Wireworm (Coleoptera, Elateridae) risk factors within potato cultivation

Cécile Bodier

Norwegian University of Life Sciences
Department of Agroecology
Master Thesis 30 credits 2013

Ecole Supérieure d'Agriculture
55 rue Rabelais
49007 ANGERS-FRANCE

ARVALIS-Institut du végétal
Station expérimentale
91720 BOIGNEVILLE-FRANCE

ISARA-Lyon
Agrapole
23 rue Jean Baldassini
69364 LYON Cedex 07-FRANCE

Norwegian University of Life Sciences
NO-1432
AAS-NORWAY

Wireworm (Coleoptera, Elateridae) risk factors within potato cultivation

Mémoire de fin d'études
Agroecology Master thesis
Double-Diploma/Double-diplôme

110th Cohort (2007-2013) **Cécile Bodier**

Date : March 2013

ESA tutor : Rim Baccar

ISARA tutor : Alexander Wezel

UMB tutor : Tor Arvid Breland

External tutors : Elise Vannetzel
Philippe Larroudé

Abstract

Confidential: No

Topic category:
(Do not write in this box)

Author: **Cécile Bodier**

Year: 2013

TITLE: Wireworm (Coleoptera, Elateridae) risk factors within potato cultivation

Key-words : Potato cultivation, Wireworm (Coleoptera, Elateridae), risk, statistical analysis, ARDI method, R software.

Abstract:

Invisible damage caused by the wireworm up to the time of harvesting make it one of the most feared pests, especially in potato cultivation. As there is no curative management possible, the only way to fight against it is preventively. To achieve this goal, it is necessary to examine which factors make the risk of wireworm attacks more prevalent. This study aims to get a better understanding of risk of wireworm attacks within potato cultivation and a better understanding of potato producer views about wireworm management. Two types of enquiries were combined within the same survey: one about technical aspects and the other one about social aspects of the problem. They were completed by going in situ meeting farmers. Information collected was processed using statistical tools: MCA, PCA, and HCPC analyses. The technical part was analyzed within seven themes: previous crops, interculture, wireworm damage, supply of organic matter, plot environment, chemical use, and mechanical passes. The social part was analyzed using the three first steps of the ARDI method: Actor, Resource, and Dynamic.

Number of pages of the main document: 45

Host institution: ARVALIS-Institut du végétal (France)

Résumé

Confidentiel: Non

Topic category:
(Do not write in this box)

Auteur: Cécile Bodier

Année: 2013

Signalement : Facteurs de risque de taupin (Coleoptera, Elateridae) en culture de pomme de terre.

Mots-clés : Pomme de terre, taupin (Coleoptera, Elateridae), enquête, analyse statistique, méthode ARDI, logiciel R.

Résumé:

Le taupin (Coleoptera Elateridae) est un ravageur redouté, notamment en pomme de terre, du fait des dégâts imprévisibles qu'il implique, le plus souvent visibles seulement à la récolte. Aucune méthode préventive n'étant à ce jour possible, le seul moyen de le maîtriser est la prévention. Pour ce faire il est indispensable de repérer les facteurs de risque permettant son développement. Cette étude a pour but de repérer ces éléments et de comprendre le contexte dans lequel se trouvent les agriculteurs par rapport à la lutte contre le taupin. Deux types d'enquêtes ont été réalisées : l'une orientée sur l'analyse technique des parcelles touchées, l'autre visant à comprendre le système dans lequel se trouvent les agriculteurs. Elles ont été mise en place au travers d'enquêtes sur le terrain avec les producteurs. Les données récupérées ont été analysées grâce à des outils statistiques : l'analyse ACM, ACP, et CAH. La partie technique a été traitée sur sept thèmes : cultures précédentes, interculture, dégâts de taupin, apport de matière organique, environnement de la parcelle, application de phytosanitaires et le travail du sol. Le système des agriculteurs a été analysé à travers les trois premières étapes de la méthode ARDI : Acteur, Ressource, Dynamique et Interaction.

Nombre de pages: 45

Entreprise d'accueil: ARVALIS-Institut du végétal (France)

Acknowledgements

I am taking this opportunity to thank all those who made a contribution to my study.

First of all I would like to thank Elise Vannetzel and Philippe Larroudé, my internship tutors, for advising and supporting me at every step of my work. Thanks for giving me the opportunity to work in the institute, during a strange period for a “normal trainee”.

Previous to this study, I had almost never set foot in either of the regions I based my work: Nord-Pas-de-Calais and Alsace. I am grateful to all the farmers and agricultural professionals I met there who helped me to complete this thesis.

Also, I would like to thank my school and master tutors, Rim Baccar and Tor Arvid Breland, for their advice on the reflection process, and for helping me to take a global view while I was “swimming” in my results. Thanks a lot for all their pertinent remarks.

As said previously, the analysis of my results was the one last big step I had to take to complete my thesis. I would like to thank Marion Gauthier (stats’master!) and Florent Duyme for their help in understanding the R software’s mystical language.

Many individuals from Arvalis helped me and even if my contact with them was occasional, they gave many useful tips and helped me to understand the potato sector and its crop sequence management. Thanks to Pierre Taupin, Guillaume Beauvallet, and Jean-Michel Gravoueille. A thought also goes to Marielle Chedot, Florence Couric, and Servane Ponthonne, with whom I spent some great times observing all the marvellous types of potato defects.

Sincere thanks also to Jean-Michel and Attracta Morin for the rereading of this work.

A special dedication goes to the trainees and fresh “CDD” people of Arvalis for the atmosphere of the internship, during and after work. Thanks to Boubyz and Little-Pig-Nose for their full-of-energy support, especially at the final stages of the study.

This thesis represents the end of my studies. I would like to take a step back and thank people I met during those five years (and a half). A special thanks to Agroecology master students, for everything we shared, with a special thought for Nathan Dorpalen.

Last but not least, I want to warmly thank my family, especially my parents, for having supported me not only during the thesis but through all my years of study. Thanks for everything.

List of charts and illustrations

List of abbreviations

ARDI: Actor, Resource, Dynamic, Interaction (interview method)

HCPC: Hierarchical Clustering on Principal Components (statistical analysis)

MCA : Multiple Correspondence Analysis (statistical analysis)

PCA : Principal Components Analysis (statistical analysis)

Table of contents

Introduction

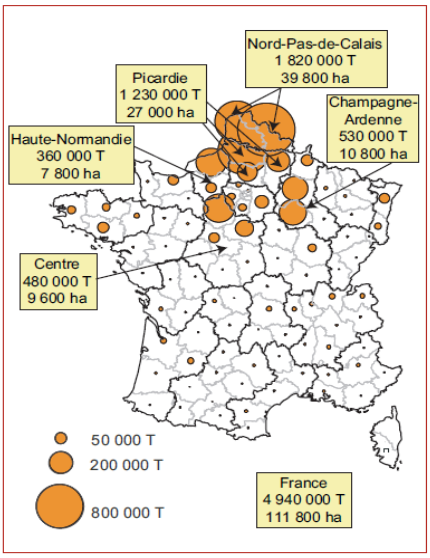
The potato is an herbaceous plant, from the Solanaceae family, gender *Solanum*, *tuberosum* L. It originates from the Andes cordillera in South America, where 400 cultivars have been recorded (ROUSSELLE et al., 1996).The potato is cultivated for its tubers and it is the fourth most consumed crop worldwide after wheat, maize and rice (FAO, 2012).

The top countries for potato production are China (72 M t per year), the Russian federation (37 M t per year), India (26 M t per year), the United States (20 M t per year) and Ukraine (19 M t per year). France only is ranked only 10^{th} as a potato producing country (6 M t per year) after Holland (7 M t per year) (FAOSTAT, 2012).

In 2007, Asia and Europe represented 80% of global production (FAO, 2012). Asia is the top potato consumer (50% of global production). Due to population figures for Asia, this translates into only about 24 kg per year per person in 2005. European people remain the first consumers with 88 kg per year per person (FAOSTAT, 2012).

In France, the annual average potato production is about 6 M tons since 1992 (FAOSTAT, 2012). This can be divided as follows: 160 000 tons of early potatoes, 400 000 tons of seedlings, 1 000 000 tons of starch potatoes and 5 000 000 tons of conservation potatoes (GRAVOUEILLE, 2012). Production is concentrated in Northern France representing 60% of the French market (Figure 1). Other regions like Southern and Eastern France are potato producers on a smaller scale (AGRESTE, 2011; UNPT 2012). For example, the Alsace region, where 60 000 tons of potatoes were produced in 2012, represents only 1% of French production (UNPT, 2012).

