Combinations of post emergence herbicides for weed control in winter wheat

AERES HOGESCHOOL DRONTEN

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EED
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To what extent do combinations of post emergence herbicides provide improved weed control in winter wheat?

By

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Preface

Practical training is an important part of the curriculum. This is the result of the general objectives of education. Indeed, in the majority of modern European school systems, students are trained for analysis and management positions. The objective being that the students provide professional expertise after graduation.

From August to November 2019, I had the opportunity to do a 16-week end-of-study internship marking the end of my European Engineer Degree (EED) course .

This internship was the opportunity to review and use the knowledge acquired during the school semester spent at the AERES hogeschool. My EED degree is specialized in plant productions, and has the particularity to give an international dimension to the courses. In addition, this diploma is combined with a French degree, thereby achieving two diplomas over a period of one and a half year.

Wishing to do an internship in agricultural research in a country using similar production methods to those I know from my region in France, I was happy to be able to do my internship at Staphyt in Germany.

This report takes place before the writing of the thesis. Its objective is to explore and learn as much as possible about the research topic, etc.

Its purpose is to fully understand what is already known about the topic and the response issues raised by the research, as well as to establish a protocol and set up a trial in effective scientifically-relevant way.

Acknowledgements

First of all, I would like to thank my parents who have always supported me in the pursuit of my studies, thank them for the various sacrifices they have made to offer me the best possible professional future.

I would like to sincerely thank Sebastien Sester my placement tutor in Staphyt. In particular for his invaluable help and the time he spent with me in setting up my research, his help in carrying out the protocol, statistical analyses and his relevant advices which helped me to conduct my research.

Also, I would like to thank all the members of Staphyt, especially the many technicians with whom I worked many times, such as Torben, Achim, Julio, Thomas and Monsen. I would like to thank them for their welcome, valuable explanations and advice. I really had a pleasant personal work experience with them. Enthusiasm, a warm working spirit and patience which I found every day were very good memories which made of my work placement a real pleasure.

Finally, my thanks go to Mr Gehner Barend, my personal coach at AERES School in Dronten for its prompt responses and relevant advice and his involvement in my work.

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Abstract

Triticum aestivum (wheat) is the second most produced crop in the world and is even the most produced crop in Europe. However, in Europe there are many laws controlling the herbicide use and approvals. An important directive that appeared in 1991 led to a significant reduction in the number of herbicides allowed. In addition to this, herbicide-resistant weeds have appeared since 1975. This problem, combined with the reduction in the number of authorized herbicides, means that today the management of weeds, particularly resistant weeds, has become more and more complex. The combination of different herbicides seems to be a good option for controlling weeds, especially those that are resistant.

To help farmers respond to this problem, an agrochemical company wanted to evaluate a set of different combinations of herbicides. The purpose was to analyse the efficacy of the different herbicide combinations on a resistant weed (*Alopecurus myosuroides*) and a non-resistant weed (*Viola arvensis*).

To answer this question, a trial was set up and the following questions were formulated:

Main question

To what extent do combinations of post emergence herbicides provide improved weed control in winter wheat?

Sub questions

1 : How do combinations of post emergence herbicides perform against *Alopecurus myosuroides* (black grass)?

2 : How do combinations of post emergence herbicides perform against *Viola arvensis* (field pansy)?

3 : Are all of these herbicide combinations crop safe?

4 : How cost effective are these combinations of herbicides from a farmer's perspective?

After analysis of the results it was found that some combinations had very good weed control results with 94% and 100% but also had a negative effect on wheat. Moreover, after economic analysis in some cases, the theoretical possible yield increases through the use of a product combination did not cover product costs which is 80€ higher. However, other combinations have interesting results and are economically viable.

Following these analyses it is recommended that before using combinations, some criteria are essential to take into account such as the weed population in order to be able to estimate the profitability of these products. It is also necessary to select the combinations according to the population and the type of population of weeds present in the field. From a global point of view to avoid the persistence or appearance of new resistances, a rotation of the different modes of action must be done every year.

Chapter I : Introduction

This research is about the efficacy of the different combinations of active ingredients in wheat for improved weed control. This topic was chosen because of a recent and important problem occurring in the agricultural sector.

Herbicide resistance and legislation

As a matter of the rapid evolution of legislation regarding authorised active substances in agriculture forced many farmers in a deadlock that could negatively affect their production methods and yields. In addition to this, poor management of the use of different active ingredients in recent years has led to the emergence of herbicides resistance in some weeds, such as *Alopecurus myosuroides* (black grass).

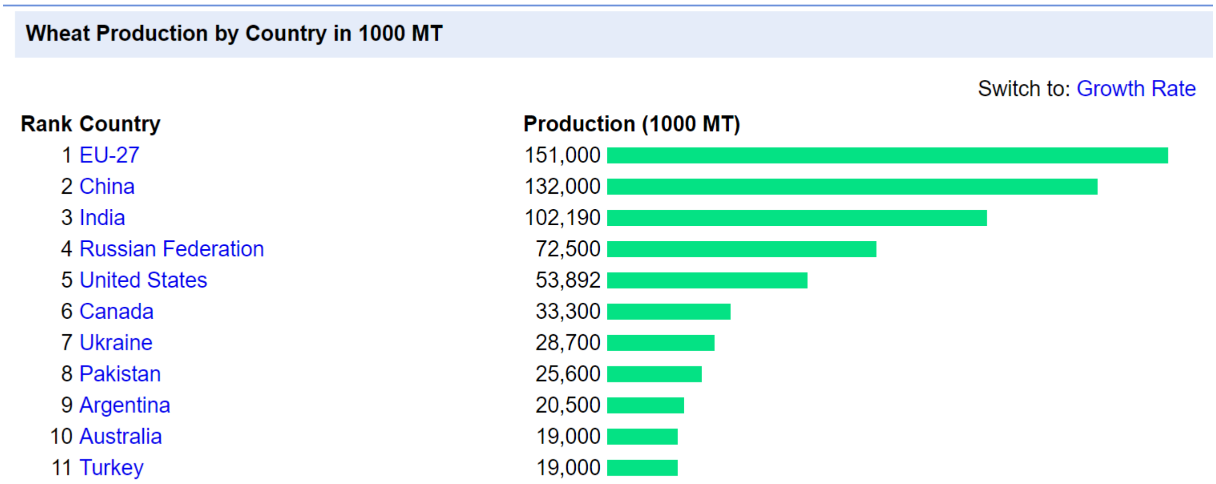


Figure 1 : Rank country for wheat production in 1000 MT by IndexMundi (Indexmundi, 2019)

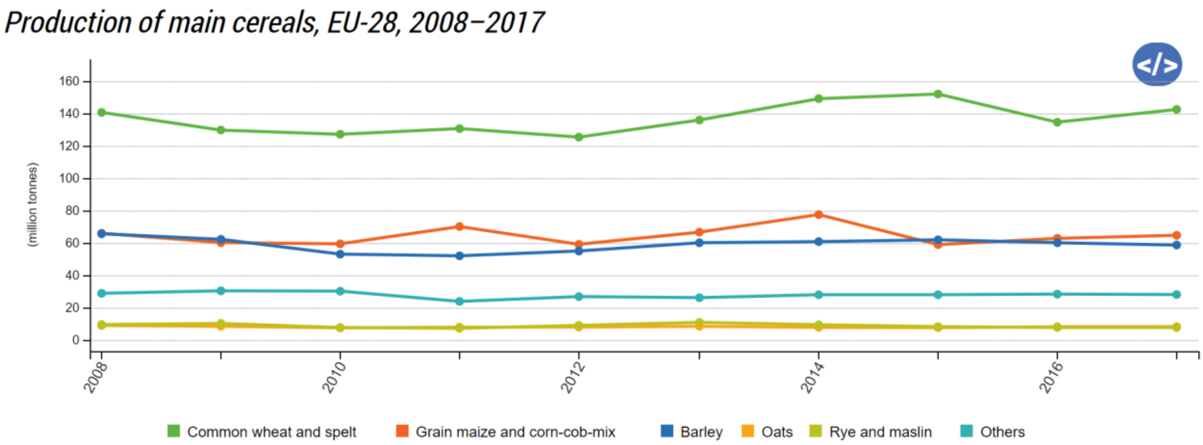


Figure 2 : Production of main cereals in EU from 2008 till 2017 by (Eurostat, 2018)

Wheat is the second most important cereal in the world after maize. In the world, cereals account for 49% of total arable land(Passion Céréales, 2018). After maize, wheat holds the second place and represents 30% of the cereals produced in the world.

Figure 1 and 2 show that in Europe, wheat is the most produced cereal and thus places Europe in first place in the world in terms of produced wheat with 145,248 kilo tonnes produced on average per year since 2008(Baron, 2019).

Weed management becomes a real challenge for farmers in the future. Agrochemical companies are also concerned, because of the significant economic loss caused by these changes. In addition, it takes increasingly more time, money and legislation processes to place a new chemical on the market. To ensure efficacy while awaiting the authorization of new molecules, agrochemical companies are increasingly working on finding new combinations with different active ingredients already available on the market.

