

The potato fungicidal protection during the active growth period

Mathieu CLAEYS
European Engineer Degree
December 2018, France
Coach : Schilt, Hermann



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Preface and Acknowledgements :

This thesis was meant to be something else through my placement in Australia. Unfortunately, following one of the most important drought for 25 years, I was not able to use any data on the trial I wanted to work on. Therefore, I used the trial field and data I had collect during my last diploma about the potato protection. The topic is one of my favourite because of the local aspect in the production and the many possibilities it offers.

I would like to thank from the bottom of my heart the Barber family who show me and made me discover a lot about Australia : its agriculture as well as its culture. I also would like to thank Mr Hermann Schilt for his support through the periods I needed it.

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Summary :

Potato, came from south America long time ago, the tuber is grow about everywhere in the world to become the fourth worldwide crop. Its worst enemy is an oomycete, the *Phytophthora infestans*. This disease is responsible for millions of deaths and forced migration in Ireland during the Great Famine from 1845 to 1852. The Late blight is present everywhere the potato is present. Its development conditions are easy to find : only liquid water and temperature between 18 and 26 °C. The disease (Late blight) is able to destroy a field in less than two weeks. To fight this pest, a lot of chemicals are present on the market with several molecules. Are also present, the biocontrol solutions such as the Potassium phosphite. Those products are based on natural process to inhibit the disease and/or improve the natural defences of the plant. The objective of this reseach was to come up with a recommendation about some chemicals tested. This thesis is based on a trial, the main question was about determinate the best chemicals during the active growth period of the potato. The stage of the crop is one of the most important because during this period the plant regularly make new leaves and stems that need to be protected to avoid any infection. In this trail, 10 modalities have been tested containing 6 different chemicals from the main phytopharmaceutical firms. Revus and Remiltine Flex have been tested with two cadences (5 and 7 days) and the Remiltine Flex has been tested with two different doses (0.5 kg/ha and 0.6 kg/ha). More than the main question, fore sub-questions have been raised. The goal was to know : the gain of gathering Mandipropamid with Cymoxanil compare to Mandipropamid alone, the benefits of a higher treatment cadence, the effect of decreasing the dose of Remiltine Flex by 100 g/ha and to determinate the better curatives solutions. To asses those treatments, visual notations of the percentage of infected area present on the micro-plot have been process along the test period. At the end of the trial, valid results have come up : the best modality is the Remiltine Flex 0.5 kg/ha with a cadence of 5 days with 12.75 % of infected area. The worst treatment is Proxanil with the higher score of 82.5 %. Trough the trial, the importance of choosing a curative product with attention has been shown. Indeed, between Proxanil and Remitline Flex both tested at the maximum dose and a 7 days cadence, the Remiltine Flex is better by 67.25 %. At the end of the thesis some recommendations have been made. First, respect the maximum utilisation number of each chemicals is essential for the potato industry. The criteria exist to prevent chemicals resistance of the *P. infestans*. Knowing the dangerousness of the disease, any resistance is a drama. For the same reason, alternate chemicals and prepare a treatment programme which is both efficient and prevent resistances is a smart move.

Chapter 1 : Introduction

1. Presentation of the potatoes.

Originally from the Andes, the potatoes (*Solanum tuberosum*) was bring in Europe by the conquistadores in 1 500. First unpopular, it took it 200 years to become a true source of food. Botanically speaking, potatoes is part of the Solanaceae family. *S. tuberosum* is an herbaceous perennial plant with stems that can reach 1.2 m tall and subterranean stolons. Its root system goes from 40 cm to 1 m deep. Tubers developing take place at the tip of the stolons. There are lot of different varieties which produce a big range of various tubers (size, weight, tuber skin and flesh colours). It has alternate and petiolate leaves with a dark green colour. The flowers are composed by a panicle with a peduncle of 5 to 15 cm long. Those flowers are white or white suffused with pink or violet. The fruits are subglobose berry with a size of 2 cm in diameter and a yellow-green colour with many seeds. There are very poisonous as they produce solanine (CABI, 2018. *Solanum tuberosum*). The growth is split in five steps (Pack, White, Hutchinson, 2016) :

- Sprout development : the eyes of the potato develop sprouts, which emerge from the soil.
- Vegetative growth : the leaves, stems, and root system form, photosynthesis begins, and the plant prepares to store nutrients in tubers.
- Tuber initiation : tubers begin forming on the end of stolons (underground stems), usually before the plant flowers.
- Tuber bulking : tubers enlarge. Sugars and starches accumulate.
- Maturation : the tubers reach full size. The top of the plant dries out and dies. During maturation, the tuber skin toughens, extending storage life.

Table 1: Production and surface of potatoes in Europe

Pays	Hectares	Tonnes
Belgique	90 727	4 010 000
Allemagne	164 500	7 485 000
France	125 250	5 106 500
Pays-Bas	72 800	3 363 000
Grande-Bretagne	99 200	4 583 000
Espagne	73 200	2 244 000
Italie	48 050	1 368 000
Total	673 727	28 159 500

Source : Panel UNPT/CNIPT et NEPG - Statistiques nationales - Campagne 2016-2017

The world potato production is 376,827,000 tonnes in 2016 (FAOSTAT, 2018) which make it the fourth crop on world (Daniels-lake, 2015). Potato is an important crop in France and in Europe. There are 125 500 ha in France with a production of 5 106 500 t which rank France second producer of Europe like shown in table 1.

Potatoes is also a source of numbers benefits antioxidant, hypocholesterolemic, anti-inflammatory, antiobesity, anticancer and antidiabetic effects : . The components in it are : proteins, carbohydrates, minerals, vitamins and biologically active phytochemicals such as β -carotene, polyphenols, ascorbic acid, tocopherol, α -lipoic acid, selenium and dietary fibers. All those nutrients are concentrate in the peel (R. Visvanathan et al, 2016)

2. Presentation of the Late blight (Phytophthora infestans)

The Late blight is a very important disease in the potato history, that was the cause of the Irish famine (The Great famine) because of the destruction of the big majority of the production between 1845 and 1852 and killing about 1 million people (History. 2018, Irish Potato Famine).

The Late blight can be found everywhere in a world where potatoes are grown. This disease attack either potato and tomato but also other species in the Solanaceae family. Often include in the fungus family, *P. infestans* is not one of them, it is an oomycete. It is more related to the algae family.

Life cycle :