To summarize, in France 80% of potatoes are sold for human consumption and 60% are not processed industrially after harvesting (UNPT, 2012). This means that for 60% of the potato production, the tuber’s appearance is a determining selling point. It must be exempt from any defect: shape, mark, holes. Several pests such as nematodes, slugs, and wireworms, all present within the soil, are directly damaging the tubers (not the plant). We will focus here on wireworm.



Source : Agreste - Statistique agricole annuelle

Figure 1: French potato production concentrated in Northern France. (AGRESTE, 2011)

Of all the pests encountered in potato culture, the wireworm larva (*Coleoptera, Elateridae*), also known as click-beetle (adult stage) has remained for a very long time one of the most feared. Often, the damage is not visible until harvesting time, at which stage nothing can be done. There is no possible curative solution, only preventative (DEDRYVER et al., 2009).

Wireworm has a long lifecycle, which makes its containment difficult. The most damaging stage for many crops is the larva stage. This ranges between two and four years (Figure 2). Adults (click-beetles) lay their eggs during their few months of life, between May and June. The adult stage does not represent a threat for crops. Larvae hatch one month after laying (TAUPIN and BLOT, 2007). At first, larvae feed on organic matter. Once they are able to move, they will feed on living plant tissues including roots (TAUPIN and BLOT, 2007; TRAUGOTT et al., 2008). To our knowledge, no plant is specifically attacked by wireworm.

Conditions favorable for wireworm development are: high soil humidity and medium temperatures. For these reasons, wireworms come to the surface only during spring and autumn when temperatures are mild, while summer and winter temperatures can be either too high or too low. For protection, they dig downwards. Geographic distribution of wireworm shows that there are two dominant species in Northern and Western France (*A. lineatus*, *A.sputator*), while a third species (*A. Sordidus)*, with a shorter cycle, is developing in Southern France (TAUPIN and BLOT, 2007).

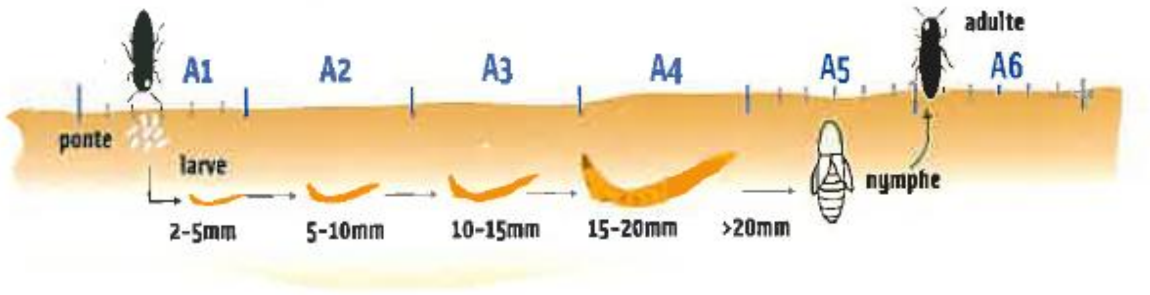


Figure 2: Wireworm life cycle: long cycle species (ARVALIS, 2004) A: année/year, ponte: laying

Until now, there is no curative way to fight against wireworm population, since wireworm damage is only visible late within the crop cycle. Its management can only use preventative tools.

Until the 1990's, chemicals were used to fight the wireworms attacks. Since the 1990's, some of these chemicals have been banned (organophosphorous, carbamates in the 70s and the lindane in 1998). One of the reasons for withdrawing them from the market was their permanency in the soil. Since 2000, resurgence of wireworm attacks has been observed on different crops (DEDRYVER et al., 2009; MADEC, 2006). There are two chemicals available today to fight against wireworms (Dursban 5G and Nemathorin 10G, (ARVALIS, 2012)), but their effectiveness is not universally agreed. Moreover, using chemicals is recognized as being a short-term solution. Overuse of chemicals will only postpone the problem and increase pest resistance to those products (GLIESSMAN, 2007).

Many preventative methods exist to manage or decrease wireworm development such as: lengthening crop rotations, harvesting earlier, drying the soil by mechanical means during the summer time (PARKER and HOWARD, 2001), avoiding planting potato straight after meadow in the rotation cycle, which enhances the insect development (TAUPIN and BLOT, 2007). However in most cases, these observations are neither followed, nor set up. Understanding why would help in exploring the farmers' situation and constraints regarding potato production.

The first goal of my study is to observe and evaluate on site what would be the main risk factors for wireworm damages in potato cultivation. Other studies have been produced by Arvalis previously on other crops such as maize and cereals (MADEC, 2006; BROUARD, 2012; GHESTEM, 2012). However there were no references to potato growth guidelines relating to the wireworm issue. The second goal was to understand the place of the potato producers in the food production system. In order to achieve my goal, I have interviewed potato producers. I decided to focus my work firstly in Northern France, the biggest French potato production zone, then in Eastern France (Alsace region) where the presence of wireworms was reported in many potato harvests

Thus I set two goals for my survey, (i) to understand what was happening on the farms (plot environment and farmers' practices), and (ii) to understand the farmer's views on the situation and problem. As said before, there is no clear answer why farmers are not setting up preventative methods already used by technicians. Consequently, I chose to conduct my survey in two parts: a survey on technical aspects (technical guidelines for the previous years, plot environment) and a survey on social aspects (understanding farmer's constraints and views on pest management) using a mental modeling method (ARDI: Actors, Resources, Dynamics, Interactions,) (ETIENNE, 2009).

Materials and method

1. Presentation of the context and general approach

This work was part of the Arvalis project « Crop protection against wireworm attacks: risk forecast and new techniques development », which has several goals. It aims firstly to find out where the wireworm occurrence rate has been increasing in France, (for main crop productions such as cereals, maize and potato). Then the factors promoting the insect's development should be identified. The final aim is the creation of a risk scale that could be used by farmers (LARROUDE; 2013).

Several studies have been conducted on cereals and maize (MADEC, 2006; BROUARD, 2012 ; GHESTEM, 2012), but none on potato. Until now Arvalis did not have technical references on potato culture related to this topic. My work aimed to focus on potato cultivation, while keeping the same approach as previous studies. I went directly to the farms to witness the damage of wireworm. Indeed in the potato production sector, contradictory observations have been reported and haven't been investigated properly.

My project was divided into two parts:

(i) The first part focused on technical information such as crop practices, and crop environmental surroundings characteristics. I needed to understand wireworm dynamics on the crops. I called this part: "survey on plot characteristics and agronomic practices".

(ii) The second part aimed at getting social or system information using farmers' views on this problem situation was called "survey on farmers' views of the system".

2. Survey on plot characteristics and agronomic practices

The goal of this part was to get information about potato cultivation plot characteristics. It aimed to understand what was happening on site and linked it to the wireworm damage.

To this end, I collected information about soil characteristics (where the wireworm is growing), plot bio-environment (Do plot surroundings have an effect on wireworm population?), plot crop sequence management over the previous four years, potato crop sequence management, wireworm damage locations (to understand where they are located on the plots), and wireworm damage observed on potato (to quantify damages) (cf. appendix 1).

2.1. Soil characteristics

Questions were asked about:

- type of soil (clay, silt, sand) detailing its components as much as possible (organic matter, pH)
- soil depth (roots depth),
- soil sensitivity to water (drained or not, slaked or not)
- soil gradient (in percentage)

2.2.Plot environmental surroundings

In this part, questions focused on elements of the landscape surrounding the plot. They have been identified (crop, wood, meadow, other) and quantified (percentage of each types of environment surrounding the plots).

2.3.Crop sequence management over previous years

The choice to have a four-year plot crop sequence management is motivated by the fact that wireworms have a five-year development cycle. Thus, I wanted to get information on how the plots had been managed previously.

Questions focused on:

- crop's type (wheat, maize etc.)
- interculture (precising the type)
- supply of organic matter
- soil mechanical passes.
- use of chemicals.
- presence of wireworm damages.
- plot environmental surroundings

Another part of the study was more detailed for crop preceding the potato culture (year n-1). There, I asked for information about crop residue (way and period of residue management), interculture (How have they been managed and when?), soil preparation (depth of soil mechanical passes), liming.