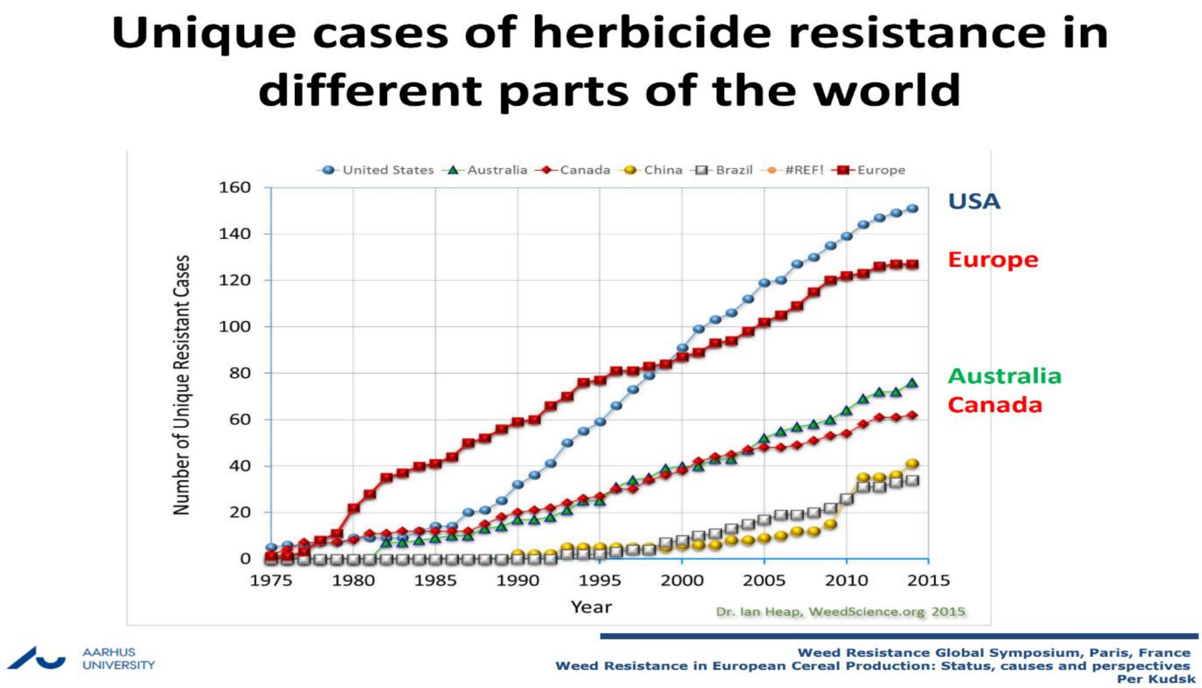


Figure 3 : Discovery Unique case of herbicide resistance in different parts of the world by Dr.

(Kudsk & Aarhus, 2016)

On the figure 3 it is possible too see, there has been an increase in resistant plants since 1975 in Europe. At first, these resistances were not a big problem in Europe because many other active ingredients remained on the market to control these problematic weeds. In 1991 a new directive came into force, with stricter authorisation criteria than the one before.

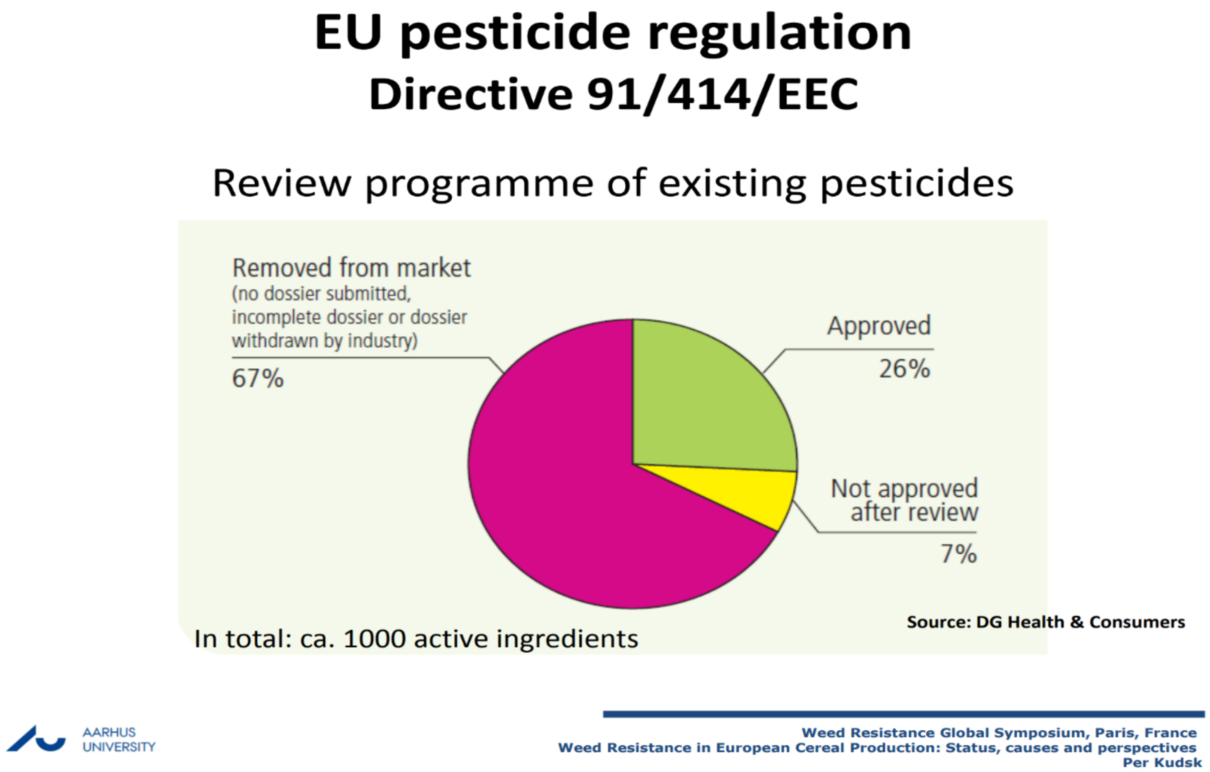


Figure 4 : Percentage of pesticides authorised after Directive 91/414/EEC on 1000

(Kudsk & Aarhus, 2016)

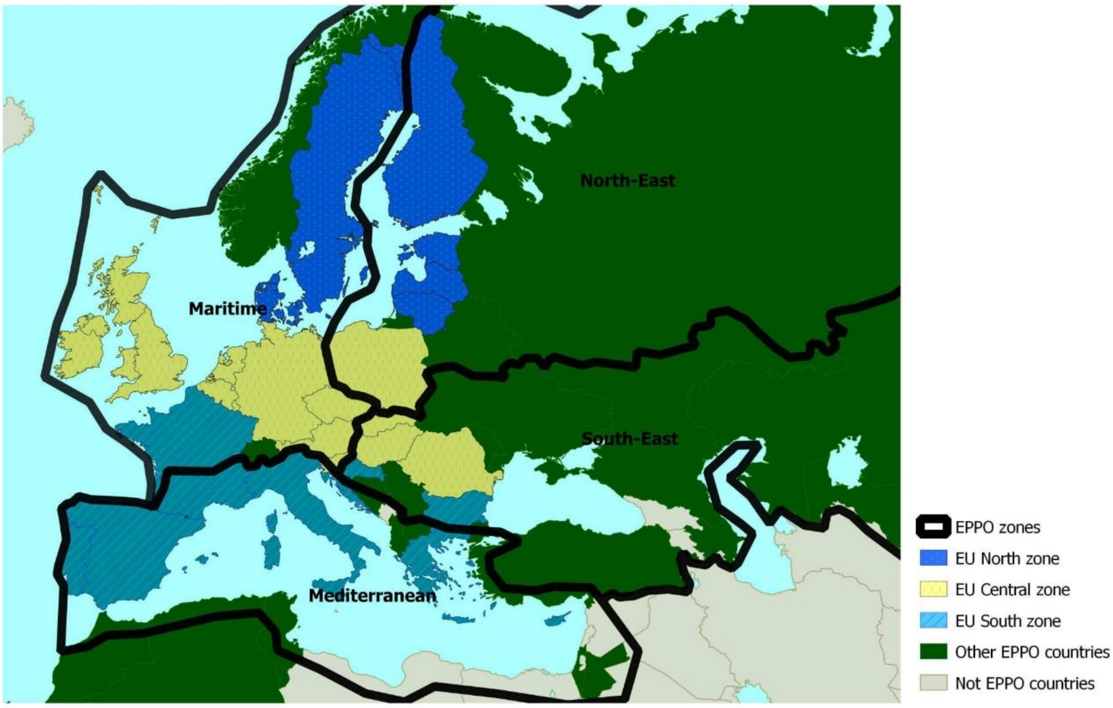
Figure 4 shows that after the directive 91/414/EEC in Europe only 26% of the active ingredients were authorized after review. This number accounts for new active ingredients to enter the market and active ingredients that were already on the market and are undergoing a new review for authorization. Since the 1991 in Europe, the marketing became more complicated and the number of authorizations has been constantly decreasing. In the meantime the number of new molecules did not compensate for this loss. For example, in 2004 there were 94 authorized products for weed control in wheat and today only 26 (Ephy, 2019) with an average of one new product coming on the market per year(Benoît et al., 2005).

The herbicide resistance in these weeds does not apply to all herbicides but depends on their mode of actions.

The decrease in the number of active ingredients directly lead to a decrease in the modes of action. Today there are 24 known modes of action for herbicides (HARC classification, 2010). Concerning the 26 authorized herbicides, only 10 modes of action are represented(Bimbard, 2018). The management of weeds in wheat, and especially that of resistant weeds has therefore become an important issue in recent years.

Herbicides used in the crop are selective herbicides. This means they are able to target the weeds without damaging the crop., These herbicides are classified into several distinct families according to their targets. For wheat, there are two families of herbicides, distinguished by the two major botanical families which are: dicotyledonous weeds (broadleaved weeds) and monocotyledonous weeds (grassy weeds).(Ordonio & Matsuoka, 2016)

EPPO Climatic Zones and EU Authorisation Zones



Zones of comparable climate in the EPPO region as defined in EPPO Standard PP 1/241 *Guidance on comparable climates* for the purposes of efficacy evaluation trials on plant protection products. The borders are intentionally broad indicating that there is an area of gradual change in climate between the zones proposed

Figure 5 : EPPO Climatic Zones and EU autorisation by : (Hucorne, 2012)

In 2009, the European Union (EU) set new legislations on the regulation of plant protection products according to geographical areas. As figure 5 shows these areas are established according to the different climate regions of Europe. In this case, the data in this trial in Germany can be used for the EPPO Maritime zone.(BASF France, 2019)

In addition to having a geographical demarcation, the trial must follow precise rules set by the EPPO. The purpose of these rules is to ensure that all trials carried out in different countries by different companies follow the same rules for setting up and evaluating data that are not false or misjudged.(EPPO, 2009)

The topic of this study is therefore based on a desire to respond to a decrease in the number of authorized products and to focus on those that are still authorized. The analysis will be based on the combinations of different products with different modes of action. The weeds will therefore be sprayed with different combinations of products with the objective to improve weed control

The objective is to ensure the best weed management while new products or new weed management methods in wheat are being developed.

Staphyt is a Contract Research Organisation (CRO) providing services in agricultural research. The main customers are therefore agrochemical and seed companies. To look for sustainable solutions against herbicide resistant weeds, the agrochemical company in this research contracted Staphyt to carry out a trial on the combination of different active ingredients. The target group is the company itself (as a client of STAPHYT) but also local farmers who will eventually receive the results of the various studies. They will therefore be able to take into account the best combinations to manage their weeds.