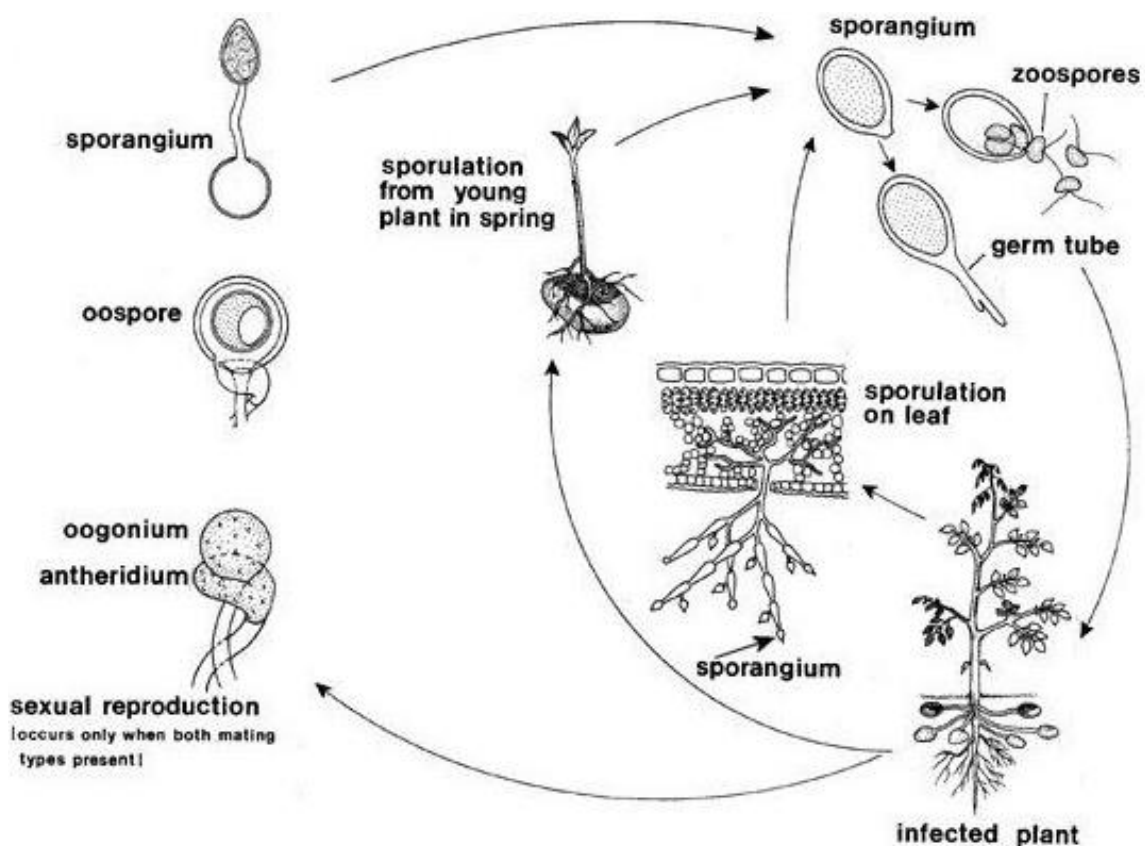


Figure 1 Life cycle of late blight, *P. infestans* (author : unknown)

Like seen on the figure 1, the *P. infestans* had a short reproduction cycle which ensure a quick dissemination of itself. The disease has two reproduction ways : sexual and asexual (Pacific Pests and Pathogens, 2018).

a) Asexual reproduction

The asexual reproduction of *P. infestans* is possible by spores called "sporangia". To germinate, no matter the temperature, those spores need liquid water on the leaves. Then depending on the temperature, there are two possibilities :

- With a temperature between 21 and 26 °C, the spores (sporangia) infect the plant directly.
- With a temperature between 18 and 22 °C, the sporangia produce smaller spores which are zoospores. Then those spores go in the plant and infect it.

b) Sexual reproduction

The sexual reproduction of *P. infestans* is possible when two compatible types are present. Antheridium and oogonium produced by the disease fuse together and form an oospore. This spore evolves in sporangia and the cycle start again. That phenomenon need to appear precisely in the same field, on the same leaf and results with a production of oospores (J. E. Yuen and B. Andersson, 2012).

The impact :

Without treatments, the Late blight can destroy a field in about two weeks. There are also post-harvest impacts where the Late blight can result in a whole rotten storage which means a big money loss. When the A1 and A2 strains meet each other, in case of sexual reproduction, the disease become more aggressive and more destructive (Pacific Pests and Pathogens, 2018). The annual cost of this major disease in England for instance is estimated at about 56 million euros just for the protection (AHDB potatoes, 2018).

The symptoms :

- On the leaves, there are irregular brown-dark spots not limited by the veins and expanding rapidly (figure 2).



Figure 2 : Late blight on potato leaves (source : potatopro.com)

- When the disease is producing spores, a white cotton is appearing on the infected spots (figure 3).



Figure 3 : Late blight white cotton (source : apsnet.org)

- When the disease reaches the tubers, humid rotten brown spots converging to the centre appear (figure 4-5).



Figure 5 : Late blight on tuber (source : potatoes.ahdb.org.uk)

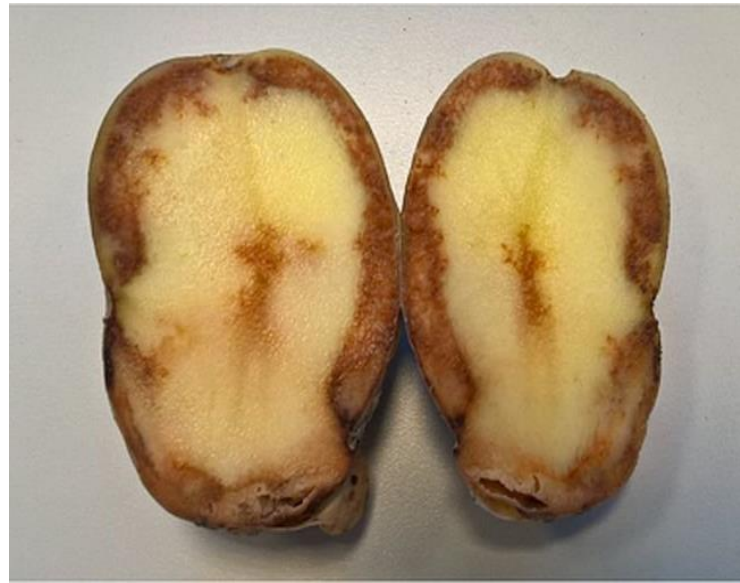


Figure 4 : Late blight trough tuber (source : potatopro.com)

Controls methods :

There are prophylactical (\neq curative) methods to prevent infections, such as : use of certified seeds, respect of length between two potatoes crop, destruction of the wild potatoes and waste from sorting.

Then there are chemicals methods. Utilisation of divers molecules such as Amectotradin, Dimethomorphe, Cyazofamid, Mandipropamid, Cymoxanil, Propamocarb, Fluopicolid and others present in commercial specialities. In 2014, the French farmers had a mean treatments frequency of 18 for the potatoes crops. In those chemicals application, 14 was only against Late Blight (Verjux, 2018).

Biocontrol :

In France the plan Ecophyto 2 (Ministère de l'agriculture, de l'agroalimentaire et de la forêt, 2015) raise by the government mandate the farming industry to use -25 % of chemicals in 2020 and -50 % in 2025 compare to the period 2009-2014 (Chambre d'agriculture, 2018). To reach those goals, the biocontrol is an effective way because that does not count as chemicals but still have a good efficiency (Machinandiarena et al, 2012). The biocontrol was the only tools farmers got before the chemical revolution. It is based on natural process to help against pests (CABI, 2018).

Against Late blight on potatoes, the most used biocontrol is Potassium phosphite. It is inducing defence reactions in the plant. Their have a direct inhibiting effect on growth and sporulation of oomycetes as well (Lijlroth et at, 2016).

Chaetomium globosum is also present in the fight as a bioagent. It is a fungus which acts like an antagonist through its secretions. Those endo and exoglucanase inhibit the mycelium growth in the plant. It has been tested in India with convincing results (Shanthiyaa et al, 2013).

Resistance management :

Considering the hazard of the Late blight due to its aggressiveness, rapidity and possibility of long terms issues, chemicals resistance is not something that farmers can risk. Unfortunately, a case of resistance has been discovered in Netherlands in 2011. The genotype responsible for that is Green 33 (33_A2) and Fluazinam is the chemical affected by the decreasing of its efficacy (FRAG-UK, 2016).