2.4.Potato crop sequence management

I wanted to get as much information as possible about potato crop sequence management. Questions were asked about:

- sowing and harvesting (potato variety, sowing date, sowing density, distance between drills, emergence from soil date, material for earthing up, earthing up's date, harvesting date)
- seedling protection (certification, chemicals used)
- protection against soil pathogens (insecticides against wireworm, nematodes, slugs; naming product, dose, date)
- crop protection (insecticides against beetle, aphid or tinea; naming product, dose, date)
- weeding (mechanical/chemical, how many passes, date)
- topkilling (mechanical/chemical, how many passes, date)
- treatment to prevent germination (product, dose, date)
- irrigation (equipment used, date, water quantity)
- fungicide use (number of treatments)

2.5.Identification of wireworm location

2.5.1. In the plot

I posed the question about the exact location of wireworm damage. I got information on their location in the cultivation areas:

- spread all over the plot or grouped?

- located in dry or humid area?

- located on packet soil or loose-soils areas.?

2.5.2. On potato

This information was based on potato sampling on site. 100 tubers per plot were harvested and inspected visually in the laboratory to estimate wireworm attack. The number of holes were reported, and a distinction between wireworm galleries (longer, more than three millimeters long) and wireworm bites (shorter, less than three millimeters long) was made.

3. Survey on farmers' views of the system.

This part aims to describe the potato production system through the farmers' worldviews. It aims to understand why farmers don't use preventative methods against wireworm, apart from chemicals,

With this systemic approach, I wanted to gather information about the influence of wireworm damage on the food production system. I thought it was relevant to use farmers' worldviews (opinions, visions, beliefs, values, mental modeling of a problem situation) about this topic. I chose to use an interview method, called ARDI (Actors, Resources, Dynamics and Interactions) (ETIENNE, 2009). It is a participatory method, developed by the ComMod collective (ETIENNE, 2010), known as « Companion modeling ».

Its aim is to get the views of a person or a group about one question. My question was « How to manage the wireworm population within potato cultivation? ». I chose such a wide question intentionally in order to let people consider what is important for them without influencing them. The interview process unfolds through several steps in order to get the person's worldviews, which represents the mental model of the interviewee.

The three first steps (A, R and D) consist of making three lists of ideas that the person is spontaneously thinking about after reading the question (cf. Figure 3).

The first is an actor list (A) that can be classified in two categories: direct or indirect actor. Direct one is acting directly on the system, while the Indirect is making decisions that will influence our direct actor. The second list is a resource list (R). It represents needs or means actors require to realize their activity. The last one is a dynamic list (D). Dynamics are processes that will significantly change system functioning. I classified them in three categories: ecologic, economic and social processes.

At the beginning of the interview process, the person was expressing spontaneously all the things on her / his mind. Once that is done, the interviewee selected elements in each list and classified them according to their importance. These selected elements were used to build the conceptual model.

In our case, after experimenting the ARDI method with the first interviews, I chose to have a maximum of 5 elements in the Actor list (A), 5 elements in the Resource list (R) and 3 elements in the Dynamics list (D).

How to manage the wireworm population within potato cultivation?

Actors:	
Potato producer	3
Technician	1
Potato cooperative	2
Agriculture Ministry	
Resources:	
Crop rotation	3
Knowledge about wireworm	
Chemicals	2
Cultural Experiment	1
Dynamics:	
Increase of wireworm population	2
Consumer acceptance for buying potato with wireworm holes	1
Developing an efficient mean to fight against wireworm	3

Number: Mark given by the person interviewed

Figure 3: Example of three first steps of ARDI survey (Actors, Resources, Dynamics)

In this example, the person interviewed had to choose three elements in each category and classify them. Elements without marks were not selected and were considered as "quoted" elements (such as"agriculture ministry").

The last step, interactions (I) is the construction of the interviewee conceptual model. Based on the selected and ranked elements of each list, the person placed them on a sheet in order to create a diagram, and connect the elements between them (arrows) (cf. Figure 4).

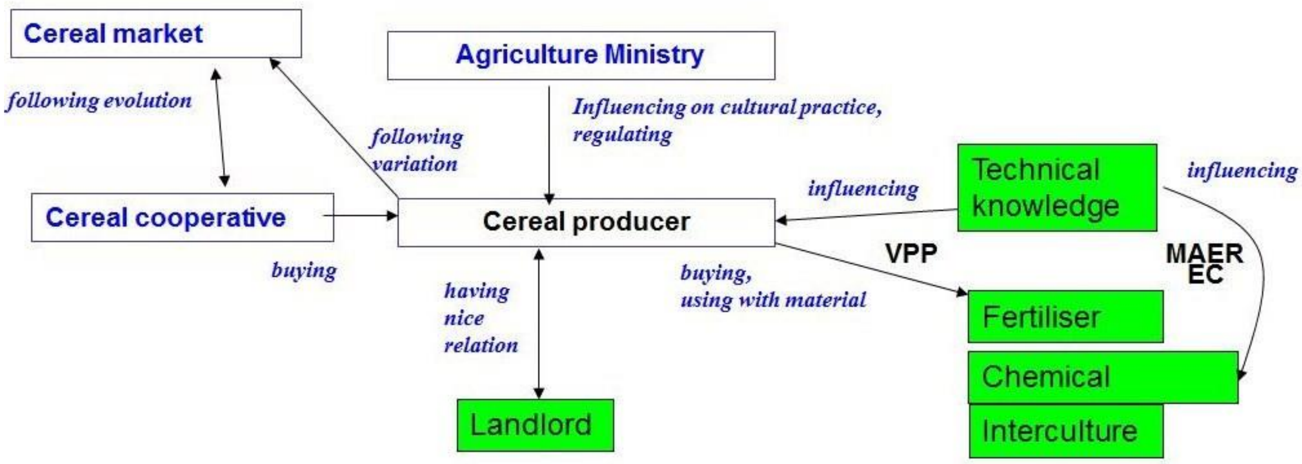


Figure 4: Interaction diagram example (last step of ARDI method) **(**personal reference**)**

Blue/Black: Actors Green: Resources **X**: Dynamics

If the ARDI method is used correctly, the interview should last three hours. As I wanted to have a technical part to the study, I chose to develop only the three first steps of the ARDI method. Thus, I obtained elements of each list in the order the person gave them. The overall interview was supposed to last between one hour and one hour and a half.

In the end, time devoted to the technical part was between one hour to one hour and a half, and to the system approach part was about an hour.

The survey began intentionally with the technical part, followed by the system approach part. It allowed me to start with information the interviewees felt comfortable with. Once they understood the information I was looking for, they were more open to the "system approach survey" as used by the ARDI method.

Time management for the technical part became an issue (lasting sometimes until 1h30). Indeed after 2 hours of interviewing, people got tired of the survey and wanted to finish it as soon as possible. The tiredness and lack of time made the interview about the system approach part less efficient.

4. Sampling

I proceeded first by finding out where wireworm attacks have been reported for the 2012 season. I contacted Institutes, technicians, managers of Chambers of Agriculture, and potato sector professionals to locate farmers affected by wireworm attacks in their fields. The surveys were carried out by visiting and interviewing the farmers.

Most of those touched by wireworm were located in the Alsace region, and some in Nord-Pas-de-Calais region. I focused my study on these areas. 18 farmers in total were interviewed, giving us a total of 47 plots for the technical part of the study (cf. Figure 5). They were all producing potatoes for consumption. When farmers had several potato plots, one technical survey was carried out for each plot.

16 plots were considered in addition to those carried out during the initial survey. They came from the same survey conducted in 2010 with potato seedling producers (cf. Figure 5). As they had a different organization and crop sequence management, I thought it would be interesting to include them in the analysis.

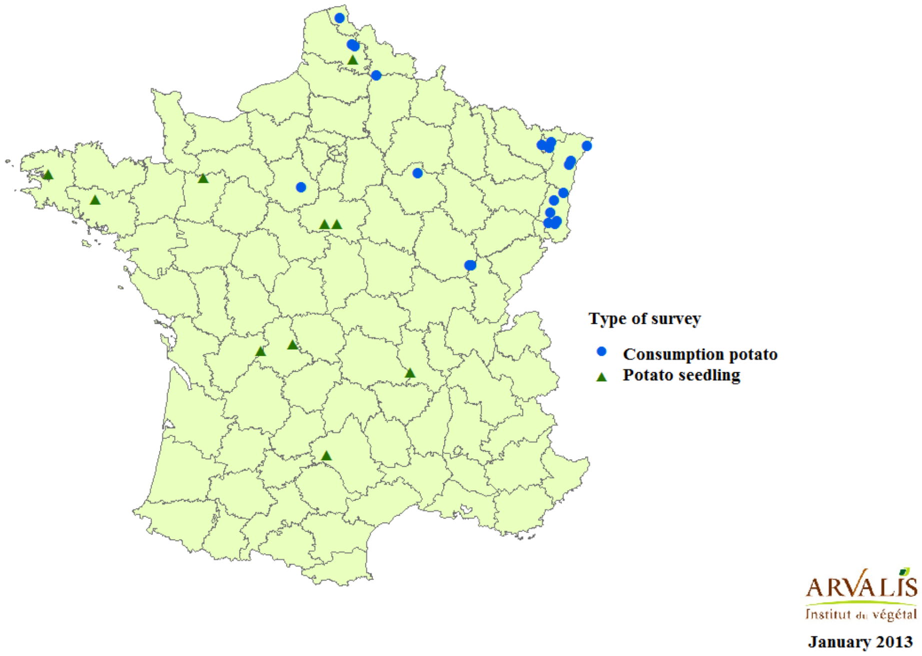


Figure 5: Places where surveys were realized.