Theorical framework and knowledge gap

This study will take place in south-western Germany, near Bavaria. In this region, *Alopecurus myosuroid*es (Black grass) is found in large numbers and has a significant level of resistance to herbicides. Another target plant is *Viola arvensis* (field pansy), although not being resistant but being very present in winter crops and increasingly difficult to control.

Definition of terms :

Post emergence : used or occurring in the stage between the emergence of a seedling and the maturity of a crop plant

Active ingredient : is the ingredient in a pharmaceutical drug or pesticide that is biologically active.

Mode of action : it is how a pesticide works. A complete understanding of the mode of action of a pesticide requires knowledge of how it affects a specific target site within an organism.

Several studies have been conducted on the efficacy of products. Those studies have been carried out more often since the appearance of the first resistances. The published studies were carried out by public organisms. Their aim was to provide a fast and concrete response to farmers, and the products studied should cover as many possibilities as possible. The products were therefore from different agrochemical companies.

A scientific article published in 2016 bringing together the results of various studies showed the different possible control methods for weed management in wheat cultivation.

These control methods concern the management of tillage, rotation, intercropping and biological control. For this research the interesting part concerned the tactical management of herbicide use. This article links numerous studies demonstrating that weed management and in particular resistant weed management required technological knowledge of herbicides, particularly through dose and family management. In addition, plants are more likely to develop resistance to herbicides with sites of action on acetolactate synthase (ALS) or group B herbicides. The management of these resistances by herbicides must be achieved by rotating the different modes of action. However, many studies highlighted in this article have shown that the efficacy of herbicides against resistant plants shows better results by combining different herbicides and modes of action than by an annual rotation of a single herbicide at full dose.(Lamichhane et al., 2017)

A recent and important study has been conducted by Arvalis in several areas in France. This study was conducted over three years and uses the most common herbicide in wheat. This study took into account the efficacy of herbicides against all grasses present in the crop, with particular focus on resistant grasses, namely *Alopecurus myosuroides* (black grass). The efficacy of those products was calculated by factoring in the cost of the product and of the application. All combinations included at least 2 different modes of action, in order to highlight the best combination of products with a price suitable for farmers.

From this research it is possible to see the comparison of different products in post-emergence application. On non-resistance plants such as Viola arvensis (field pansy) the application of a herbicide alone gives an efficacy of 85% on 57% of the plants present in the trial. The efficacy on the 43% of the other plants is much lower with only 30% of efficacy. In combination with two to three products at the same spraying date, the results are really interesting with an efficacy of 80% to 90% on all plants sought. But the costs per hectare raised from 42€ to 58€.(Arvalis, 2017)

The results obtained in this study by Arvalis in post emergence spraying of *Alopecurus myosuroid*es (black grass) were as follows: it is better to combine the products. A single product showed an efficacy of 72%, while in combination with one or two products the efficacy increased by more than 10%. While the cost for one single product is 52€ per hectare, the combination with the other products cost 83€ per hectare. However, the price of these applications is higher by 31€ per hectare. The application rates of each product are reduced when in combination in order to comply with the legislation.(Arvalis, 2017)

Some conflicts of interest may arise when combining herbicides. Indeed, herbicides represent a large part of the turnover of agrochemical companies and the research are expensive. The companies are therefore waiting for conclusive results with their products. They also aim to develop products that are financially affordable to farmers. Additionally, a field trial is expensive. It requires machinery for sowing, spraying, seed bed making, and a field needs to be rented to a farmer for carrying out the research. In addition to this, there is also the payment of the technicians who will carry out the field work, spray the trial and collect the data. At a social and environmental level, uncertainty about the impact of herbicides on the environment has become a concern for many people especially about the impact on the human health.

Regarding the results of the study carried out in this research, many factors can influence the data. Indeed, many natural factors influence the efficacy of herbicides such as soil type, soil pH, cation exchange capacity. Climate plays an important role too, since temperature, humidity, wind force and solar radiations directly and strongly influence the product, the crop and the target. The location of the trial in the field may also have an influence, such as tractor tracks, leading to soil compaction and therefore delayed crop growth. The crop history of the field is also important to be able to anticipate which weeds will be present. To avoid unwanted variability between the different plots, the selected field must be homogeneous, have the same cultivation history and the replicates must be placed perpendicularly to the usual direction of traffic. The efficacy of a herbicide is also related to its selectivity capacity, which means there are no or few negative effects on the main crop.

The demarcation of this research is that it essentially takes into account the products offered by a single company and not all the products available on the market. This is a good way for this company to find out if it has the ability to offer high-performance products in view of current issues.

This study will take into account different herbicides and compare their efficacy on two weeds mainly present in winter crops in the studied area (*Alopecurus myosuroid*es and *Viola arvensis)*.

Main question and sub questions :

Main question

To what extent do combinations of post emergence herbicides provide improved weed control in winter wheat?

Sub questions

1 : How do combinations of post emergence herbicides perform against *Alopecurus myosuroides (black grass)*?

As mentioned earlier in this report, many plants have become resistant to herbicides. Among them *Alopecurus myosuroides* is a rather global problem in cereals in the EPPO maritime zone. Indeed, since the appearance of herbicide resistance, *Alopecurus myosuroides* has been able to establish very quickly and be persistent in winter crops with little spring crop in the rotation. Its management has become a real challenge for farmers but also for the agrochemical industry. Similarly, in this region of Germany, it is very well represented and is a significant a problem for farmers.

2 : How do combinations of post emergence herbicides perform against *Viola arvensis (field pansy)*?

To fully test the efficacy of a product and combinations of products, it is relevant to look at their impacts on other non-resistant weed species. As mentioned, it is not intended to analyse the impacts of herbicides on all the weeds occurring in winter crops. Therefore, a plant that is present in large numbers in winter crops was selected. After discussion with my colleagues, *Viola arvensis* - very present in the region – was selected.

3 : Are all of these herbicide combinations crop safe?

The efficacy of an herbicide is directly associated to its selectivity. Negative effects on the main crop are rare when using a product alone, and are often the result of misuse (rate, timing of the application, climate conditions). But when mixing herbicides, unwanted damage on the crop are more likely to appear. An analysis of the crop health is therefore needed to assess the selectivity of the tested products.

4 : How cost effective are these combinations of herbicides from a farmer's perspective?

In the different herbicide studies taken into account, it showed that product combinations have a higher efficacy but come at higher costs for the farmer. In some cases, these costs do not cover the theoretical estimated yield loss due to the presence of weeds. It is therefore relevant to compare the costs according to the theoretical yield loss caused by weeds in order to define which products provide the best return on investment for farmers.

Objectives:

Resistance is observed on the black grass today. The number of molecules authorized on the market is lower than before and the efficacy is also lower. The combination of different modes of action therefore represents an opportunity to help the farmer in the control of the weed. The results obtained by this research will be used by the agrochemical company. This data will allow them to improve weed control advice for farmers. And thus to provide possible solutions against resistant herbs while waiting for new molecules to be authorised in Europe.

Chapter II : Materials and methods

This chapter will describe how and with what the study will be conducted. The way in which the test had to be set up and the conditions, the material and the tools needed. The method of data recovery and the ways in which it will be analysed is also explained in this part.

Materials

Trial Implementation:

- Plan
- Homogeneous field (soil structure,)
- Machinery : cultivator, harrow, seed drill
- Pins with label for the demarcation of the test plot
- Wheat variety: Julius
- Measurement tools for set up the trial area (decametre, prism)

Treatments:

- Plan
- Use of an experimental sprayer (boom sprayer)
- Spray cleaner (Agro Quick)
- Protective clothing for the application
- Product mixing equipment (measuring buckets)
- 10 herbicides

Data collection and analysis:

- Plan
- Paper collection of data in the plots
- Statistical analysis software for experimentation (ARM)
- 1 square meter frame for counting weeds

Methods

Localisation and plan:

The trial field was located in an homogenous field that has had the same crop history and tillage system for several years. The soil was homogeneous as possible. The weed population was naturally high (< 5 plants.m^2), with known herbicide resistance.

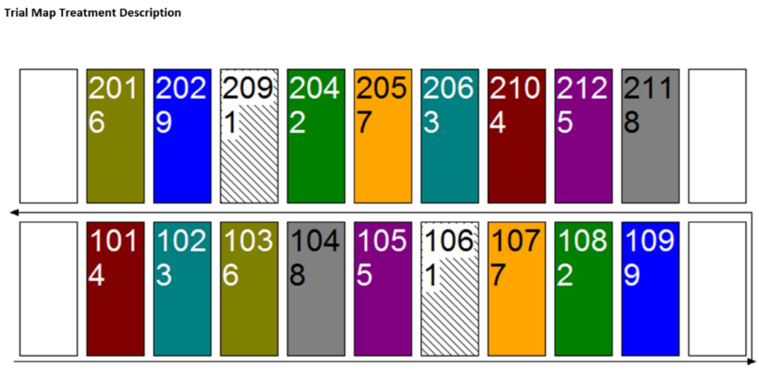


Figure 6 : randomisation of the plots

As figure 6 shows the plots is placed in a randomised complete block design with two replicates (see figure 1). Plot size was 21 square meter (7 m long by 3 m wide). The GPS coordinates of the lower left corner of the trial were recorded to allow it to be easily located. The different plots had an unique number to avoid as much as possible the risk of error. Plots with treatment 1 correspond to the untreated checks and are used as a basis for estimating the number of weeds present. Border plots on both sides of the trial are included.

Implementation:

The farmer prepared his field and plant the crop normally, as he did the years before. The chosen variety must be representative of the area. In this trial, variety Julius was selected. The sowing density was 360 seeds per square meter with a 13-cm row spacing. Sowing depth was 3 cm. The sowing took place in beginning of October, which is common practice in the selected region.

Once the field was sowed, trial lay out takes place. The replicates were perpendicular to the farmer's usual working tracks. The trial should be placed at least 20 meters from the border of the field to avoid edge-effect. The plots formed a rectangle. This was achieved by using a prism measurement tool. Once the trial area has been marked out, the plots were placed using a decametre tool. Micro plots were labelled with their unique numbers and treatment numbers.

Treatments:

The different rates were established according to the doses recommended by the company and the maximum amount authorized by the EU.

At application, wind speed was not exceed 3 meters per second to avoid any drift of the products during spraying.