Quick management guideline extracted from FRAG-UK (2016, p3) :

1. Cultivar : when the product destination/contract allows it, a resistant potatoes variety is a start to avoid contaminations.
2. Outgrade piles : those are important to destroy because they are an important source of inoculum. The entire destruction can require more than one action, it is useful to check the piles during the season.
3. Regrowths : some tubers are always left behind during the harvest and can regrowth in the crop. Because those individuals are not protected specifically, they are inoculum sources and a proper destruction is required.
4. Seed : being assured to use healthy seed, free from any inoculum (of any kind) is an easy way to avoid primary contamination in the field.
5. Starting of the population programme : few tools are available to help the grower in the fight against the *P. infestans*, e.i : BLITE-SVR. Being in the right time is important to contain the disease.
6. Tubers : when the disease is well established, it is preferable to top-kill the crop in order to protect the tubers but also brake the spore's dissemination.
7. Action modes repetition : using a maximum of different molecule with different action modes is the way of avoiding the selection of resistant populations among the disease.
8. End of the season : to avoid tubers infections, it is important to protect the crop until the whole vegetation is dead. Using fungicides with tubers blight activity might be needed.
9. Rotation : respect a 4-5 years period between two potatoes crop. The cadence of potatoes return on the same field is part of what define the amount of inoculum in the soil. It requires time to break the cycle.

3. Context of the research :

This research has been done in the experimentation team of Syngenta. The goal was to test the efficiency of the Mandipropamid alone and in a couple but also to compare the Syngenta range with the other actors of the market. The active growth period is an important stage of the plant because it produces new leaves regularly and those need to be protected as well to avoid any infection that could be the start of a disease dissemination. The trial fields are also support for a client's presentation.

4. Limits of the research/trial :

In this protocol, only one chemical is applied on the crop during the whole season. This is an aberration for a farmer, but this is the only way to attribute the results collected to the chemicals tested.

5. Main question and sub-question :

Which commercial speciality is the most efficient to manage the Late blight during the active growth stage ?

SQ 1) What is the adding value of the Mandipropamid with Cymoxanil compare to the Mandipropamid alone ?

This question aims to test the efficacy of the Remiltine Flex which contains Mandipropamid (spreading way) and Cymoxanil (penetrating way) that is able to take back recent infections (less than 3 days).

SQ 2) What is the adding value of a 5 days cadence compare to a 7 days cadence ?

This question aims to know if the effectiveness increases with more treatments in the same period. For that, both the Syngenta chemicals were tested with two cadences.

SQ 3) What is the adding value of a dose of 0.6 kg Remiltine Flex compare to 0.5 kg Remiltine Flex ?

This question aims to know to real efficiency of the Remiltine Flex with 100 g/ha below the approved dose.

SQ 4) What is the best curative modalities ?

There is only one curative molecule working on *P. infestans*. In this trial, two chemicals tested have it (Cymoxanil) but always with a partner. This question aims to know which chemical is the most efficient.

6. Objective :

The objective was to determinate which commercial speciality is the most efficient. In the case of the Syngenta range present in the experimentation (Revus and Remiltine Flex), which cadence, and which dose give the more efficiency.

The answers expected was : the higher cadence is the higher efficiency; the higher doses are the higher efficiency and the Mandipropamid is more efficient than other molecules.

The goal of writing this thesis was to show the importance of the chemicals choices during this sensitive period that is active growth on potato.

Chapter 2 : Material and Method

In order to realise this research, the equipment used was :

- Plantation machine
- Experimentation sprayers
- Water sprinklers and irrigation station
- A weighting scale

1. Method per question :

Main question : Which commercial speciality is the most efficient to manage the Late blight during the active growth stage ?

To answer this question, 6 chemicals from 5 firms have been tested. Those chemicals have been chosen either because they are the actual reference and because there are from the Syngenta range for 2 of them.

SQ 1) : What is the adding value of the Mandipropamid with Cymoxanil compare to the Mandipropamid alone ?

To answer this question, 2 chemicals containing 250 g/l of Mandipropamid have been tested with one of them containing 180 g/l of Cymoxanil in complement (Remiltine Flex).

SQ 2) : What is the adding value of a 5 days cadence compare to a 7 days cadence ?

To answer this question, the two Syngenta chemicals (Revus and Remiltine Flex) have been tested at the same doses but one modality with a treatment every 5 days and one modality with a treatment every 7 days.

SQ 3) : What is the adding value of a dose of 0.6 kg/ha Remiltine Flex compare to 0.5 kg/ha Remiltine Flex ?

To answer this question, the method is simple : two modalities with the wanted doses have been tested.

SQ 4) : What is the best curative modalities ?

To answer this question, a comparison between Proxanil and Remiltine Flex, both containing Cymoxanil have been tested.

2. Trial protocol :

A) Studied factor and modalities :

Chemicals used in the trial :

Table 2 : Chemicals used in the trial : characteristics of each of them

Commercial Specialty/Name	Firm	AD	Active gradient	Nbr of Treatment Max/year	LBH	Resistance to leaching
Zampro Max	BASF	0,8 L/ha	Amectotradin 300 g/L Dimethomorphe 225 g/L	3	7 j	100 mm
Ranman Top	Belchim	0,5 L/ha	Cyazofamid 160 g/L	6	7 j	100 mm
Remiltine Flex	Syngenta	0,6 kg/ha	Mandipropamid 250 g/kg Cymoxanil 180 g/kg	6	21 j	100 mm
Proxanil	Belchim	2 L/ha	Cymoxanil 50 g/L Propamocarb 400 g/L	6	14 j	100 mm
Infinito	Bayer	1,6 L/ha	Propamocarb 625 g/L Fluopicolide 62,5 g/L	4	7 j	100 mm
Revus	Syngenta	0,6 L/ha	Mandipropamid 250 g/L	4	21 j	100 mm

The table 2 present all the chemicals present in the trial. The main firms are present with their flagship product of the moment. Each product comes with its proper regulation. Thereby, the approved dose, the number of maximum treatment per year and the Length Before Harvesting (LBH) are determinate in the approval file during the homologation period. Regulate the spaying amount of certain molecules is one of the way to contain the P. infestans chemicals resistance. The resistance to leaching means the ability of the chemicals to endure a certain amount of rain. In this trial, all the chemicals are upmarket this is why they all have this important leaching resistance.

Table 3 : Modalities presentation : chemicals, doses and date of treatment per modality

	6/6	14/6	19/6	21/6	24/6	26/6	29/6	3/7	4/7	9/7	10/7	14/7	17/7	19/7	24/7	29/7	31/7	3/8	6/8	7/8	12/8	13/8	18/08
BBCH	12	12	21	22	22	23	31	31	33	33	35	55	55	55	55	55	55	55	55	55	55	55	61
Moda 1 Control																							
Moda 2 Zampro 0,8l	X		X		X		X		X		X		X		X		X		X		X		X
Moda 3 Infinito 1,6l	X		X		X		X		X		X		X		X		X		X		X		X
Moda 4 Revus 0,6l	X	X		X		X		X	X		X		X	X	X		X		X	X	X		
Moda 5 Revus 0,6l	X		X		X		X		X		X		X		X		X		X		X		X
Moda 6 Remiltine Flex 0,5kg	X	X		X		X		X	X		X		X	X	X		X		X	X	X		
Moda 7 Remiltine Flex 0,5kg	X		X		X		X		X		X		X		X		X		X		X		X
Moda 8 Remiltine Flex 0,6kg	X		X		X		X		X		X		X		X		X		X		X		X
Moda 9 Proxanil 2l	X		X		X		X		X		X		X		X		X		X		X		X
Moda 10 Ranman Top 0,5l	X		X		X		X		X		X		X		X		X		X		X		X
	Dithane Neotech 75 WG											Shirlan 500 SC (0,4 L/ha)											

Like shown is the table 3, there are 10 modalities. The control allows the test to be placed in the context of disease pressure of the year and is therefore used as a reference for calculating the differences between treated and non-treated. Modalities 4 and 6 received 9 treatments and the other 8. Cover fungicides used outside the active growth period are intended to be representative of farmers' techniques and to protect young shoots (Dithane Neotech) and tubers at the end of the cycle (Shirlan). The conditions of application were an average temperature of 18 °C and an average humidity of 77 %. The chemicals used in the trials are presented in the table 3.

