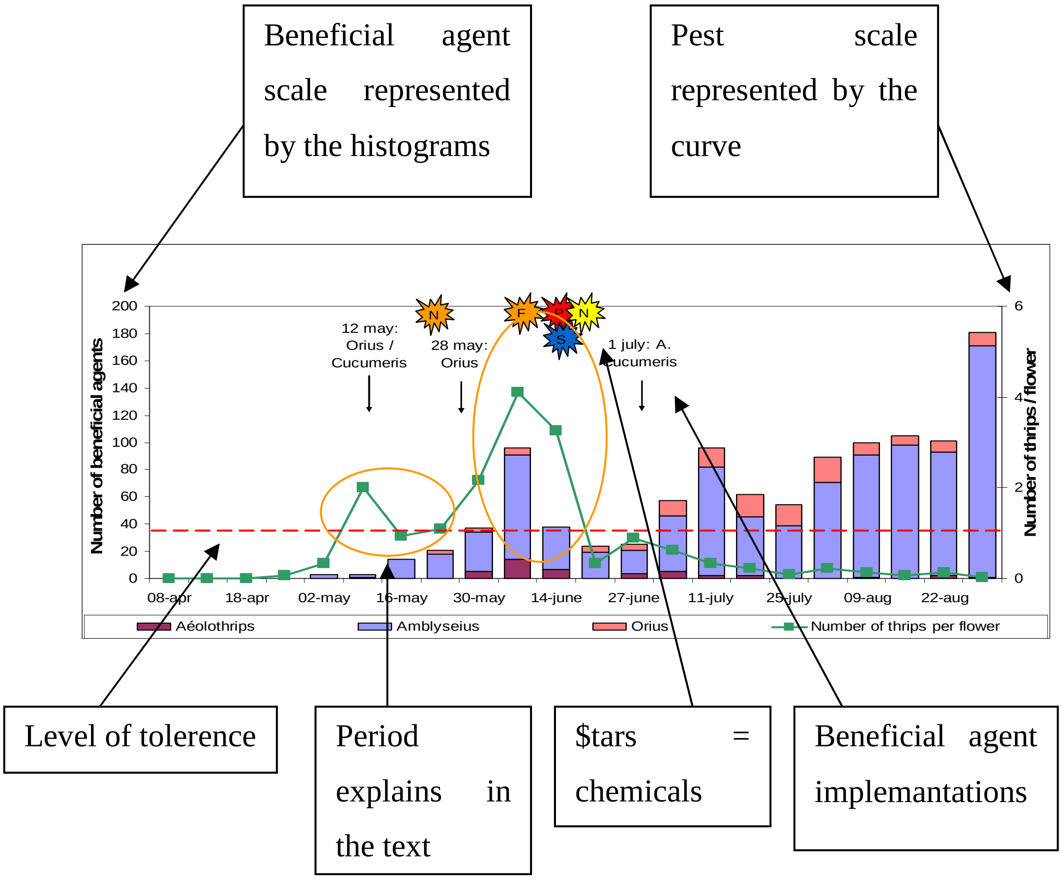
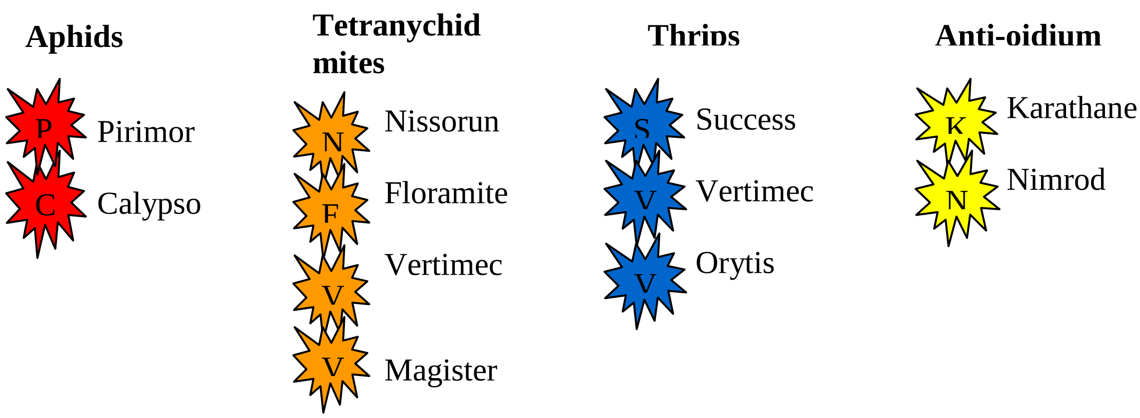
Appendix 1: Graph description