The products must not been mixed in the sprayer tank. For this after each application of the different treatments, the sprayer was cleaned with washing solution and water.

Doses are the following :

Table 1: Doses and products of the different treatment

Trt No.	Type	Treatment Name	Form Conc	Form Unit	Form Type	Description	Rate	Rate Unit
1	CHK	Untreated Check				not treated		
2	HERB	Product 1	500	G/L	SC		0,3	L/ha
		-Flufenacet	500				150	g AI
	HERB	Product 2	360	G/L	SC		0,75	L/ha
		-Diflufenican	120				90	g AI
		-Flurtamone	120				90	g AI
		-Flufenacet	120				90	g AI
3	HERB	Product 3	462	G/KG	WG		0,02	kg/ha
		-Flupysulfuron	462				9,2	g AI
	HERB	Product 4	360	G/L	EC		3	L/ha
		-Pendimethalin	300				900	g AI
		-Flufenacet	60				180	g AI
4	HERB	Product 3	462	G/KG	WG		0,02	kg/ha
		-Flupysulfuron	462				9,2	g AI
	HERB	Product 5	800	G/L	EC		3	L/ha
		-Prosulfocarb	800				2400	g AI
5	HERB	Product 3	462	G/KG	WG		0,02	kg/ha
		-Flupysulfuron	462				9,2	g AI
	HERB	Product 5	800	G/L	EC		2	L/ha
		-Prosulfocarb	800				1600	g AI
	HERB	Product 6	400	G/L	SC		2	L/ha
		-Pendimethalin	400				800	g AI
6	HERB	Product 3	462	G/KG	WG		0,02	kg/ha
		-Flupysulfuron	462				9,2	g AI
	HERB	Product 5	800	G/L	EC		2	L/ha
		-Prosulfocarb	800				1600	g AI
	HERB	Product 7	600	G/L	SC		2	L/ha
		-Diflufenican	200				400	g AI
		-Flufenacet	400				800	g AI
7	HERB	Product 8	497,5	G/kg	WG		0,1	kg/ha
		-Diflufenican	444				44,4	g AI
		-Flupyrsulfuron (56 g/kg Methylester-Na)	53,5				5,35	g AI
	HERB	Product 3	462	G/KG	WG		0,01	kg/ha
		-Flupysulfuron	462				4,6	g AI
	HERB	Product 5	800	G/L	EC		3	L/ha
		-Prosulfocarb	800				2400	g AI
8	HERB	Product 3	462	G/KG	WG		0,02	kg/ha
		-Flupysulfuron	462				9,2	g AI
	HERB	Product 9	590	G/L	SC		2	L/ha
		-Chlortoluron	250				500	g AI
		-Pendimethalin	300				600	g AI
		-Diflufenican	40				80	g AI
9	HERB	Product 3	462	G/KG	WG		0,02	kg/ha
		-Flupysulfuron	462				9,2	g AI
	HERB	Product 9	590	G/L	SC		2	L/ha
		-Chlortoluron	250				500	g AI
		-Pendimethalin	300				600	g AI
		-Diflufenican	40				80	g AI
	HERB	Product 10	700	G/L	SC		1	L/ha
		-Chlortoluron	700				700	g AI

The table 1 shows the different combinations of the 10 herbicides that make up 9 different treatments.

The application took place at crop stage BBCH 10, when the first leaf of the wheat has fully emerged. The quantity of water to use with the products is 0.63 litres per plot. 0.63 litres per 21 m² plot corresponds to a quantity of 300 litres per hectare, which is an amount commonly used by farmers.

The spraying equipment is the same used for all experiments, a compressed air sprayer with boom length of 3 meter with 6 nozzles. The boom must be at 40 cm from the ground.

To ensure spraying at the right dosage, the settings made at the boom sprayer were the following:

- Air pressure : 2,4 BAR
- Nozzle size : 110-025
- Nozzle Calibration : 900 ml/min
- Spraying speed : 3,5 km per hours

After application the following elements were measured:

- Application date
- Application start and end time
- Air temperature (in degree Celsius)
- Relative humidity (in %)
- Wind Velocity (in meter per second)
- Wet leave (yes or no)
- Soil temperature
- Soil moisture (yes or no)
- Cloud cover (in %)

In the case of unexpected results this data can be very useful.

Data collection :

The measurements of the number of weeds per square meter was carried out randomly in the untreated plot using a 1 m² frame.

The following assessment were done at application, stage BBCH 10 of the wheat:

- Evaluation of the percentage of *Triticum aestivum* ground cover on the untreated plot
- Evaluation of the BBCH stage of *Triticum aestivum* on the untreated plot.
- Evaluation of *Alopecurus myosuroid*es population on 1m² on the untreated plot.
- Evaluation of the percentage of *Alopecurus myosuroid*es ground cover on the untreated plot
- Evaluation of the BBCH stage of *Alopecurus myosuroid*es on the untreated plot
- Evaluation of the percentage of *Triticum aestivum* ground cover on the untreated plot.

The following assessment were done at stage BBCH 11 of the wheat:

- Evaluation of the percentage of *Triticum aestivum* ground cover in the plot on the untreated plot
- Evaluation of the BBCH stage of *Triticum aestivum and Viola arvensis* on the untreated plot.
- Evaluation of *Alopecurus myosuroid*es population on 1m² on the untreated plot.
- Evaluation of the percentage of *Alopecurus myosuroid*es ground cover on the untreated plot.
- Evaluation of the BBCH stage of *Alopecurus myosuroid*es on the untreated plot.
- Evaluation of the percentage of *Viola arvensis* ground cover on the untreated plot.
- Evaluation of the percentage chemical damage on *Triticum aestivum* on all the plot Visual.
- Evaluation of the efficacy (% pest control) on *Alopecurus myosuroid*es and *Viola arvensis* on every plot.
- Evaluation of the percentage of *Triticum aestivum* ground cover on untreated plot.
- Evaluation of the efficacy (% pest control) on every weeds in every plot.

The following assessment were done at stage BBCH 13 of the wheat:

- Evaluation of the BBCH stage of *Triticum aestivum* on the untreated plot.
- Evaluation of the efficacy (% pest control) on *Alopecurus myosuroid*es and *Viola arvensis* on every plot.
- Evaluation of the BBCH stage of *Triticum aestivum and Viola arvensis* on the untreated plot.
- Evaluation of the percentage chemical damage on *Triticum aestivum* in the plot Visual on every plot.
- Evaluation of the percentage of *Triticum aestivum* ground cover on untreated plot.
- Evaluation of the efficacy (% pest control) on every weeds on every plot.

Data analysis:

Assessment data was analysed using a one-way analysis of variance (ANOVA). The probability of no significant difference occurring between treatment means is calculated as the F probability value p (F). Statistical groups are indicated by letters in the treatment tables. Treatment means with no common letters are considered as significantly different at a 95% confidence level.

Before using ANOVA, the validity of following assumptions must be checked:

-Homogeneity of variances of scores in each population. This can be done with a Bartlett's test

-Normal distribution of scores in each population. This can be done by determining the skewness and kurtosis of the distribution of the data set.

If assumptions of ANOVA are valid, a mean comparison test can be done with a NEWMAN KEULS test (threshold 5 %). Statistical classes are indicated by letters in the treatment tables. Treatment means with no letters in common are considered as significantly different at a 95% confidence level.

Sub-question number 4 concerning the best value for money will be calculated using the price per litre of each product in comparison with their observed efficacy and the theoretical yield loss caused by the presence of weeds.

Planning of proposed research

The planning of the research is in accordance with my internship period. The first ones will take place at the BBCH 11 course, so around the end of October. The first data collections will be carried out 15 days after spraying. Winter is a dead period for outdoor work, this quiet period will allow to analyse the data and write the report.

Concerning the needs in equipment and labour needs, the equipment necessary for the conduct of this research is present in the company. Staphyt authorized me to use the necessary hardware as well as some software that can help me analyse the data. The plot where my research takes place was rented by Staphyt to a farmer. The company allowed me to use part of this plot to set up the test. The herbicides required for the experiment are provided directly by the company which are producing them because they are also interested in the results of this trial. However, in agreement with this company, for reasons of confidentiality it is not allowed to communicate the names of the products and the results obtained must not be made public. Concerning the labour need, In agreement with colleagues they volunteered to help with the implementation and execution of the test. After collecting all the data it was agreed that meeting is scheduled with the internship supervisor to discuss about the results and the writing of my thesis.

In this chapter the results obtained after the test described in the previous chapter are presented. the different treatments are compared with each other using statistical analyses. Their presentations follow the order of the sub questions. After presenting the different results for each sub question, the most effective combinations are highlighted.

The European and Mediterranean Plant Protection Organization (EPPO) published a table referencing the level of success of products according to their efficacy rate. These criteria will complement the statistical analyses of the different combinations.

Table 2: Efficacy of whole programs on target weeds ranked according to efficacy scale used in EPPO general herbicide method, 2013

Efficacy %	**Efficacy level**	**Susceptibility of weed**
95 to 100 %	**Very high**	Very susceptible
85 to 94 %	**High**	Susceptible
70 to 84 %	**Medium**	Moderately susceptible
50 to 69 %	**Low**	Weakly susceptible
< 50 %	**Not sufficient**	Very weakly susceptible
0%	**No control**	-

How do combinations of post emergence herbicides perform against *Alopecurus myosuroides (black grass)*?