B) Measured and calculated Variables:

To measure the effectiveness of the products, the team had conducted two types of measurements. Just prior to each treatment for the period 17th May to 17th June, the assessments were in the form of Late blight spots counts on all of the microplots (leaves + stems), which followed the evolution of the Late blight in the trial field.

The assessments that followed were made just before the treatments for the period from 27st May to 16th August. These were made in the form of visual notations of the destruction of the Microplot due to Late blight in percentage.

No other variables were considered as this test is not conducted until the tubers are harvested.

B) Experimental device

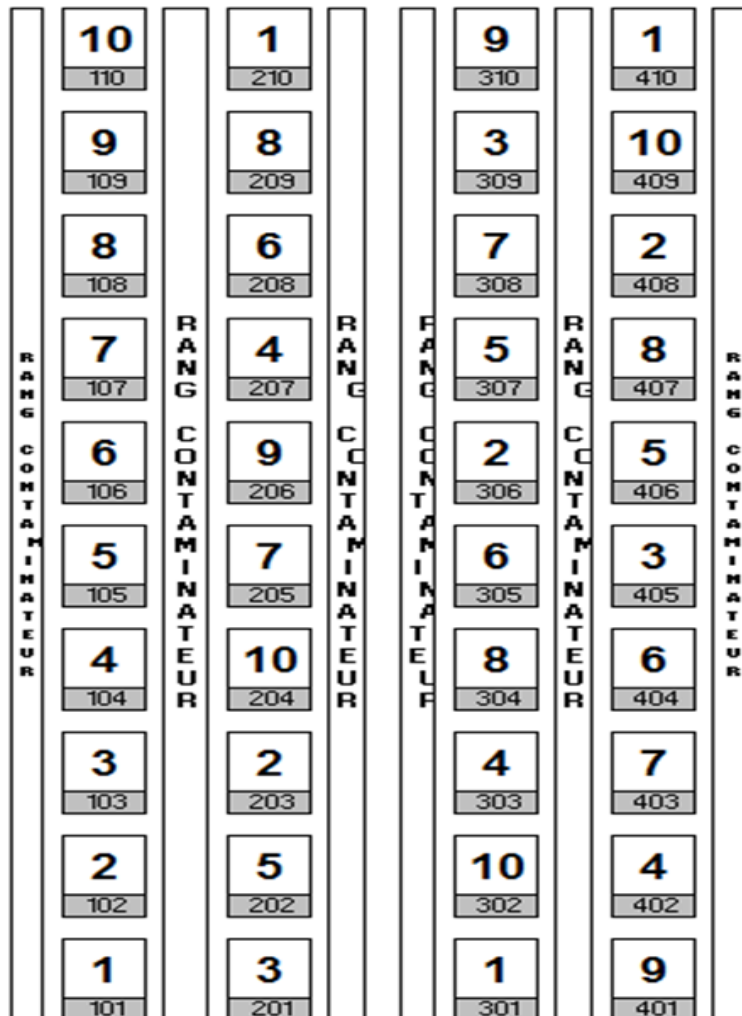


Figure 6 : Trial map

This test is conducted with four repetitions to have as much data as possible with a limited cost. The four repetitions correspond to the four blocks divided into Fisher blocs (figure 6). This mode of experimentation allows to limit the variability of results which are not due to the treatments themselves and thus to increase the accuracy. This is possible thanks to the randomization of the microplots on each block, avoiding that two modalities are next to each other twice in the test to limit the effects of borders and blocs. The Fisher blocs dispositive is also the handier for the team because there are less risks of failures in treatments, the map is simple to use. A microplot is composed of three rows of 75 cm wide over 8 m long, giving a microplot of 18 m². These are planted in the direction of the soil work, but this is not problematic thanks to the very good homogeneity of the test platform. Furthermore, it is an interest in the occupation of the available space. Each block is intercalated between two contaminants rows (untreated and inoculated) to allow homogeneous contamination throughout the test.

C) Conduct and procedure of the test:

The test has been conducted in such a way as to be representative of agricultural practices common to the Hauts-de-France region. Each operation (weeding, fungicide) is carried out in the same way on the test to not cause non-treatment-related differences.

Technical information about the test :

- Grain Corn Harvest
- Winter ploughing
- Tillage 8th April
- Fertilization (200-200-200) 12th April
- Plantation at 36 000 seeds/ha (Bintje) 13th May
- Mounding 14th May
- Weeding 22th May
- Artificial Contamination of contaminants ranks 20th June
- Insecticide 11th July
- Fungicide treatment from 6th June to 16th august
- Altitude : 43 m
- GPS : 49°46'22.3"N 2°22'06.5"E

The test is located on a platform which has been used for potato testing for 15 Years. This parcel was chosen as a platform by Syngenta because it is in an area where there are not much potatoes around, it is 20 min from the offices and it has a silty-sandy texture which makes the soil-work quite easy. To be sure to get a major Late blight attack, many factors are gather : the potatoes returns every 5 years, an irrigation system is installed to bring 65 mm each week (activated according to rainfall) and the variety is sensitive.

In addition, contamination of the contaminants ranks took place about 5 weeks after planting to ensure the development of the *Phytophthora infestans* on the test.

Chapter 3 : Presentation and interpretation of the results

To build this chapter, the data in appendix 1 have been used. The statistical analysis has been done with XLSTAT free trial version which is an extension of Excel. With this statistical software, an ANOVA has been processed . The row data came from visual notations of each micro-plot before each treatment like it is already informed in the chapter 2.