5. Data analysis

5.1.Plot characteristics statistical analysis

As explained before, a lot of data has been collected from the surveys. After a first analysis of what I gathered, I decided to process data based on literature (university researches, scientific articles published on wireworm) and other trends observed in previous surveys completed by Arvalis.

I decided to analyze data by focusing on the following topics:

- History of crops
- previous wireworm damage in the plot
- interculture
- mechanical passes
- use of chemicals
- Supply of organic matter
- plot environmental surroundings

A major part of the data contained qualitative data. My goal was to get an idea of main modalities coming out and link them. An MCA (multiple correspondence analysis) was implemented using R software ®, version 2.15.1 for qualitative data. A PCA (principal components analysis) was implemented for two quantitative data I had: use of chemicals and mechanical passes.

The initial goal was, after identifying relevant dimensions of the MCA, to realize an MFA (multiple factorial analysis) to test main trends identified between them. Then, a HCPC (Hierarchical Clustering on Principal Components) would permit to group plots according to those trends. However, data quantity was not sufficient to realize all those steps. I decided to process data until the dimension identification stage through MCA/PCA and apply HCPC to highlight emerging groups.

5.2. Farmers' views statistical analysis

Data linked to this part was summarized in a database (for actors, resources, and dynamics); similar ideas quoted by interviewees were homogenized and grouped under categories with the aim of making the results easy to understand.

The latter was analyzed first by using classical graphs in order to find out patterns or trends. Then I wanted to group farmers with similar answers. The HCPC (Hierarchical Clustering on Principal Components) diagram was used through R software ® version 2.15.1.

Results

1. Plot characteristics and agronomic practices

Two types of data were processed here, qualitative and quantitative. Both came from the surveys described in the M&M section. We want to establish emerging trends from the enquiry we have.

1.1. MCA and HCPC analysis

After producing a synthesis of the data gathered, I decided to process the data based on literature (university studies and scientific articles published on wireworms) and other trends observed in previous surveys completed by Arvalis. Thus, data was selected by focusing on five different themes: previous crops, interculture, supply of organic matter, plot environmental surroundings and wireworm damage in previous years.

In the case of the qualitative data, an MCA analysis was implemented, followed by a clustering analysis (HCPC).

With the MCA, I obtained an individual typology, a variable typology and the variables' modality typology according to the theme we want to work on. I am presenting here the results of individuals and variables' modalities typology.

Once I got those typologies we applied a HCPC (Hierarchical Clustering on Principal Components) in order to homogenize and group all the plots together.

1.1.1. Previous crops

I observed the four years of crops previous to the target year of potato cultivation. The previous four year crops grown by farmers are grouped in the variable modalities MCA analysis graph (cf. Figure 6). The number of individuals concerned by those kinds of crops is represented in the individual diagram (cf. Figure 7).

In the variable modalities MCA analysis three groups can be observed (cf. Figure 6). The first (G1) is the most diverse one. All arable crops (wheat, maize, rapeseed, barley) and vegetables (cabbage, beetroot, carrot, onion and potato) are grouped there. I also notice that the maize crop is present for all four previous years (n-1, n-2, n-3, n-4).

The second group (G2) contains meadow, cereals (triticale, oat) and potatoes. As for maize, meadow is present in all four previous years (n-1, n-2, n-3, n-4).

The third group (G3) represents all the exceptions outside these two groups (alfalfa, oat, flax, barley and wheat). In many cases, they are present only for one year.

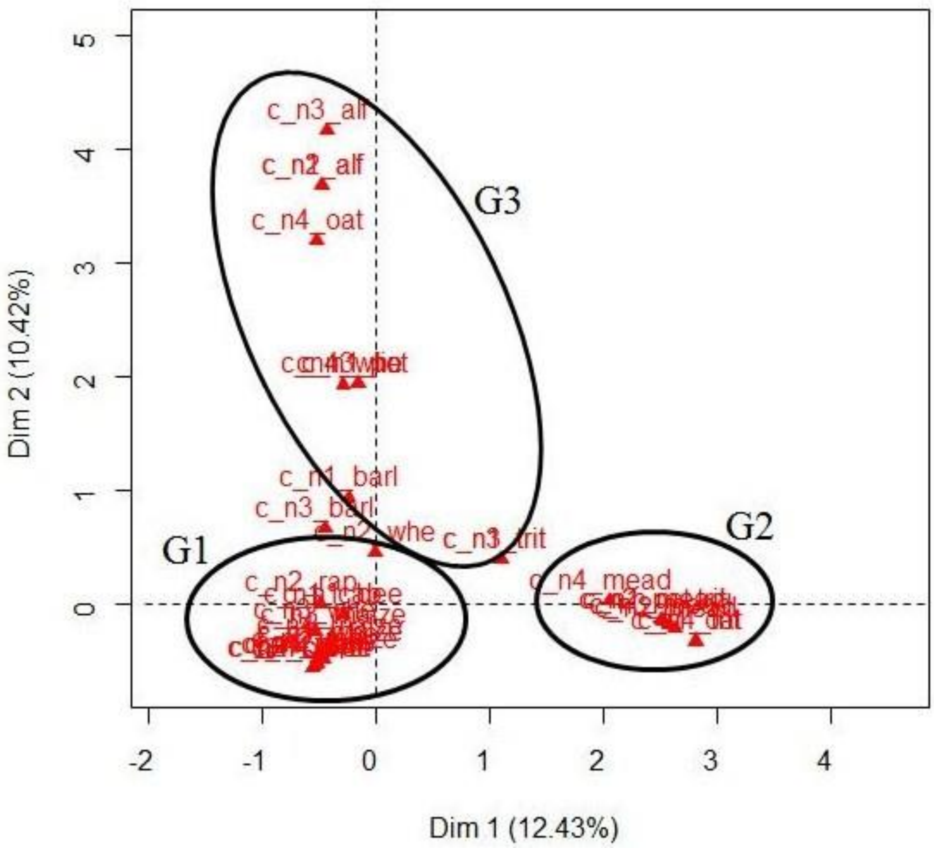


Figure 6: MCA factor map of previous crops (modalities)

Legend: c: crop; nX: preceding year; alf: alfalfa; mead: meadow; barl: barley; rap: rapeseed; cab: cabbage; pot: potato; oni: onion; bee: beetroot; GX: group

By comparing that MCA to the individual one (cf. Figure 7) we can see that the first two groups are including the majority of plots. Elements of the third group concern only one or two plots, so they can be considered as special cases.