The populations of *Alopecurus myosuroides* were measured at two BBCH stages of winter wheat cultivation. The graphs below show the average number of *Alopecurus myosuroides* at BBCH stage 10 and 11in the untreated checks (UTC) (Figure 8) and the average percentage ground cover in the UTC (Figure 9)

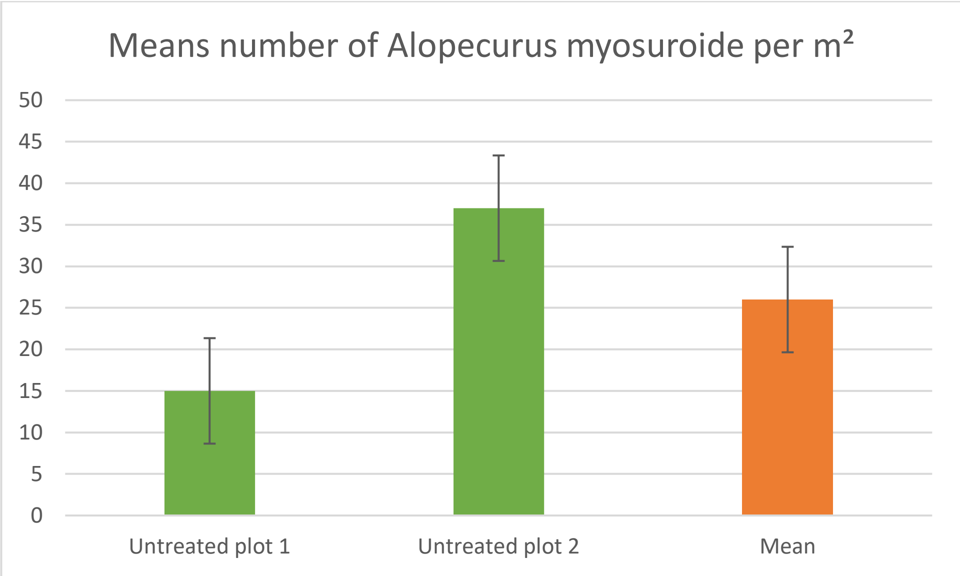


Figure 8: Average number of Alopecurus myosuroides per m² in the UTC

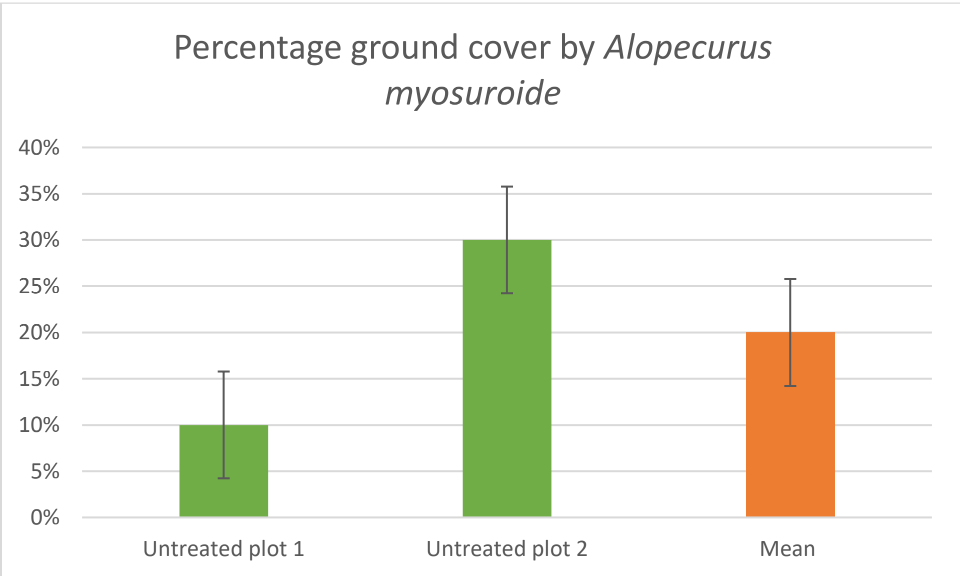


Figure 9 : Percentage ground cover by Alopecurus myosuroides in the UTC

From the two figures 8 and 9 above it can be seen that the populations of *Alopecurus myosuroides* was heavy with 20% of the ground which was covered by the weed. The two counts carried out at stage BBCH 10 and BBCH 11 do not show any differences. This criteria is important to ensure that at the time of application (at BBCH 10 stage) the majority of the population of *Alopecurus myosuroides* had emerged from the ground.

The evaluation of the efficacy of the different product combinations is not carried out separately between the two untreated checks, the calculation uses the average of the populations evaluated at each stage.

Table 3 : Percentage of Alopecurus myosuroides control of combination of treatments

Combination	Treatment name	Rate	Rate unit	Percentage of *Alopecurus myosuroides* control by combination of treatments at BBCH 11	Percentage of *Alopecurus myosuroides* control by combination of treatments at BBCH 13
1	Untreated			0b	0e
2	Product 1 Product 2	0,3 0,75	L/ha L/ha	26,5a	75,5bcd
3	Product 3 Product 4	0,02 3	kg/ha L/ha	29a	83abc
4	Product 3 Product 5	0,02 3	kg/ha L/ha	30a	70cd
5	Product 3 Product 5 Product 6	0,02 2 2	kg/ha L/ha L/ha	35a	66,5d
6	Product 3 Product 5 Product 7	0,02 2 2	kg/ha L/ha L/ha	32,5a	94a
7	Product 8 Product 3 Product 5	0,1 0,01 3	kg/ha kg/ha L/ha	29a	87,5ab
8	Product 3 Product 9	0,02 2	kg/ha L/ha	29a	83abc
9	Product 3 Product 9 Product 10	0,02 2 1	kg/ha L/ha L/ha	31,5a	77,5bcd
P=0,5				4,68	10,26
Standard deviation				1,98	4,34
Coefficient of variation				6,53	5,45

As explained in the materials and methods of the statistical analysis, the statistical classes are indicated by letters in the tables. For a better visual understanding they are differentiated by a colour code in the table.

As table 3 shows for all treatments the spraying took place at crop stage BBCH 10, more precisely on 31/10/2019. The first evaluation of the efficacy of the combinations was made at the BBCH 11 stage on 14/11/2019. At first sight, differences were already noticeable. However, after statistical analysis it was found that all combinations were not significantly different. Indeed as seen in the tables they are all classified in class a. There is a statistical difference between all treated plots and the UTC, thereby validating the efficacy of the treatments and validating the trial set up.

At the second assessment, the (efficacy assessment carried out at BBBCH 13, on 29/11/2019) various differences were observed. From the statistical analysis, the efficacy of the different combinations can be sorted into 6 classes. Here too, there is a statistical difference between the treated plots and the UTC, proving the efficacy of the combinations.

Table 4 :Classification of the different combinations according to their efficacy on Alopecurus myosuroides

No.	Name	Percentage of *Alopecurus myosuroides* control by combination of treatments at BBCH 13	Classification according to statistical classes	Classification according to EPPO criteria
1	Untreated Check	0e		
2	Product 1 Product 2	75,5bcd	Fourth	Medium efficacy
3	Product 3 Product 4	83abc	Third	Medium efficacy
4	Product 3 Product 5	70cd	Fifth	Medium efficacy
5	Product 3 Product 5 Product 6	66,5d	Sixth	Low efficacy
6	Product 3 Product 5 Product 7	94a	Most effective	High efficacy
7	Product 8 Product 3 Product 5	87,5ab	Second	High efficacy
8	Product 3 Product 9	83abc	Third	Medium efficacy
9	Product 3 Product 9	77,5bcd	Fourth	Medium efficacy

As table 4 shows according to the EPPO table, 3 levels of efficacy at stage BBCH 13 were identified. Looking at the statistical analysis, combination number 6 is the most effective. According to the EPPO table, combinations number 6 and 7 are in the same class.

How do combinations of post emergence herbicides perform against *Viola arvensis (field pansy)*?

The percentage of ground cover by *Viola arvensis* is very variable between the two untreated plots. Indeed as figure 10 shows it is possible to see a gap of 30% between both plots. For the statistical calculations above, the average between the two blocks was used.

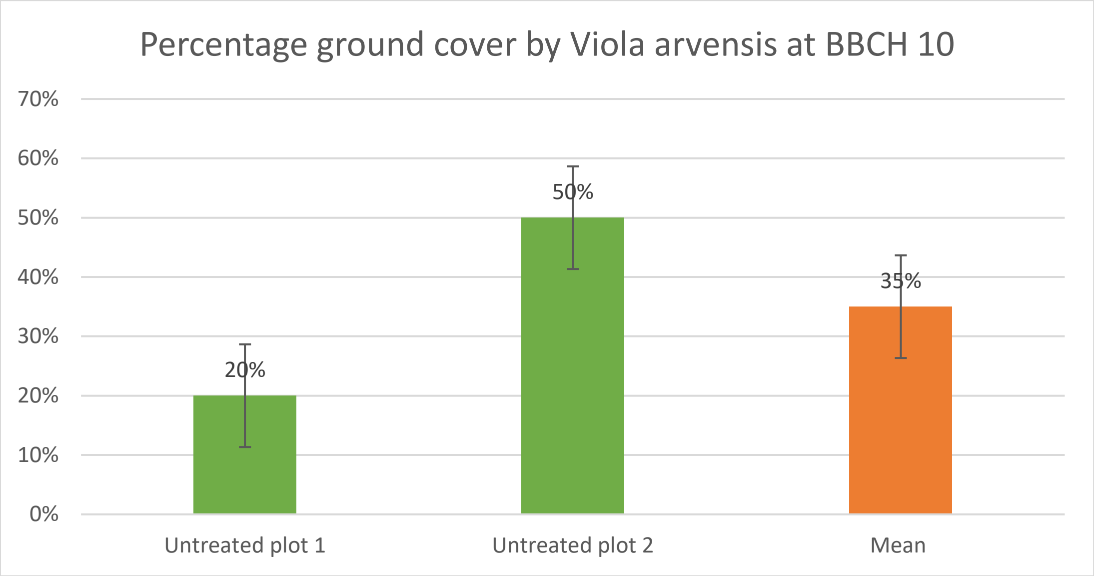


Figure 10 : Percentage ground cover by Viola arvensis at stage BBCH 10

Table 5 : Percentage of Viola arvensis control by combination of treatments

Combination	Treatment name	Rate	Rate unit	Percentage of Viola arvensis control by combination of treatments at BBCH 11	Percentage of Viola arvensis control by combination of treatments at BBCH 13
1	Untreated			0b	0b
2	Product 1 Product 2	0,3 0,75	L/ha L/ha	29,0a	82,5a
3	Product 3 Product 4	0,02 3	kg/ha L/ha	30,5a	87,5a
4	Product 3 Product 5	0,02 3	kg/ha L/ha	33,0a	77,5a
5	Product 3 Product 5 Product 6	0,02 2 2	kg/ha L/ha L/ha	36,5a	85,0a
6	Product 3 Product 5 Product 7	0,02 2 2	kg/ha L/ha L/ha	33,5a	100,0a
7	Product 8 Product 3 Product 5	0,1 0,01 3	kg/ha kg/ha L/ha	31,0a	91,5a
8	Product 3 Product 9	0,02 2	kg/ha L/ha	31,0a	77,5a
9	Product 3 Product 9 Product 10	0,02 2 1	kg/ha L/ha L/ha	34,5a	55,0a
P=0,5				4,87	57,24
Standard deviation				2,06	24,21
Coefficient of variation				6,37	29,5

The table 5 shows that no combinations have a significant difference at either BBCH stages. Only untreated plots statistically differ from the others. The different combinations therefore have an effect on the control of *Viola arvensis*, but none of them shows superior results to another. At stage BBCH 11 the values are fairly grouped and do not show significant differences. However at BBCH 13, despite significant numerical differences as between combinations number 6 and 9, no different statistical classes were found. This is explained by the coefficient of variation which is very high at stage BBCH 13, it is related to the large difference in the percentage of soil covered by the weed that can be seen in figure 3. The population of *Viola arvensis* was too heterogeneous and in too few numbers to say that 95% of the observed differences are due to the product applied.