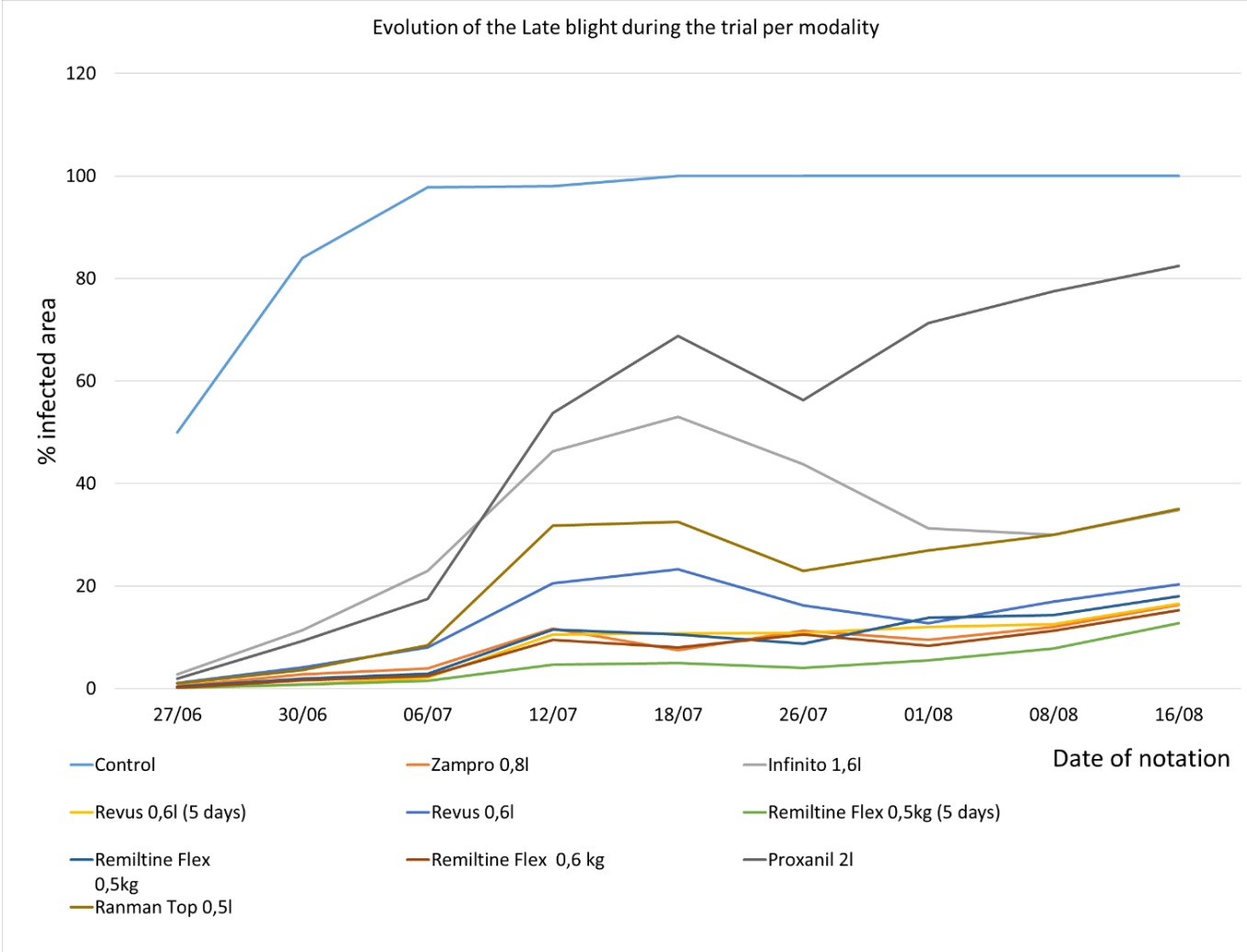


Figure 7 : Evolution of the Late blight during the trial per modality

The figure 7 allows to follow the evolution of the disease during all the trial period. Like it is shown, the disease has destroyed, on every bloc, the control modality entirely quite fast confirming its aggressiveness. To facilitate the analysis and be near by the farming reality, only the last notation has been worked. This is the one that interest the farmer because it gives the sanitary situation just before the senescence. Like presented in the previous chapter, the notations have been made by visual notation of the infected area percentage on the micro-plot.

- Which commercial speciality is the most efficient to manage the Late blight during the active growth stage ?

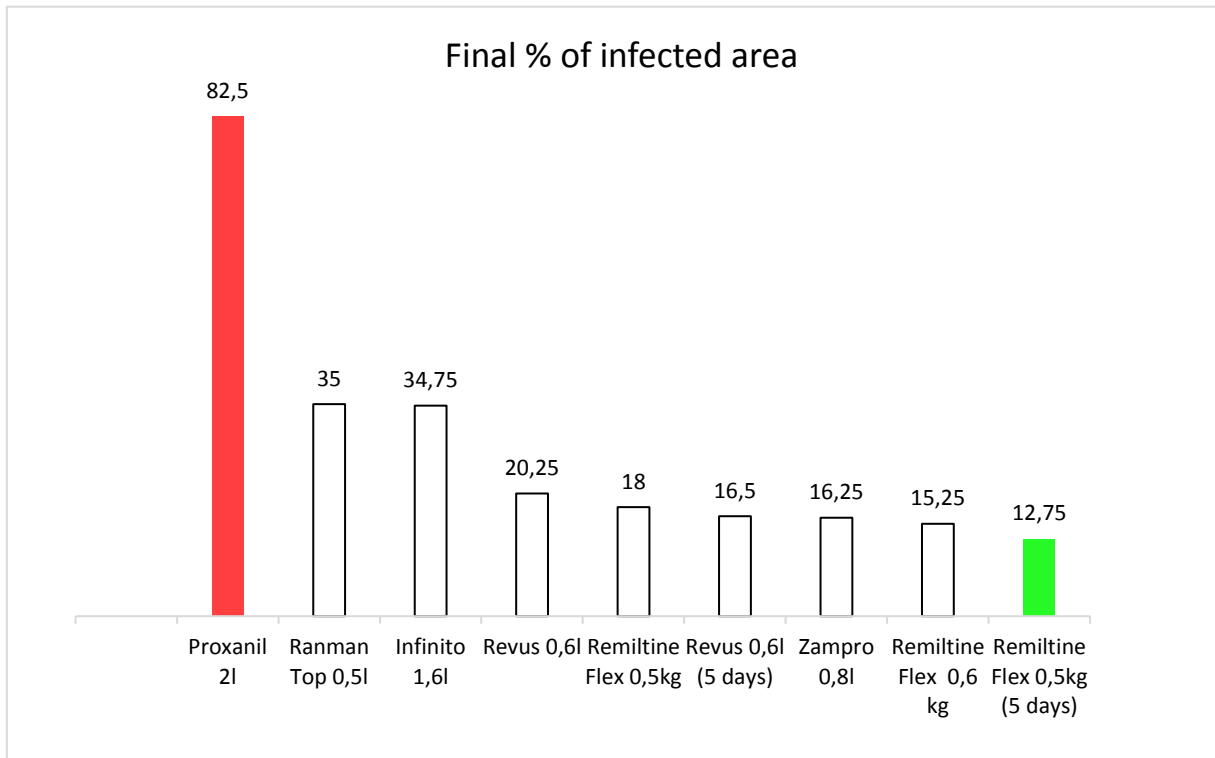


Figure 8 : Final notation of the trial

With the figure 8, the differences between the chemicals is quite easy to see. On the first step : the modality “Remiltine Flex 0,5 kg/ha ; 5 days” and on the second step : “Remiltine Flex 0,6 kg/ha”. Those two products are from the Syngenta range and are composed with Mandipropamid and Cymoxanil. The worst chemical is the Proxanil which contain Cymoxanil as well but with Propamocarb. The efficacy difference between the best and the worst modalities is 69,75 %.

- What is the adding value of the Cymoxanil with Mandipropamid (Remiltine Flex) compare to the Mandipropamid alone (Revus) ?

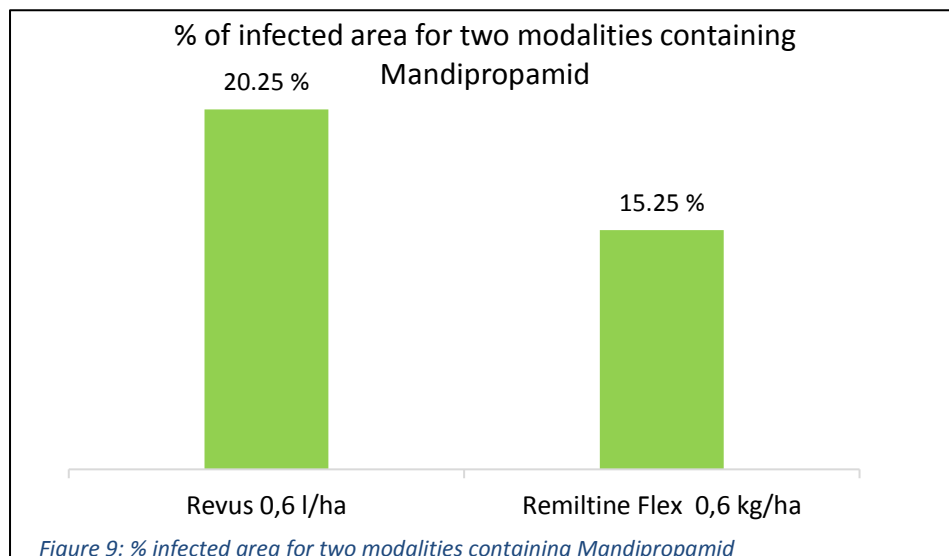


Figure 9: % infected area for two modalities containing Mandipropamid

The first sub-question was about the gain of Cymoxanil combine with Mandipropamid. For that, both chemicals from Syngenta, with the same dose/ha of Mandipropamid but with 180 g/l of Cymoxanil in one of them have been tested. With the figure 9, the non-neglectable gain of 5 % less of infected area appears. The gain is also creditable to the ability of Cymoxanil to be 48 hours retro-active (Belchim, 2018).