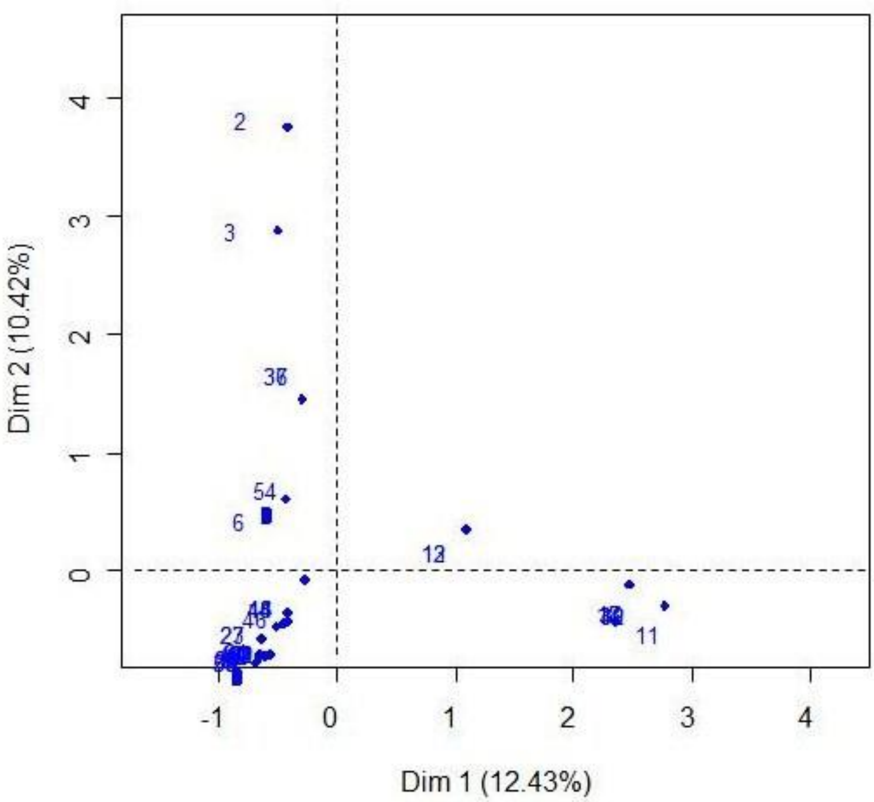


Figure 7: MCA factor map of previous crops (individuals)

Legend: Number: plot representation

This hierarchical cluster dendrogram is divided into three main groups (cf. Figure 8). The first (G1) is comprised only of plots situated in the Alsace region. This group's trend is to have at least 2 years of maize in the four year crop rotation and sometimes four years. In most of the cases there is always one wheat crop in rotation, and no meadow. 61% of those plots had wireworm attacks (11 plots out of 18). Many were slightly damaged (around 1% of the harvest attacked) and others were damaged by up to 30 to 40%. Group one represents 22, 2% of the total harvest damage.

The second group (G2) has a majority of plots in the Nord Pas de Calais region. There is only one plot from the Alsace region. This group is characterized by having mainly cereal in the crop rotation (wheat, triticale, barley, and oat). There is at least one year of cereal within the rotation. 58.3% of those plots showed wireworm attacks (7 plots out of 12). The average wireworm damage on the harvest is 24.4%.

The third group (G3) can be divided in two sub-groups with plots from both Alsace and Nord Pas de Calais regions: one sub-group is predominantly used for meadow while the other is more diverse in its use of crop (cereals, rapeseed, and vegetables). The latter sub-group had at least one year of wheat.

None of these two sub-groups had maize in the rotation. 84.6% of these plots were attacked by wireworms (11 plots out of 13). The average wireworm damage on the harvest is 18.4%.

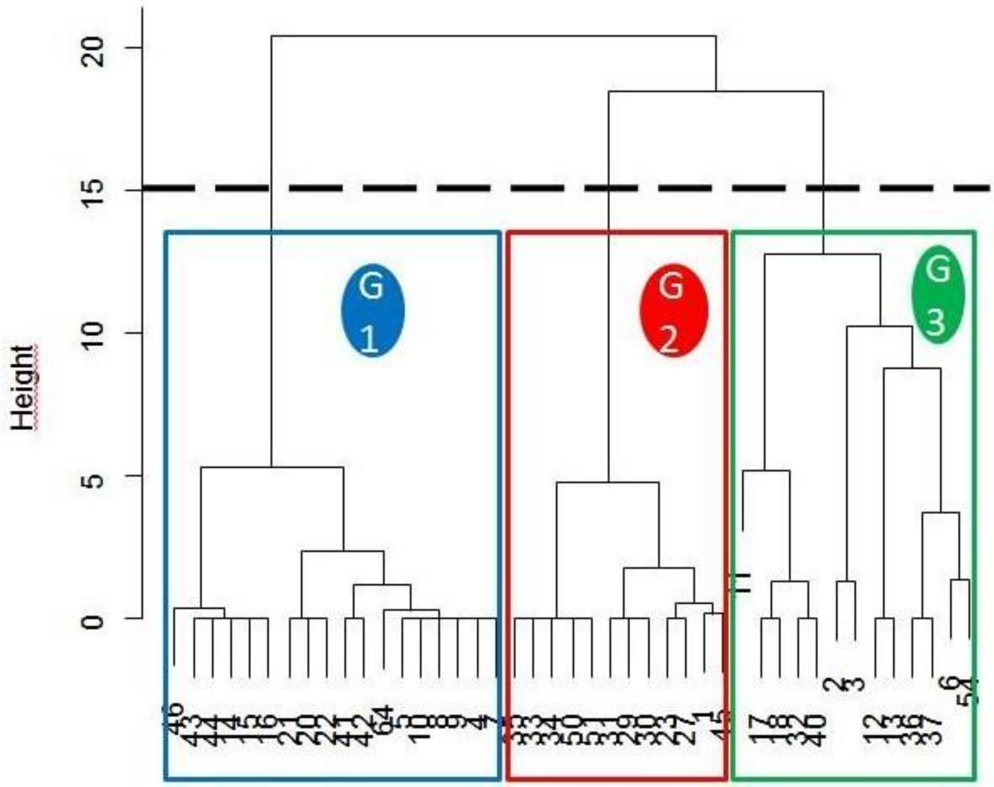


Figure 8: Cluster dendrogram of previous crops

Legend: G1: group one; G2: group two; G3: group three

Looking at these results, in the studied plots, wireworm damage to the harvest is around 20%, whatever the type of rotation (maize, wheat or other dominance). What should be highlighted is a higher rate of plots attacked by wireworm in the third group, especially where 100% of the plots were meadow.

1.1.2. Interculture

We looked to see if interculture was set up in the previous 4 years.

In the variable diagram of the MCA analysis three observations can be made (cf Figure 9). Firstly, most modalities are concentrated in the centre of the diagram. The main modality is “absence of interculture”, meaning that most of the plots did not have interculture in the previous four years. Then, the “presence of interculture” modalities surround the middle group. Lastly, the only regrowth modality is located on its own at the top of the diagram.

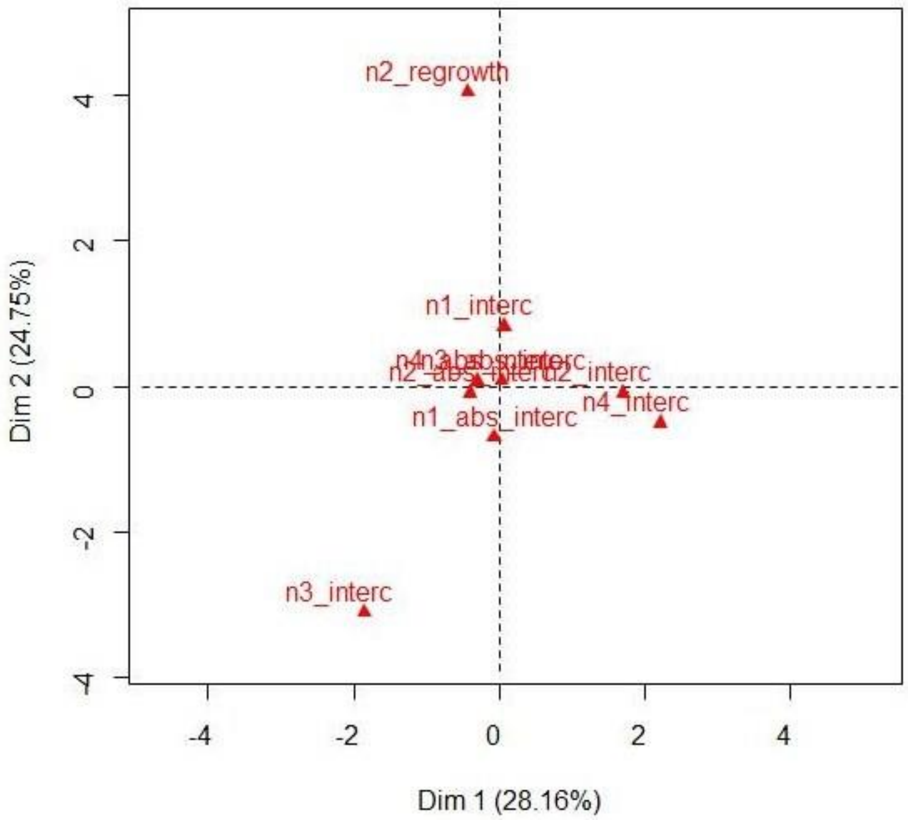


Figure 9: MCA factor map of interculture (modalities)

__Legend__: nX: year; interc: interculture; abs_interc: absence of interculture

Comparing this diagram to the individual MCA analysis one (cf. Figure 10), what should be highlighted is that a majority of plots are concentrated in the “absence of interculture” section. Ten plots show intercultures over the previous four years, and other elements can be considered as exceptions.