According to the EPPO table, the combinations can be sorted into 4 levels of efficacy at stage BBCH 13:

Very high efficacy: Combination 6

High efficacy: Combination 5, 7 and 3

Medium efficacy: Combination 2, 4 and 8

Low efficacy: Combination 9

From the classification of the efficacy of the different combinations, it appears that combination number 6 is once again the most effective and is classified as very high efficacy. Combinations 5, 7 and 3 also have high efficacy. However, these differences are not statistically significant.

Are all of these herbicide combinations crop safe?

As can be seen in Table 6, some of the different combinations have negative effects on the crop *Triticum aestivum*. 2 statistical classes can be seen, the combination 6 has the most negative effects on the culture.

Table 6 : Percentage of damage in Triticum aestivum

Combination	Treatment name	Rate	Rate unit	Percentage of damage in *Triticum aestivum* at BBCH 11	Percentage of damage in *Triticum aestivum* at BBCH 13
1	Untreated			0b	0b
2	Product 1	0,3	L/ha	5b	0b
	Product 2	0,75	L/ha		
3	Product 3	0,02	kg/ha	6b	2,5b
	Product 4	3	L/ha		
4	Product 3	0,02	kg/ha	0b	0b
	Product 5	3	L/ha		
5	Product 3	0,02	kg/ha	0b	0b
	Product 5	2	L/ha		
	Product 6	2	L/ha		
6	Product 3	0,02	kg/ha	37,5a	32,5a
	Product 5	2	L/ha		
	Product 7	2	L/ha		
7	Product 8	0,1	kg/ha	8,5b	4b
	Product 3	0,01	kg/ha		
	Product 5	3	L/ha		
8	Product 3	0,02	kg/ha	0b	0b
	Product 9	2	L/ha		
9	Product 3	0,02	kg/ha	0b	0b
	Product 9	2	L/ha		
	Product 10	1	L/ha		
P=0,5				11,05	4,29
Standard deviation				4,67	1,81
Coefficient of variation				65,56	37,18

A slight decrease in crop damage at the BBCH 13 stage for the treatment 6 can be observed. However this decrease is not high enough not to identify a significant difference. All other combinations belong to the same statistical class that also show reductions in negative effects between the two BBCH stages.

On picture 1 it is a leaf of *Triticum aestivum* following the treatment of combination 6. This leaf shows areas of necrosis testifying to a reaction of the plant to defend itself.

Picture 1 : leaf of Triticum aestivum after spraying of the combination 6

How cost effective are these combinations of herbicides from a farmer's perspective?

The table below shows the price per hectare of the different combinations of treatments. The prices used are the reference prices recommended by the company that markets these products .

Table 7 : Calculation of the price per hectare of the different combinations of treatments

Combination		Rate	Unit	Price/l	price/100g	price/hectare	Total price/hectare
2	Product 1	0,3	L/ha	115,05		34,52	64,03
	Product 2	0,75	L/ha	39,35		29,51	
3	Product 3	0,02	kg/ha		132,6	2,65	40,75
	Product 4	3	L/ha	12,7		38,10	
4	Product 3	0,02	kg/ha		132,6	2,65	43,45
	Product 5	3	L/ha	13,6		40,80	
5	Product 3	0,02	kg/ha		132,6	2,65	62,15
	Product 5	2	L/ha	13,6		27,20	
	Product 6	2	L/ha	16,15		32,30	
6	Product 3	0,02	kg/ha		132,6	2,65	167,45
	Product 5	2	L/ha	13,6		27,20	
	Product 7	2	L/ha	68,8		137,60	
7	Product 8	0,1	kg/ha		23,44	2,34	44,47
	Product 3	0,01	kg/ha		132,6	1,33	
	Product 5	3	L/ha	13,6		40,80	
8	Product 3	0,02	kg/ha		132,6	2,65	27,05
	Product 9	2	L/ha	12,2		24,40	
9	Product 3	0,02	kg/ha		132,6	2,65	39,70
	Product 9	2	L/ha	12,2		24,40	
	Product 10	1	L/ha	12,65		12,65	

As table 7 shows prices per hectare are very heterogeneous with prices ranging from 27€ to 167€, from this it is easy to define which combinations are the most economically interesting for farmers

Table 8 : Different combinations and their prices

No.	Name	Percentage of *Alopecurus myosuroides* control by combination of treatments at BBCH 13	Percentage of *Viola arvensis* control by combination of treatments at BBCH 13	Percentage of damage in *Triticum aestivum* at BBCH 13	Total price/hectare
1	Untreated Check	0e	0b	0b	0 €
2	Product 1 Product 2	75,5bcd	82,5a	0b	64,03
3	Product 3 Product 4	83abc	87,5a	2,5b	40,75
4	Product 3 Product 5	70cd	77,5a	0b	43,45
5	Product 3 Product 5 Product 6	66,5d	85,0a	0b	62,15
6	Product 3 Product 5 Product 7	94a	100,0a	32,5a	167,45
7	Product 8 Product 3 Product 5	87,5ab	91,5a	4b	44,47
8	Product 3 Product 9	83abc	77,5a	0b	27,05
9	Product 3 Product 9 Product 10	77,5bcd	55,0a	0b	39,7

From the table 8 it is possible to discuss the quality/price ratio of certain products as well as their economic interest in terms of possible yield gains through weed control.

The prices obtained are compared with the theoretical possible gain in yield due to the control of weed. The interest of their uses is presented in the discussion part of the results.

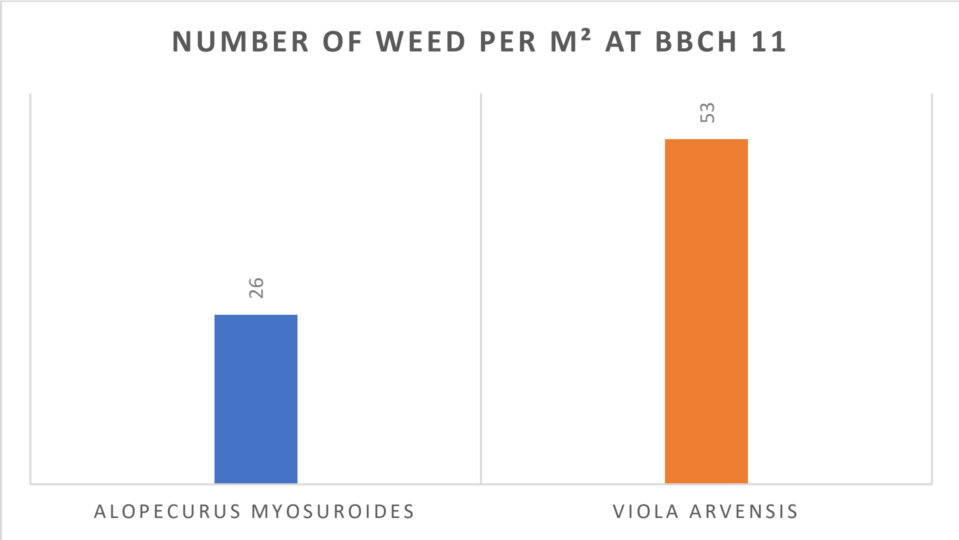


Figure 11 : Number of weed per m² at BBCH 11

Figure 11 shows the number of weed per square meter between *Alopecurus myosuroides* and *Viola arvensis* is heterogeneous. But these weeds have different pest pressure on the crop. Their influence on the culture in place depends on their population.

Chapter IV : Discussion of result

Throughout this study, the objectives were to compare different combinations of post-emergence herbicides in winter wheat. Since the implementation of a new directive in the 1990s, the number of molecules on the market has steadily decreased. It is also at this date that many herbicide-resistant weeds appeared. Among them is *Alopecurus myosuroides* (black grass), which is present in large numbers in winter crops in most of the cultivated area in Europe. To evaluate the efficacy of the different herbicide combinations, the following elements were measured on a resistant plant *Alopecurus myosuroides* (black grass) and a non-resistant plant *Viola arvensis* (field pansy):

- efficacy against *Alopecurus myosuroides* (black grass)

- efficacy against *Viola arvensis* (field pansy)

- Their impact on winter wheat cultivation (crop damage)

- The calculation of their prices per hectare

This chapter presents the methodology used and the results obtained. The results obtained are analysed by comparison between each other in this chapter but also by what has been seen in the literature. Comments were made on the conduct of the test and the possibility of improvements if the test were to be repeated in the future.

How do combinations of post emergence herbicides perform against *Alopecurus myosuroides (black grass)*?

The follow-up of this test was carried out correctly, the weather (see weather data in appendix 1) was in accordance with the different application dates. Germination and emergence of wheat and weeds went according to plan. After the first counting it was very interesting to see that the population of *Alopecurus myosuroides* was high and rather homogeneous. Weather conditions, hygrometry, wind speed, temperature were favourable during spraying. These optimal conditions have led to visible results over the time expected in the protocol.

The 9 combinations studied on *Alopecurus myosuroides* showed very heterogeneous results and allowed to be classified into several statistical classes. The statistical analysis resulted in the definition of 6 statistically different classes. In first place is the number 6 combination with a very high efficacy of 94% against *Alopecurus myosuroides*. Combination number 7 is in second place with an 87.5% efficacy against *Alopecurus myosuroides*. In third place are the combinations 3 and 8 with an efficacy of 83%. Combination 2 had an efficacy of 75.5% and combination 9 scored 77.5%. They are both in the same statistical class and are in fourth place. Combination 4 was in the fifth place with an efficacy of 70% against *Alopecurus myosuroides*. Combination number 5 is therefore in last place with an efficacy of only 66.5%.