- What is the adding value of a 5 days cadence compare to a 7 days cadence ?

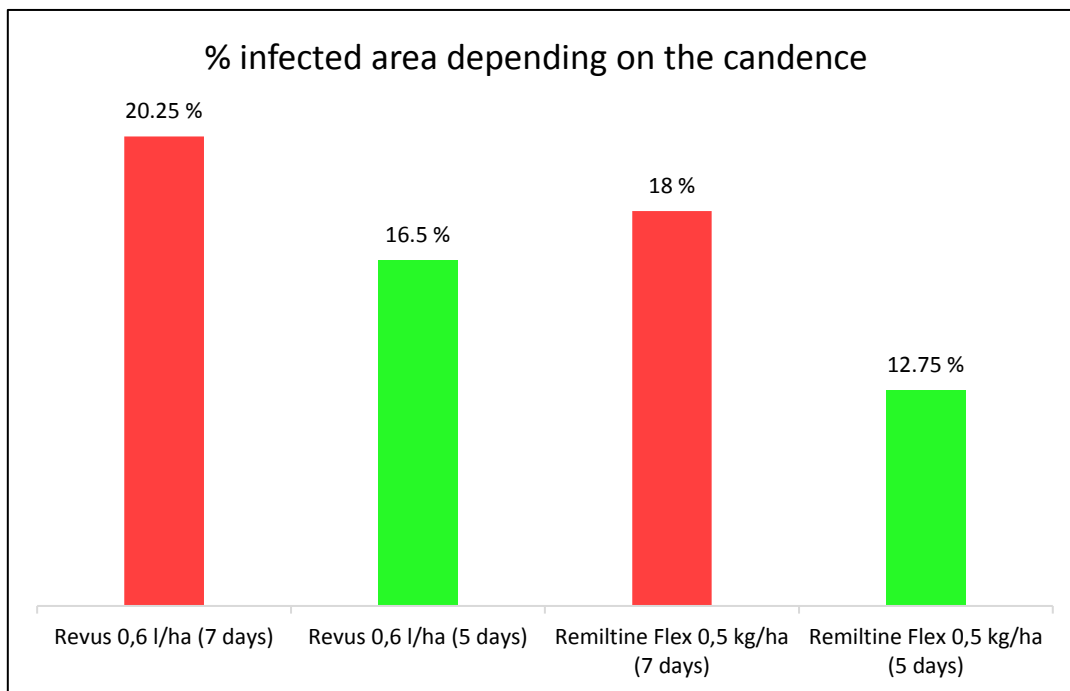


Figure 10: % infected area depending on the cadence

About that sub-question, it is obvious that the highest cadence gives the best result. The point was to assess the gain. The fact of increasing the cadence by 2 days, decrease the infected area by about 4,5 % in average for those modalities (figure 10).

- What is the adding value of a dose of 0.6 kg Remiltine Flex compare to 0.5 kg Remiltine Flex ?

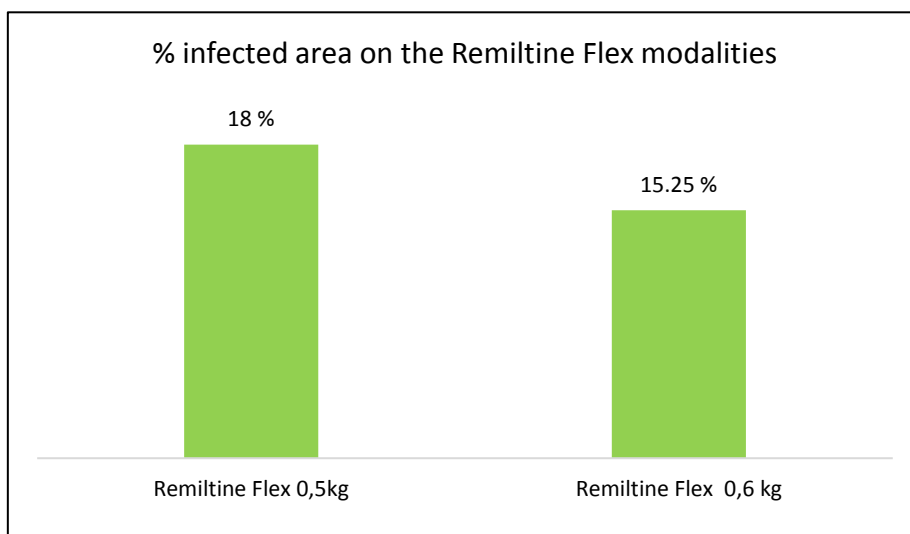


Figure 11: % infected area on the Remiltine Flex modalities

Like seen on the figure 11, the gap induced by 100 g/ha difference of Remiltine Flex is not big. There is only 2.75 % more infected area for the decreasing.

- What is the best curative modalities ?

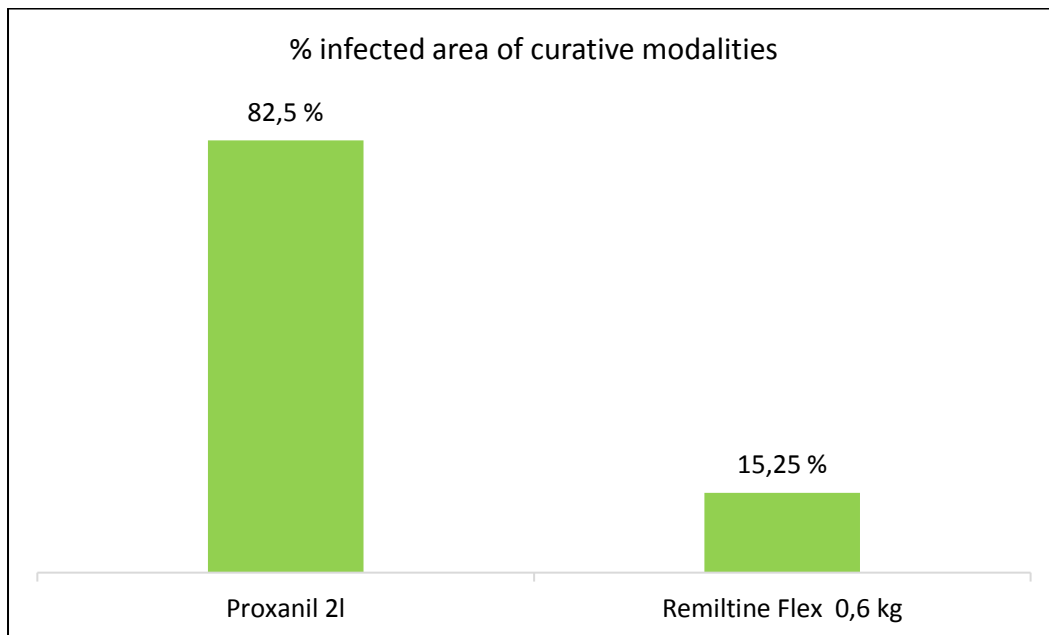


Figure 12 : % infected area of curative modalities

An important point is to determinate the best curative modality present on the trial. The only curative molecule is Cymoxanil. Therefore, two chemicals containing that component have been tested : Proxanil (Cymoxanil 50 g/L and Propamocarb 400 g/L) and Remiltine Flex (Cymoxanil 180 g/kg and Mandipropamid 250 g/kg). On the figure 12, appear the worst and the second modalities of the trial. The higher concentration in Cymoxanil and the better efficacy of the Mandipropamid compare to the Propamocarb are the reason of the better score for the Remiltine Flex. The difference is obvious with a gap of 67.5 % between the two treatments.