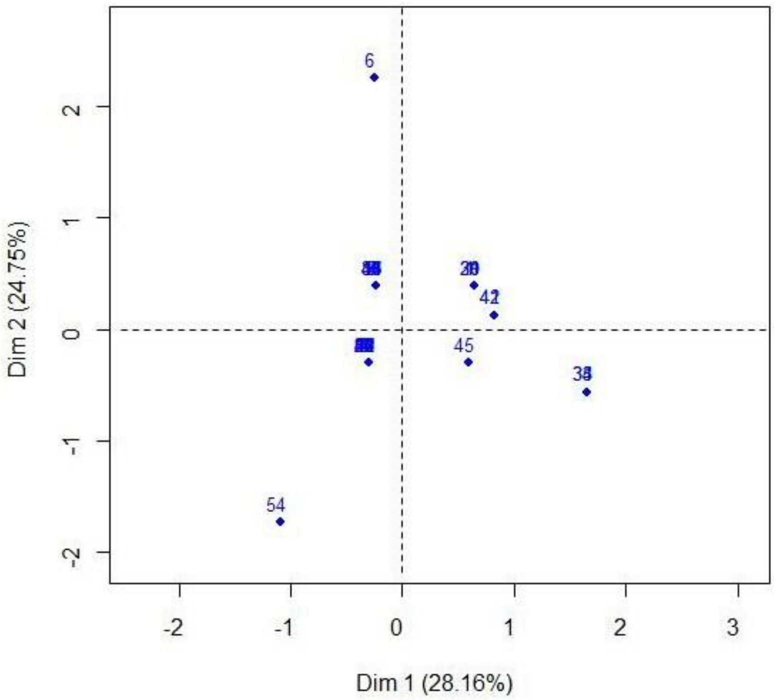


Figure 10: MCA factor map of intercultures (individuals)

Legend: **Number**: plot representation

The hierarchical cluster dendrogram is divided into three groups (cf. Figure 11).

The first (G1) represents all plots having no interculture at all for the previous four years. 77.7% (14 plots out of 18) of them show wireworm attacks. The average wireworm damage on the harvest is 23%.

The second group (G2) has a majority of plots having interculture in n-1 year and n-3 year. 84.6% (11 plots out of 13) of them show wireworm attacks. The average wireworm damage on the harvest is 19.5%.

The third group (G3) represents plots having interculture from one to three years over a four year rotation. 33.3% of them were damaged by wireworm attacks (four plots out of 12). The average wireworm damage on the harvest is 26.3%.

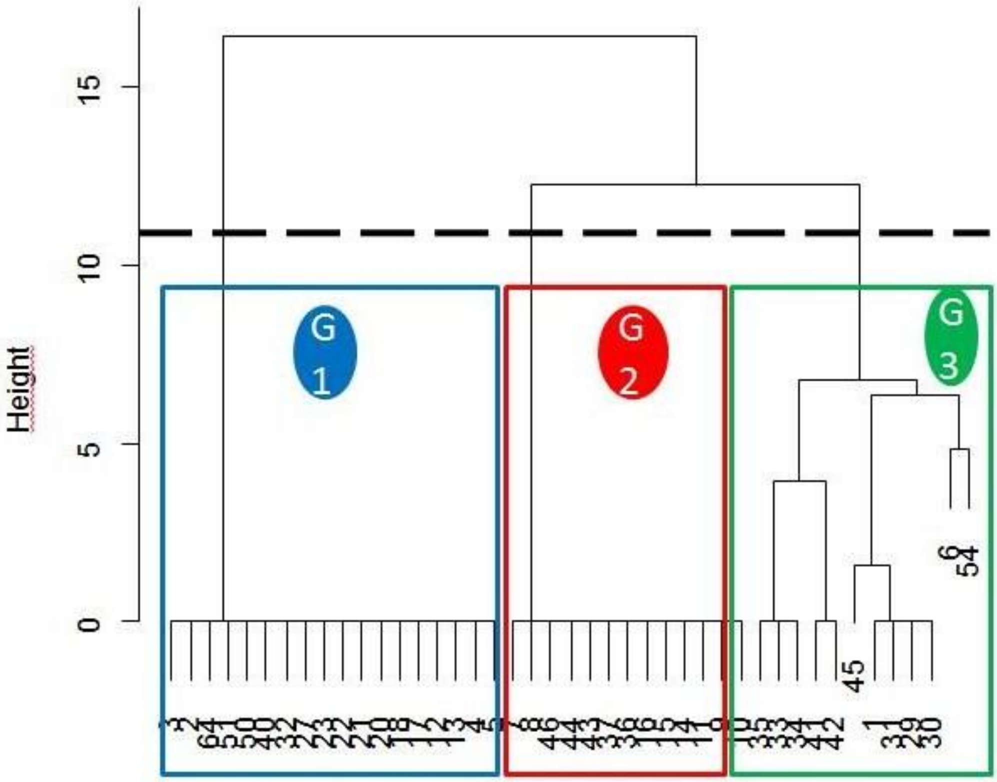


Figure 11: Cluster dendrogram of interculture

<u>Legend:</u> G1: group one; G2: group two; G3: group three

No clear distinction can really be made between having interculture (twice or less) in the rotation or not. However, in the plots having three times interculture in the rotation (i.e., G3), the percentage of wireworm attacks has decreased. No clear distinction can be made between the Alsace and Nord Pas de Calais regions.

1.1.3. Supply of Organic matter

The data shown here is the frequency of organic matter supply during the previous four years. In the variables modalities MCA analysis diagram (cf. Figure 12) there is no clear group to be analysed.

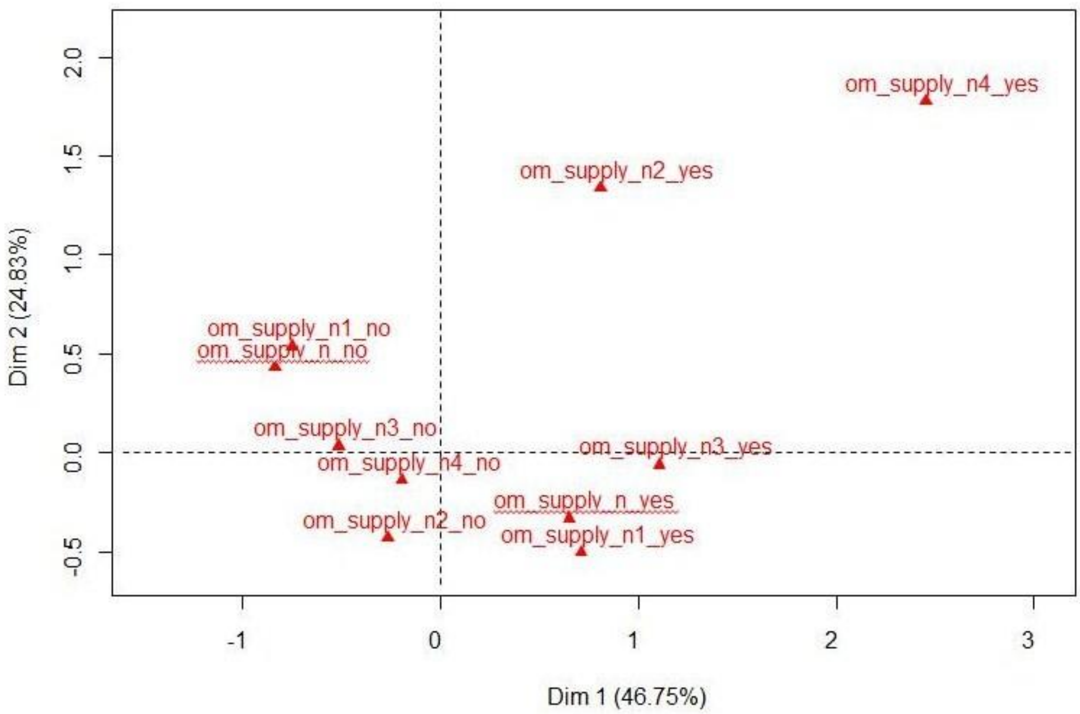


Figure 12: MCA factor map of organic matter supply (modalities)

Legend: om_inputs: organic matter inputs

Comparing this with the individual MCA analysis diagram (cf. Figure 13), it confirms that individuals are spread all over the dimensions identified by the MCA analysis. The clustering approach allows an easier identification of the trends on the organic matter supply topic.