Alopecurus myosuroides being a resistant weed to certain herbicides, it therefore requires very careful control. Indeed, it is necessary to avoid that resistant weed do not grow in numbers. So it is important to avoid that they do not reach the seed production stage. It is therefore necessary to control them at early BBCH stages when they are still in the form of seedlings or plants with a low number of leaves. In order to ensure maximum efficacy to avoid the development of a resistant plant population in the future, it is recommended to use products or product combinations with very high efficacy. Referring to the EPPO table, only combinations 6 and 7 are appropriate for the control of *Alopecurus myosuroides*. It would still be more appropriate to use the combination number 6 that has a higher score and is statistically different from the number 7 combination.

Due to the small difference in the population of *Alopecurus myosuroides* between the two untreated blocks, the coefficient of variation is only slightly impacted. At the BBCH 11 stage the efficacy values are relatively close, despite the low standard deviation. However, at the BBCH 13 stage, the efficacy of the different combinations begins to differentiate, yet with a higher standard deviation. This has still made it possible to classify the combinations into 6 statistical classes.

Regarding possible improvements, it would have been interesting in this trial to add one or two treatments with controls using a single product without combinations. This would have made it possible to compare the efficacy between combinations and uses of a single product. This would probably even have made it possible to identify which mode of action Alopecurus myosuroides has become resistant to. Probably that for this sub-question which studies a resistant plant it would have been interesting to involve a more detailed analysis on the mode of action. This could have explained in further details the difference in the results obtained.

Comparisons with data seen in the literature

With what has been seen in the literature presented in the "Theorical framework" section, notably by the major national study conducted by Arvalis, data as a reference value to compare the results obtained on *Alopecurus myosuroides*. Among them are the following values:

- 72% which is the average obtained after testing the 3 most commonly used herbicides in single use.

- Average 10% increase in efficacy with products in combinations

(Arvalis, 2017)

As Table 1 shows, there is no major statistical difference between the number of products used. As an example combination number 5 which contains 3 products and has an efficacy of 66.5% and is classified in statistical class d. However the combinations numbers 3 and 8 contain only 2 products and have an efficacy of 83% and are classified in the statistical class abc. Some of the results are therefore contradictory to what has been seen in the literature. In particular the combination number 5 which presents very low and unexpected results.

How do combinations of post emergence herbicides perform against *Viola arvensis (field pansy)*?

The methodology and conduct of the tests for this part were the same as for *Alopecurus myosuroides*. The weather conditions and application dates were well aligned with the plan provided in the protocol. Only one negative thing was noticeable for the *Viola arvensis*; its population indeed was very heterogeneous between the two untreated blocks.

This heterogeneous population has directly influenced the statistical analysis. Indeed, at the two-stage BBCH evaluation of the efficacy of the combinations, only one statistical class was defined, despite numerical differences such as between combination 6 which had a result of 100% and combination 9 which had only 55%. The large differences between the untreated plot number 1 which had a soil cover by *Viola arvensis* of only 20% and the second plot which had a soil cover of 50%, resulted in a high coefficient of variation. This did not allow to confirm at 95% that the differences observed were only related to the product combinations.

With the EPPO table it is possible to classify the different combinations according to their efficacy. However, these results are only illustrative, since no combination statically stand out . One cannot use the EPPO table as a reference. The following results are debatable. Combination number 6 is in first place with a very good efficacy of 100%. Then come the combinations 7 with 91.5% efficacy, 3 with 87.5% efficacy and finally 5 with 85% efficacy they are all classified as highly efficient. In the middle efficacy class it is combination 2 with an efficacy of 82.5%, combinations 4 and 8 with both an efficacy of 77.5%. And finally, with a low efficacy classification, it is still the combination 9 with an efficacy of 55%. It is noteworthy that the same combination with the same classification is found in almost the same way according to the EPPO table. Notably in the first place the combination number 6 followed by the 7 in the last place the combination 9, however it would be scientifically incorrect to say that one is better than the other. In this analysis the EPPO table serves only as an indicative classification but cannot be used as a scientific element.

Concerning possible improvements, in the case of this situation where no significant statistical difference appeared, many possibilities for improvement can be identified. First, the population of *Viola arvensis* were wild and their distribution in the plot was therefore random, even if the selected field was known to have recurring weed problems. The idea of sowing grasses to ensure a homogeneous population is conceivable, but the aim of this trial was to get as close as possible to the situations present on the farms. Moreover, this sown population would have been added to the wild population, their numbers would probably have been just as random. Another possibility would have been to analyse the efficacy of combinations on all non-resistant weeds present in trial.

Comparisons with data seen in the literature

About *Viola arvensis* the results obtained by Arvalis were mixed with the various non-resistant weeds. The values obtained were as follows:

- The use of a single product gave an efficacy of 85%.

- The use of products in combinations gave an efficacy ranging from 80% to 90%.

(Arvalis, 2017)

The results of the tests are very heterogeneous and difficult to compare with the results obtained by Arvalis, since Arvalis obtained very similar results between the use of a product alone or in combination. As mentioned in the introduction, the combinations are mainly effective against resistant weeds. Statically no significant difference is noticeable for the control of *Viola arvensis*. As an indication, it is possible to compare the results obtained by Arvalis with the percentages obtained in this test and their classification in relation to the EPPO table. Like the combination 6 composed of 3 products and which has a very good efficacy of 100%. Compared to combination number 9 which has a low efficacy of 55%.

Are all of these herbicide combinations crop safe?

The evaluation of damage on *Triticum aestivum* have been conducted to analyse if the combinations are crop-selective. In fact products can have a high efficacy against weeds, but they can affect the main crop too. Selectivity is as important as the efficacy of the products. Indeed products are using to kill weeds and increase the yield, but in case of damage on the crop they can directly reduce the yield.

After the first assessment at stage BBCH 11 significant crop damage with the combination number 6 was observed. Combination 6 is statically different and has negative effect on the main crop (37,5 % crop damage). At BBCH 13 the damage was lower, with 32,5% but the results was the same, combination number 6 is highlighted by statistical analyse. This fact is interesting because the combination 6 came out twice in first place concerning its efficacy on *Alopecurus myosuroides* and *Viola arvensis*. This allows to state that this combination has very good results but is not selective enough to say that it is the best one. Some other combination as 7, 3 and 2 made also some small damage on the crop. The other combinations do not have a negative effect on wheat. They are in the same statistical class as the untreated plots. So it means that their selectivity is very good and that the main crop has not been affected at all by the use of these combinations. As seen, the percentage of damage is higher at the stage BBCH 11 than at BBCH 13. This means that the *Triticum aestivum* was not dead but just weakened, with yellow leaves and broken leaves. The improvements observed after two weeks may lead to believe that the damage caused will not greatly affect wheat growth, and that the crop will recover after a period of time.

The standard deviation is greater at the BBCH 11 stage because this is the stage closest to spraying and therefore the observed damage on wheat is greater. The standard deviation decreases at the BBCH 13 stage and is relatively small due to the reduction in observed damage. The coefficient of variation is relatively high at the BBCH 11 stage but slightly lower at the BBCH 13 stage.

Improvements for this part are possible. However, one of the most interesting was not possible in the timing of this trial. Indeed it would have been interesting to continue to follow the evolution of the damages on culture to see if over time they reduce and in the end, make a comparison of the yield between the different modalities.

How cost effective are these combinations of herbicides from a farmer's perspective?

Methodologically this analysis could not have inaccurate data. Indeed, the only data collected in the trial concerned the population of *Alopecurus myosuroides* and *Viola arvensis*. Prior to the implementation of the test, the prices of the products were already known. A literature search was required to find theoretical values for assessing yield loss as a function of different weed populations.

Prices are relatively heterogeneous with prices ranging from 27€/hectare to 167€/hectare. The average price of the nine combinations is 61€. With such a price gap it becomes interesting to study the profitability of these products to ensure that the cost per hectare does not exceed the theoretical possible profit.

Studies have made it possible to define the number of weeds per square metre that results in a 5% yield loss. The limit for *Alopecurus myosuroides* was evaluated at 26 plants per square meter. The limit of *Viola arvensis* was evaluated at 133 plants per square meter (Arvalis et al., 1985). As a reminder, the population of *Alopecurus myosuroides* evaluated in the tests was 26 plants per m². With such a population it is therefore possible to assert a theoretical loss of yield of 5%. The one for *Viola arvensis* was 53 plants per m². It is possible to claim a yield loss above the number of 133 plants per m², however it is not possible to claim a yield loss below this threshold. Although this population will have an influence on yields but its assessment is very difficult because it also depends on many other factors such as weather and soil type. Based on the average wheat prices in the last three years which is €182 per tonne (Statista, 2019), and a loss of 5 % in land normally allowing production of 8.5 tonnes of wheat per hectare. It is possible to define with a simple calculation that the 5% decrease in yield results in an economic loss per hectare of 77€. From this value it is possible to see that all combinations are profitable from the farmer's point of view. Except the combination number 6 which represents a very high cost (even more than twice too high to be profitable). Moreover, it is interesting to add that it was found that the combination of numbers 6 caused significant damage to the crop. It is therefore conceivable that a loss of yield will also occur as a result of the use of this combination.

Another element that is difficult to measure may also be an important factor for a farmer in deciding to spray or not. Plants that have not been destroyed will produce seeds that will allow new plants to appear in the next crop. Which can lead to the conservation of an important population and it is increase .

Concerning the improvement, first of all the values of yield loss are very accurate because they include a large number of studies, but they are not 100% accurate because many other factors also influence pest threshold, such as weed survey date, soil type, weather, wheat variety, etc. To be as accurate as possible and to be able to statistically analyse the results it would have been necessary to make a comparison of yields between the modalities but again this was not possible in the time devoted to this test. Secondly it would have been more accurate to evaluate all the weeds present in the test to really compare the profitability of the combinations. Indeed the combinations were not intended only to control *Alopecurus myosuroides* and *Viola arvensis* but of course the entire range of weeds present in the plot. It is therefore possible that other plants may also have exceeded the pest threshold, which would have increased the profitability of the combinations.

Comparisons with data seen in the literature

The prices displayed in the Arvalis study was as follows:

- The average price per hectare for the application of combined products is 71€.

In this trial the average price of the combinations was 54€ per hectare. This value is only an indication, it is not necessary to make a comparison or analysis between these 2 values. Indeed, in this test only the products proposed by a manufacturer were used. In the tests conducted by Arvalis, products of all origins were used. As an indication, the modes of action of all the products will be available in the appendix section 2.