The results are based on graphics. A short description is needed. This page can be kept open during all the report for the chemical legend.

The scales are not always the same.

Not all anti-oidium treatments are represented. (A treatment every one or two weeks)





Chemical legend

Colours are linked to aimed pest

Appendix 2: Non desirable effect of pesticides on beneficial insects in strawberry production

LCA
Légumes Centre Actions

Non desirable effects of pesticides on beneficial insects in strawberry production

	Mites						Aphids				
	Appolo 50c	Nissorun	Floramite	Magister	Vertimec	Ortyis	Pirimor G	Calypso	Karate	Talstar	Decis
	Clofentezine	*Hexythiazox*	*Bifenazate*	*Fenazaquin*	*Abamectin*	*Acrinathrin*	*Pyrimicarbe*	*Thiacloprid*	*Lambda-cyhalothrin*	*Bifenthrin*	*Delta-methrin*
Amblyseius andersonii											
Amblyseius californicus					5 d						1 <=> 4
Amblyseius cucumeris							1E / 3L & A				
Amblyseius swirski											
Aphidius			3L / 1A		1L / 4A					2L / 4A	2 <=> 4
Aphelinus											
Chrysoperla carnea					1L / 4A	3L / 4A		4L / 2A	2L / 4A		
Orius leavigatus				3L / 2A		4 d					
Phytoseiulus persimilis			1 w	1 w	1 w			2 w			
Aphidoletes aphidimyza					1 w						
Ladybug											
Staphylinides											
Syrphes									↑	↑	↑
Feltiella acarisuga			1 w		1 w				8 w	8 w	8 w

	Thrips			Oïdium						Botrytis	
	Success 4	Orytis	Dicarzol 200	Ortiva	Nimrod	Systhane *	Iodus	Topaze	Karathane	Rovral	Reduction of the capacity of fight of the beneficials
	Spinosad	*Acrinathrin*	*Formetanate*	*Azoxystrobin*	*Bupirimate*	*Myclobutanil*	*Laminarine*	*Penconazole*	*Methyldinocap*	*Iprodione*	
Amblyseius andersonii											1 : 0-25%
Amblyseius californicus									2 w		2 : 25-50%
Amblyseius cucumeris	1 <=> 4										3 : 50-75%
Amblyseius swirski											4 : 75-100%
Aphidius		3L / 4A									No data
Aphelinus											
Chrysoperla carnea	1L / 4A										Persistance :
Orius leavigatus	4L / 2A										d :days
Phytoseiulus persimilis					4 d				5 d		w : week
Aphidoletes aphidimyza											L : Larva
Ladybug											A : Adult
Staphylinides											E : Egg
Syrphes											<=> :
Feltiella acarisuga	1-2 d	4 d									Contradiction

Compilation of data of three sources : Koppert / Biobest / E-phy

* Mycloss / Atomium / Licorne

Appendix 3: Compatibilities between aphid species and parasitoid species

	Aphidius ervi	*Aphidius matricariae*	*Aphidius colemani*	*Ephedrus cersicola*	*Praon volucre*	*Aphelinus abdominalis*
Macrosiphum euphorbiae	**x**				**x**	**x**
Chaetosiphon fragaefolii				**x**	**x**	
Rhodobium porosum	**x**				**x**	**x**
Aphis forbesi		**x**				
Aphis gosypii		**x**	**x**	**x**	**x**	

(Source: Viridaxis advisor)