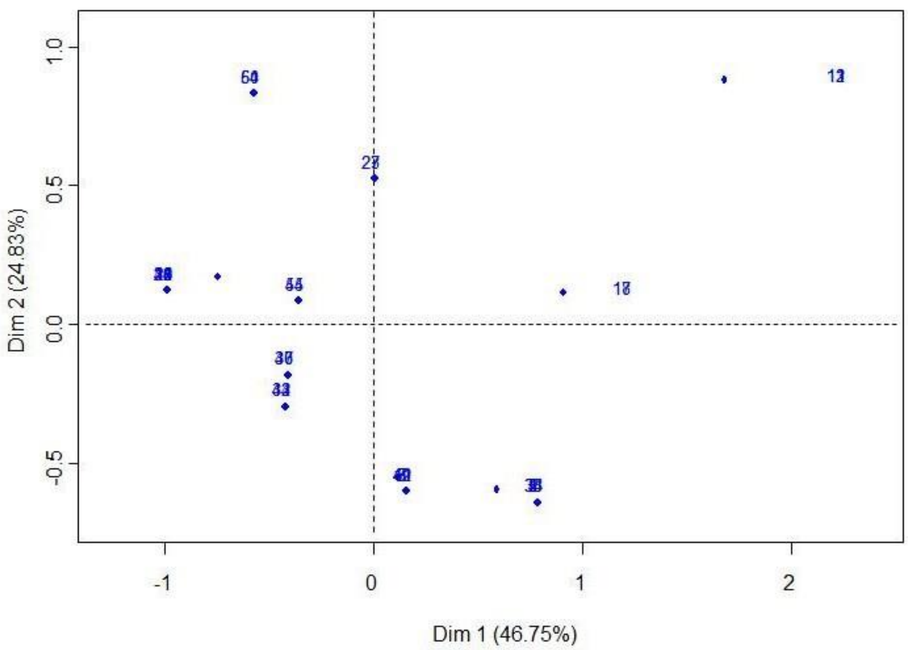


Figure 13: MCA factor map of organic matter supply (individuals)

Legend: Number: plot representation

According to the hierarchical cluster dendrogram (cf. Figure 14) two groups can be distinguished. The first one (G1) contains plots that received organic matter on one or two occasions over the previous four years. 65.2% had wireworm attacks (15 plots out of 23). The average wireworm damage on the harvest is 19.5%.

The second group (G2) gathers together plots where organic matter supplies occurred two to five times over the previous four years. 72.2% of them show wireworm attacks (13 plots out of 18). The average wireworm damage on the harvest is 30%.

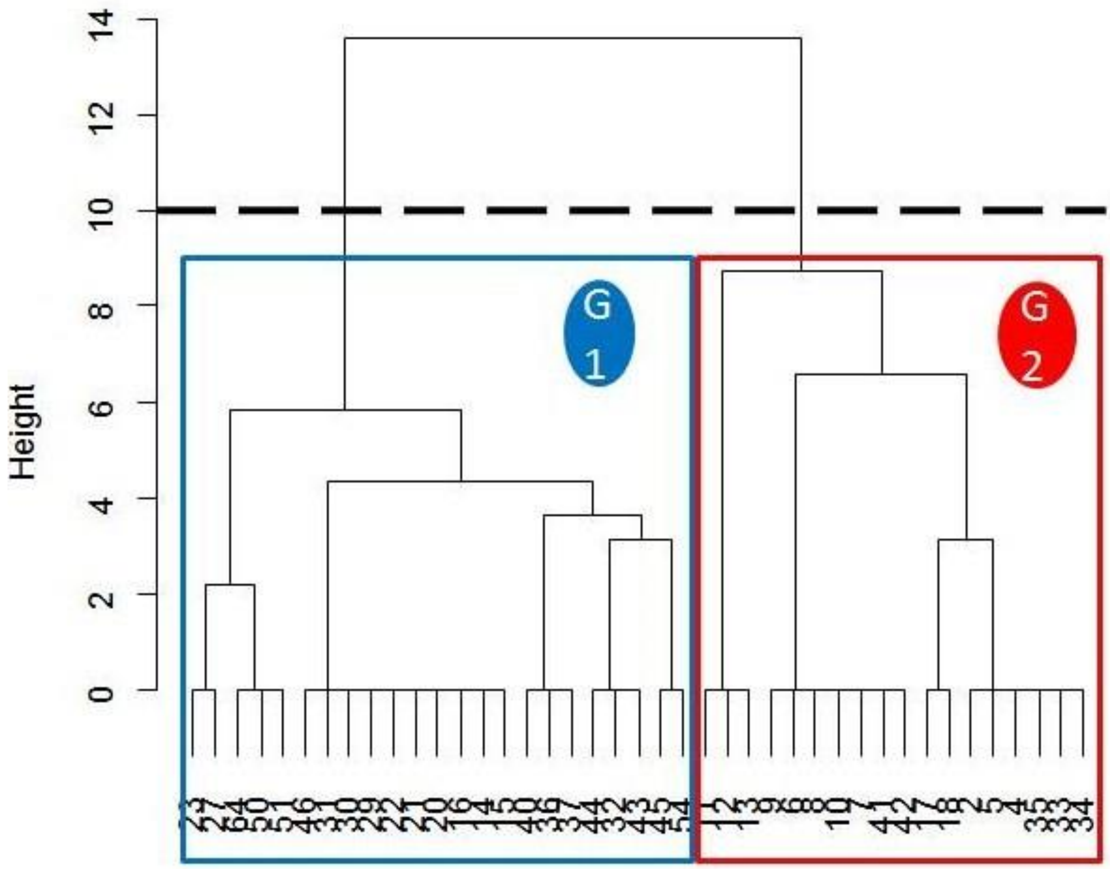


Figure 14: Cluster dendrogram of Organic matter supply.

<u>Legend:</u> G1: group one; G2: group two

Where more than two supplies of organic matter were delivered, one can notice that wireworm attacks are more frequent (more than 10%). No clear difference can be seen between the Alsace and Nord Pas de Calais regions.

1.1.4. Plot environmental surroundings

The data examined here is the type of landscape surrounding the potato plot used for the survey. The diagram (Figure 15) shows the type of landscape present (path, grass strip, crop, meadow, other).

In the variables modalities MCA analysis (cf. Figure 15), the group in the centre (G) shows the cases where the information “absence of any landscape features” can be observed more into details there. The presences of meadow or crop around the plot modalities surround this group (G).

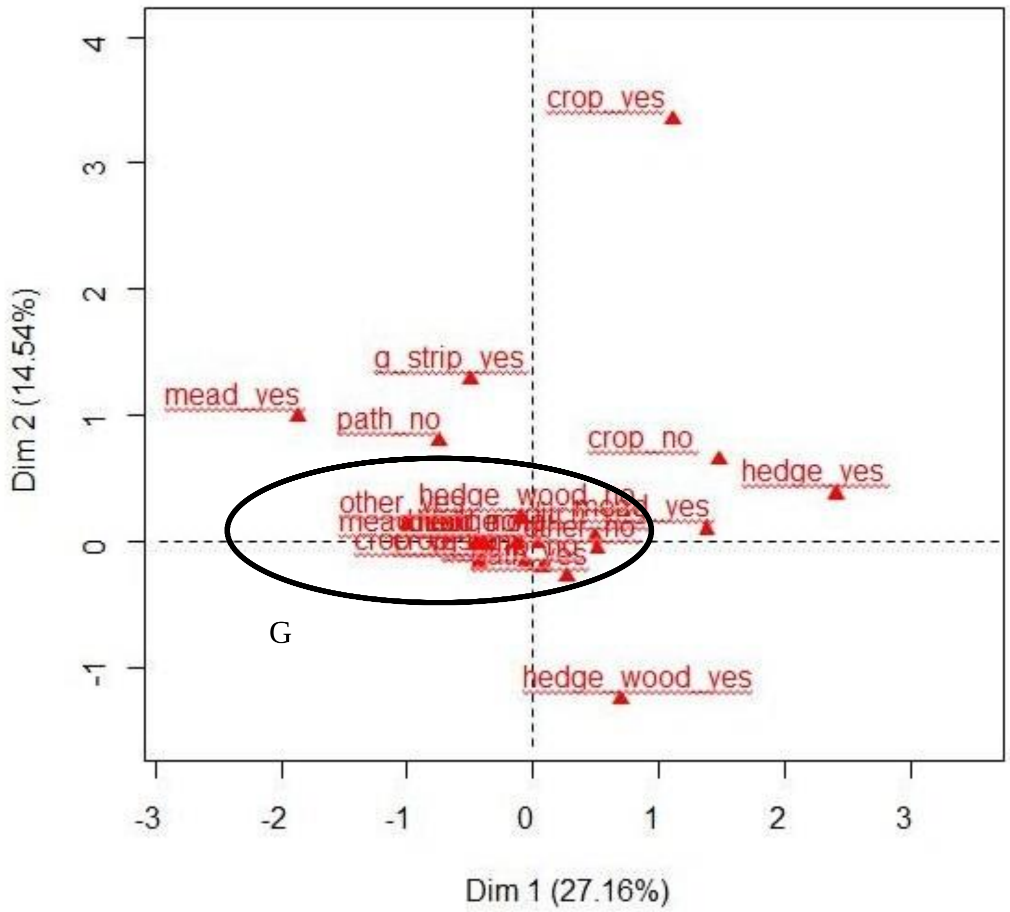


Figure 15: MCA factor map of plot environmental surroundings (modalities)

<u>Legend:</u> G: group; mead: meadow; g_strip: grass strip; hedge_wood: hedge including trees.