Chapter V - Conclusions and recommendations

Conclusions

Triticum aestivum has always been an important crop in the world, it is the most widely grown cereal second in the world after maize and the first cereal grown in Europe. The development of agriculture in the post second world war years, particularly in terms of technology (chemicals, fertilizers, etc.) and machinery, has made it possible to increase yields significantly. But in the 70s herbicide problems appeared, resistance indeed the number of plants become resistant to some herbicides went from 0 in 1975 to 120 in Europe in the 90s. The number of products available on the market at that time did not make these resistances appear to be a problem. However, a new directive came into force in 1991 in Europe making approval controls much more complex. The number of registered herbicides has therefore to be reduced significantly each year. Indeed in 2004 there were 94 herbicides registered in Europe for weed control in wheat and today there are only 26. What has resulted today has a kind of deadlock, where resistant plants are still present but they have to be managed with fewer products available.

An agrochemical company therefore asked about the different product combinations it could offer according to the products it has available on the market. The objective was therefore to see what the results were obtained after combining the products against a resistant and a non-resistant weed. The weeds studied were chosen according to known problems in a specific environment. It was therefore decided to choose *the Alopecurus myosuroides* as a resistant plant and the *Viola arvensis* non-resistant plant.

After the trial was set up and data collection, the analysis was carried out, now conclusions can be drawn. With statistical analyses it was seen that combination number 6 has a high efficacy on *Alopecurus myosuroides*. However, no significant difference has highlighted this combination for *Viola arvensis* control. Referring to the evaluation table of herbicide efficacy made by the EPPO, it appears that combination number 6 still stands out in first place. However, this combination causes significant damage to the wheat crop that can affect yield. From an economic point of view, this combination is not interesting to control weed populations as it was in the trials. Indeed it represents a much higher cost compared to the possible yield gains.

If it was necessary to identify the best combinations in this trial it is possible that it is the 7, because it is statistically efficient to control *Alopecurus myosuroides*. However, it is only effective against *Viola arvensis* according to the EPPO table, but it does not stand out statically compared to other combinations. And it causes little damage to the wheat crop, in fact it belongs to the same statistical class as the untreated check. Moreover, it is economically interesting with a price per hectare of only 44.47€ per hectare.

Combinations 5 and 3 show good results according to the EPPO table for *Viola arvensis* control, but they have not been highlighted for statistical analyses of *Viola arvensis* and *Alopecurus myosuroides*. It is therefore not possible to say from a scientific point of view that these two combinations are really effective.

This research has made it possible to really highlight certain combinations but also to discard some of them in relation to their low efficacy. This was also the way to demonstrate that the management of combinations remains complex, the choice of products to be combined requires very precise choices. Some combinations even with 3 products do not necessarily lead to conclusive results. Similarly, they can have very good results on weeds but also affect the crop in place. The miracle combination is not yet available (will it ever be?!), the combinations are also to be selected according to the problems known for certain resistant herbs and their population to ensure profitability. The research on the different possible combinations still has a long way to go and will continue to evolve according to the products available and the problems of resistant weeds.

Recommendation

After pooling different results it is possible to remove the 3 best combinations. Combinations number 7 seems to be the most suitable combination for weed control in general. Then it is the combinations 3 and 8 which are both at the same level.

It is also important to find out about the damage that combinations can do to the crop. As seen, some combinations can have very good results but can cause significant damage to the culture. The cost is also important because if the weed population is not controlled high it may be that the price of the treatment without including the prices of working time and equipment exceeds the possibility of possible gain.

This research made it possible to identify the efficacy of the different combinations. But it was also a way to understand the reasons for the emergence of resistant weeds. In general, many levers can be tilled to control weeds. First of all herbicides remains the most common, however in the case of the presence of resistant plants it is important to rotate the herbicides used with a combination of different herbicides this allows to v ary the modes of action used. Then before applying a treatment it is important to know which weeds are most likely to grow. In order to properly select the products to be used. Do not hesitate to make product combinations with herbicides from different manufacturers. Then there are other means of control such as longer crop rotations with a frequent alternation of winter and spring crops, tillage is also a key factor in weed management.

By comparing the results seen in the literature with those obtained in this test differences were observed. On the one hand, on the efficacy of combined products, there have been counter-examples. These two studies are close in purpose but their set-up is different. Indeed, the products used were not the same. Through these comparisons a hypothesis can be formulated confirming what (Lamichhane et al., 2017) have presented in his studies. This study, which was presented in the "theorical framework" section, mentioned an interesting part: "This article links numerous studies demonstrating that weed management and in particular resistant weed management required technological knowledge of herbicides, particularly through dose and family management". This confirms what has been seen for the control of *Alopecurus myosuroides*. Indeed some herbicide combinations have a better effect on the control of resistant weeds but this is not the case for all combinations. The key combination factors would therefore be the management of the association of the different herbicide families.

Assessment of the recommendations:

- Farmers need to know the types of weeds present on the field, whether they are resistant or not, and their populations.

- The choice of combinations must be made according to the weeds present and their resistance, the price of the combinations and their efficacy, the mode of action of the different herbicides and the mode of action of the herbicides previously used on the plot.

- For agrochemical companies, continuity of research is very important, for the discovery of new products, but also for a better control of combinations.

- Research can still be done on the control of resistant weeds according to the different modes of action of herbicides and on alternative weed control measures

List of references :

Arvalis. (2017). *National herbicide trials*.

Arvalis, J.W, W., ACTA, & HAGCA. (1985). *Quelle est la nuisibilité des mauvaises herbes ?* https://www.arvalis-infos.fr/_plugins/WMS_BO_Gallery/page/getElementStream.jspz?id=22421&prop=file

Baron, C. (2019). *Principaux pays producteurs de blé Monde 2016-2019*. Statista. https://fr.statista.com/statistiques/559831/principaux-pays-producteurs-de-ble-dans-le-monde/

BASF France. (2019). *Mes 'Anti-sèches' phytos* (Studio zèbre).

Benoît, M., Bonicelli, B., Guichard, L., Delorme, R., Faloya, V., & Ruelle, B. (2005). *Connaissance de l'utilisation des pesticides*. 61.

Bimbard, M. (2018). *Préconisations désherbage céréales 2019*. 10.

Ephy. (2019). *List of authorised herbicides in Europe*. https://ephy.anses.fr/lexique/substance/a

EPPO. (2009). *European and Mediterranean Plant Protection Organization Organisation Européenne et Méditerranéenne pour la Protection des Plantes*.

EuWerostat. (2018, October). *Agricultural production—Crops—Statistics Explained*. https://ec.europa.eu/eurostat/statistics-explained/index.php/Agricultural_production_-_crops

HARC classification. (2010). *The world of herbicide*.

Hucorne, P. (2012). *Zonal efficacy assessments*. https%3A%2F%2Fwww.eppo.int%2FACTIVITIES%2Fplant_protection_products%2Fzonal_assessments

Indexmundi. (2019). *Wheat Production by Country in 1000 MT - Country Rankings*. https://www.indexmundi.com/agriculture/?commodity=wheat&graph=production

Kudsk, & Aarhus. (2016). *Weed resistance in European cereal production: Status, causes and perspectives*. University Denmark. file:///C:/Users/vince/Downloads/KW51_Per_Kudsk%20(1).pdf

Lamichhane, J. R., Devos, Y., Beckie, H. J., Owen, M. D. K., Tillie, P., Messéan, A., & Kudsk, P. (2017). Integrated weed management systems with herbicide-tolerant crops in the European Union: Lessons learnt from home and abroad. *Critical Reviews in Biotechnology*, *37*(4), 459–475. https://doi.org/10.1080/07388551.2016.1180588

Ordonio, R., & Matsuoka, M. (2016). *Herbicides—An overview | ScienceDirect Topics*. ScienceDirect. https://www.sciencedirect.com/topics/neuroscience/herbicides

Passion Cérales, P. (2018, April). *Les céréales en chiffres*. Passion Céréales. https://www.passioncereales.fr/dossier-thematique/les-c%C3%A9r%C3%A9ales-en-chiffres

Statista. (2019). *Wheat monthly price 2019*. Statista. https://www.statista.com/statistics/692714/wheat-monthly-price-european-union-eu/

1

Daily climatical data

Data collected less than 3 km of the trial

	October 2019			November 2019		
	Rain (mm)	T C min	T C max	Rain (mm)	T C min	T C max
1	3.6	8	17	2.4	0	9
2	2.6	7	14	2.2	10	16
3	0	5	11	8	9	12
4	6.1	5	11	4.5	8	10
5	6.3	6	10	0	6	10
6	12.1	4	8	1.1	6	8
7	1.8	6	10	1.7	4	10
8	7.8	9	14	9.7	4	6
9	7.7	8	13	0.5	1	6
10	7	7	11	0	0	5
11	0	7	16	0	-1	2
12	0	9	20	0.4	1	7
13	0	13	25	0.1	1	5
14	0	13	24	0	-1	6
15	2.8	11	21	0.8	0	5
16	0.4	9	14	1.1	1	8
17	1.5	9	16	0.3	1	5
18	6.7	10	16	0.2	2	5
19	4.7	10	13	0	-1	4
20	1.4	10	17	0	-2	1
21	0	10	18	0	1	5
22	0	8	16	0	1	3
23	0	9	13	0	2	10
24	0.1	10	15	0	2	9
25	0	9	15	0.1	2	5
26	0	8	19	0	4	10
27	4.5	6	16	1.3	5	11
28	0.2	4	9	2.8	7	9
29	0.1	3	7	6	2	7
30	0	0	7	0	-1	5
31	0	-1	8			
Average		7.5	14.3		2.5	7.1
Amount	77.4			43.2		
Historical	42.1	5.8	13.8	52.8	2.0	7.6

2 Mode of action of different combinations

Combination No.	*Type*	*Mode of action*
1	CHK	
2	Product 1 Product 2	K3 F1
3	Product 3 Product 4	B K1
4	Product 3 Product 5	B N
5	Product 3 Product 5 Product 6	B N K1
6	Product 3 Product 5 Product 7	B N K3 + F1
7	Product 8 Product 3 Product 5	F1 + B B N
8	Product 3 Product 9	B K1 + F1 + C2
9	Product 3 Product 9 Product 10	B K1 + F1 + C2 C2