Chapter 4 : Discussion of results

In this chapter, the results will be discussed regarding their statistical validity as well as the methodology.

To elaborate this thesis and come with proper results, the XLSTAT-Premium (Free trial version) software has been used, which is an Excel extension.

On order to validate the results of the trial, two hypotheses must be verified with the Fisher test at risk of 5 % :

- H0 : There no significative differences among the modalities
- H1 : There significative differences among the modalities

Table 4 : Fisher test analysis

Effects	Num DOF	Den DOF	F	Pr > F
Modalities	9	21	28,444	< 0,0001

The hypothesis H1 is confirmed because the associated probability is under 0.05 which is the maximum limit (table). There are significative differences among the modalities.

Through the statistical analysis, another test has been run : the Newman and Keuls (table 5). It allows to see the homogenic groups of modalities and their efficacy. In this trial, there 4 groups and the control modality is alone is the group D, which means that the treatments have been all efficient. The A group is the most efficient, the modalities 6, 8, 2, 4,7 and 5 have the same statistical efficiency. The B represent the average efficiency and the group C is the lower efficiency.

Table 5 : Newman and keuls analysis

Modalities	Estimated Average	Groups			
Modalités-6	12,750	A			
Modalités-8	15,250	A			
Modalités-2	16,250	A			
Modalités-4	16,500	A			
Modalités-7	18,000	A	B		
Modalités-5	20,250	A	B		
Modalités-3	34,750		B		
Modalités-10	35,000		B		
Modalités-9	82,500			C	
Modalités-1	100,000				D

About the methods, this protocol is run every year for about 10 years, it allows to place the Syngenta range in the fungicide market. This trail is not representative at all of the farming reality, the fact of spraying the same product on a field is impossible. Nevertheless, it is the better way to assess the proper efficiency of each product.

The figure 14 show the data collected at Villers St Christophe which is 70 km away from the trial. On the graph, it is proven that this year was a high disease risk. The trial had received a contamination, but the experimentation team, regarding the important amount of Late blight, had to destroy the contaminated rows rapidly to maintain the trail and ensure the results.

The objectives of the research were to compare Syngenta with the other actors of the market. For the proper Syngenta range, the objective was to determinate the efficiency of the Mandipropamid alone and with a partner at different cadence.

It has been shown that the Syngenta have the best results compare to the other firms even that wasn't the goal. This trial is also the support of client's visits. Those clients are buyers from resellers which will elaborate their catalogue and sell chemicals to the farmers. It is very important to show them that the Syngenta is the leader and their best asset.

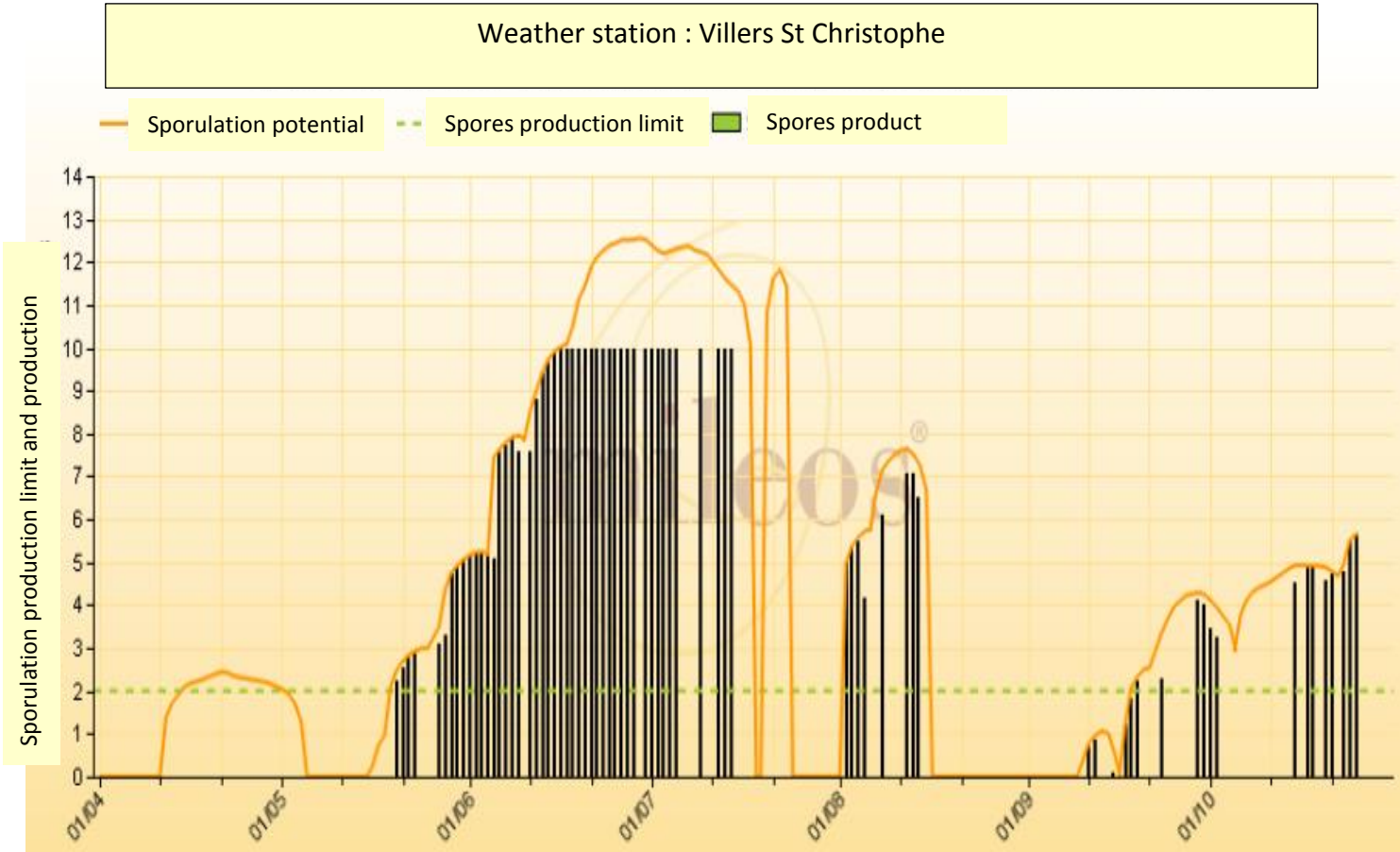


Figure 13: Sporulation of the Late blight

About the process, everything went well, the conditions of hygrometry and disease dissemination have been respected. There has been no failure or error in the treatments which means that the results are highly reliable. About the method, there is one important point that is not perfect, the notations did not been process every time by the same person, this can include some divergences.

From my point of view, this trail has been a success, the conditions were optimal, and the protocol has been followed perfectly. The visits were very interesting, and clients seemed happy about the what they saw.

For the next trail, it could be interesting to go until the harvest and the conservation. The Late blight is also a big issue during the storage period. Assessing the percentage of rotten tubers for each modality allow to measure the capacity of maintaining a clean product to the costumer. One important key in the future will be the biocontrol. For sure, integrate some modalities with biocontrol alone and biocontrol with a chemicals partner would be interesting.

Conclusion :

The objectives of the research were to place the Syngenta range among its competitors from other chemicals firms. More accurately, the trial aimed to know which chemicals on the market is the most efficient on the fight against the Late Blight (*P. infestans*) during the active growth period. To build the frame of the research, few questions have been raised.

The main question of the thesis is about determining which commercial speciality is the most efficient to manage the Late blight during the active growth stage ? In this trial with a high risk of disease context, the best solution against the Late blight is to spray Remiltine Flex (Mandipropamid + Cymoxanil) at 0,5 kg/ha every 5 days. This modality has given the best result with 12.75 % of infected area across the micro-plots compare to Proxanil 2 l/ha that has given a very high percentage : 82.5 % of infected area across the micro-plot.

Further than the main question, fore sub-questions have been raised as well, starting with : what is the adding value of the Mandipropamid with Cymoxanil compare to the Mandipropamid alone ? The asset of adding 180 gr/l of Cymoxanil to Revus which is Mandipropamid alone is noticeable. It allows to reduce by 5 % the infected area. It is important to highlight the ability of the Cymoxanil to take back infections from 2 days long.

The second sub-question was about the treatment cadence. It is obvious that if the farmers sprays more, the crops are healthier. The point was to assess and verify the adding value bounded to a higher cadence. With this trial, Syngenta wanted to get more data on its products, therefore they made modalities to test the Revus and Remiltine Flex with two cadences. The results are : switching from one treatment every 7 days to one treatment every 5 days allows to gain about 4,5 % of infected area on the potatoes.

The third sub-question was about dose reduction for Remiltine Flex. By reducing the dose by 100 g/ha to reach 0,5 kg/ha, the disease increases by 3 % of infected area.

The fourth sub-question was about determinate which chemicals the best curative product was. Both Proxanil and Remiltine Flex contain Cymoxanil, which is the curative molecule, have been tested. The results give 15.25 % of infected area for the Remiltine flex against 82.5 % for the Proxanil. This big difference is first explained by the higher concentration of Cymoxanil in the Remiltine Flex (180 g/L) than Proxanil (50g/l). The second reason is the better proper efficacy of the Mandipropamid present in the Remiltine flex than the Propamocarb present in the Proxanil.

Through the statistical analysis ran with the XLSTAT software, the trial has been confirmed valid with statistical differences among the chemicals tested.

Recommendations :

- This trial allows to bring informations to farmers, potatoes growers. Even if the protocol is far from the farming reality because of the utilisation of only one chemicals during the season, it allows to show important differences between chemicals present on the market.
- The first recommendation is to respect the maximum number of utilisation per year for each chemical. This point is important because that is the way of limiting the selection pressure on Late blight, which means limiting the resistance development. This is about sustainability of our agricultural model as it is for the Late blight management nowadays.
- The second recommendation is to alternate chemicals but more specifically the active matters in them. Always in the same objective of limiting the resistance development. This time thanks to the complementarity of all the different action modes of different chemicals. Preparing a programme before the season is way to insure the respect of all the criteria and allows to have chemicals stock when needed and to be reactive.
- At the end of the trial, the efficacy of each chemical tested has been shown. As third recommendation, there are chemicals to avoid, to use as alternative and the ones that are heads of the fungicide programs :
 - Knowing the score of Proxanil, it is preferable to avoid its application. However, it can bring a different active matter to the programs when the risks are very low (low sporulation, dry and hot weather, resistant variety) at the beginning of the program.
 - The chemicals that represent an alternative : Ranman top and Infinito. Both chemicals have shown a relatively interesting score of 30 % infected area. They are advisable when there is an average risk of contamination. However, there are important in the objective of chemicals alternating when the Late blight is well present.
 - The programs heads : Revus, Remiltine Flex and Zampro. Those chemicals have shown the best score no matter the cadence. They have to be use wisely to maintain their efficacy. They are the best asset in the fight against the disease.
- The fourth recommendation is about the doses. First of all, the farmers must respect the approved doses which represent the law. In a context of high risks, make economy on the dose is unlikely profitable. The unique effect would be a decreasing of efficacy like it appear with the modality 7 (Remiltine 0,5 kg/ha) and an opportunity for the P. infestans to proliferate.
- The fifth recommendation is about curative treatments. For now, only one curative molecule is available on the market, the Cymoxanil. When an important contamination period occurred, and the farmer could not spray in time, this molecule can take back infection from 48 hours ago. Therefore, choosing the right chemicals to use must be based first on the concentration of Cymoxanil in the product as well as its partner.

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Appendix 1 : Results of the trial

Modality		% aera infected									
		Spots Nbr	21/06	27/06	30/06	06/07	12/07	18/07	26/07	01/08	08/08
M2	102	56	0,5	4	7	10	8	12	6	6	10
	203	88	0,15	2	4	12	10	10	12	17	25
	306	305	1	4	4	20	8	10	14	15	20
	408	52	0,05	1	0,7	5	4	13	6	10	10
Average		125,3	0,425	2,75	3,93	11,75	7,5	11,25	9,5	12	16,3
M3	103	72	6	15	25	65	70	60	10	10	12
	201	122	2	12	25	45	60	27	27	30	40
	309	220	3	17	40	65	70	70	70	70	75
	405	52	0,05	1,5	2	10	12	18	18	10	12
Average		116,5	2,763	11,38	23	46,25	53	43,75	31,3	30	34,8
M4	104	98	0,25	0,5	3,5	15	12	18	12	12	12
	207	110	0,15	0,5	1	10	10	2,5	7	8	14
	303	149	0,2	1,5	2,5	12	12	13	12	15	20
	402	45	0,1	0,5	1,5	5	9	10	17	15	20
Average		100,5	0,175	0,75	2,13	10,5	10,8	10,88	12	12,5	16,5
M5	105	44	0,5	2	5	17	17	15	8	8	9
	202	475	3	10	20	25	40	12	10	20	30
	307	133	0,7	2,5	3	25	18	18	18	20	25
	406	12	0,08	2	4	15	18	20	15	20	17
Average		166	1,07	4,13	8	20,5	23,3	16,25	12,8	17	20,3
M6	106	89	0,1	1	0,7	5	3	3	5	5	6
	208	81	0,07	0,5	1	3	3	1	3	4	10
	305	73	0,08	0,5	2	3,5	4	6	8	10	20
	404	60	0,3	1	2,5	7	10	6	6	12	15
Average		75,8	0,138	0,75	1,55	4,63	5	4	5,5	7,8	12,8
M7	107	68	0,3	2	2,5	8	6	6	7	7	7
	205	70	0,7	2	4	15	15	7	20	20	30
	308	68	0,15	1,5	2	8	6	5	10	12	15
	403	11	0,1	2	3	15	15	17	18	18	20
Average		54,3	0,313	1,88	2,88	11,5	10,5	8,75	13,8	14,3	18
M8	108	67	0,3	1,5	3	8	7	8	6	8	9
	209	99	0,08	1,5	2,5	8	5	7	8	10	12
	304	141	0,3	2,5	3	17	10	12	10	12	25
	407	180	0,1	1	1,5	5	10	15	9	15	15
Average		121,8	0,195	1,63	2,5	9,5	8	10,5	8,3	11,3	15,3
M9	109	85	3	10	15	60	70	70	75	75	80
	206	166	4	15	25	55	80	60	65	75	80
	310	100	0,7	8	20	60	60	50	75	85	90
	401	222	0,1	4	10	40	65	45	70	75	80
Average		143,3	1,95	9,25	17,5	53,75	68,8	56,25	71,3	77,5	82,5
M10	110	103	2	5,5	8	35	25	25	35	40	45
	204	235	1,5	5	15	40	50	20	25	30	40
	302	103	0,5	2	6	27	30	22	23	20	25
	409	73	0,06	2	5	25	25	25	25	30	30
Average		128,5	1,015	3,63	8,5	31,75	32,5	23	27	30	35