However, the individual MCA analysis (cf. Figure 16) shows that there is a small number of individuals with plots of meadow or crop around the potato plot making them exceptions. . The clustering approach will allow the identification of trends.

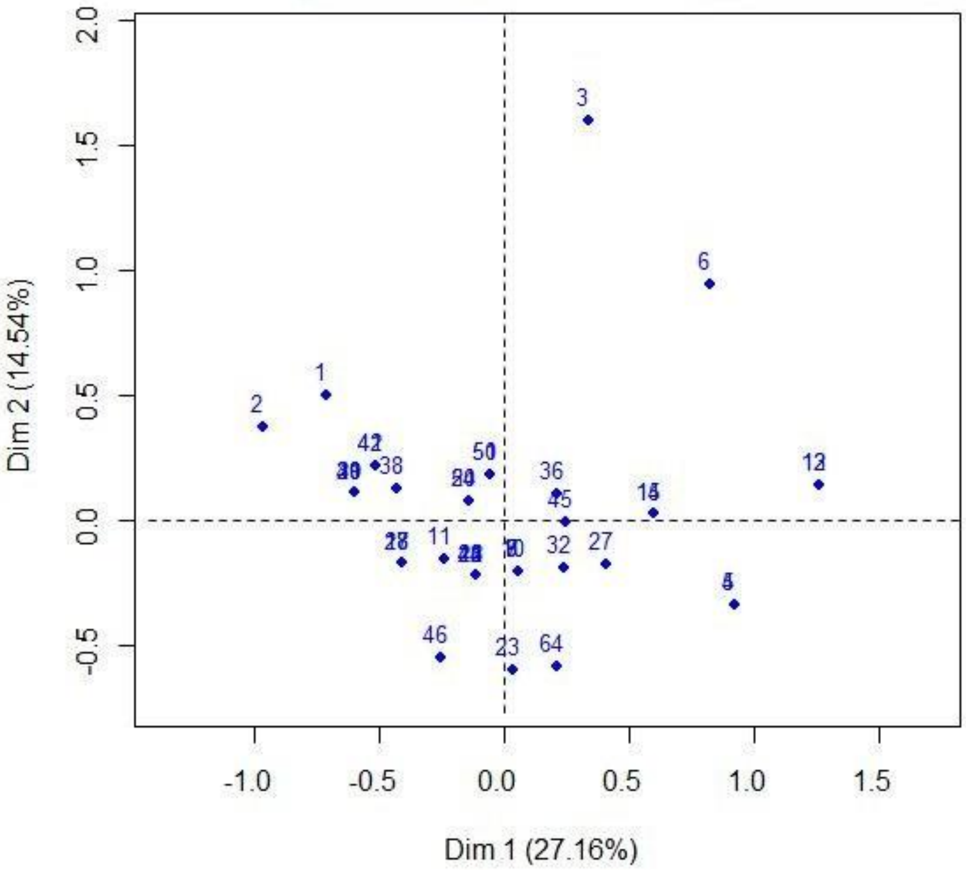


Figure 16: MCA factor map of plot environmental surroundings (individuals)

<u>Legend:</u> Number: plot representation

The hierarchical cluster dendrogram (cf. Figure 17) contains three groups. In the first (G1), we have plots mainly from the Alsace region. The common surrounding feature of these plots was grass strip. 76.9% of these plots were attacked by wireworm (10 plots out of 13). The average wireworm damage on the harvest is 16%

In the second (G2), comprising of both Alsace and Nord Pas de Calais regions, the surrounding features, common to all plots are ditch, crop and grass strip. 83.3% of them were attacked by wireworms (10 plots out of 12). The average wireworm damage on the harvest is 22%.

The last group (G3) comprises of all the other plots where the common surrounding feature was crops. 50 % of them were attacked by wireworms (8 plots out of 16). The average wireworm damages on the harvest is 30%. It is interesting to notice that 100% of the plots showing wireworm attacks were surrounded by either road, railway or fallow.

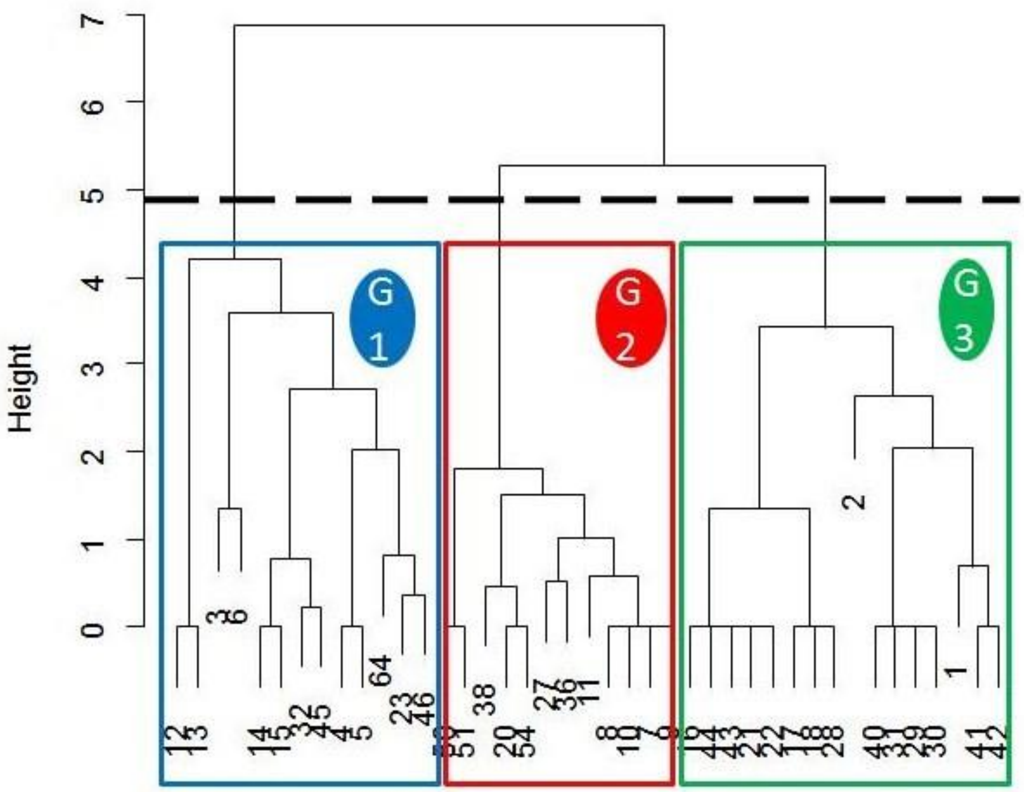


Figure 17: Cluster dendrogram of plot environmental surroundings

Legend: G1: group one; G2: group two; G3: group three

The main surrounding landscape features were either grass strip, ditches, road, railway or fallow surrounding. The last group (G3) has a greater wireworm damage level (an extra 10%) and includes most of these features. However, elements such as "ditches", "road" or "paths" do not allow distinguishing plots between them in a relevant way. Obviously, the roads and paths are there to allow farmers access to their plots. In the analysis, only the presence or absence of these was considered. It would be interesting to have included the percentage of the types of the surrounding features (e.g. roads, woods, ditches, etc....).

1.1.5. Wireworm damages in previous years

Wireworm attacks over the previous four years were observed (including the year of my study).

In the variables modalities MCA analysis diagram (cf. Figure 18) two observations can be made. A main group is on the left side (G). It contains all plots where no wireworm attacks were observed in the previous four years. There are several modalities spread out within that group. They represent all the plots which had at least one a wireworm attack in the previous four years.

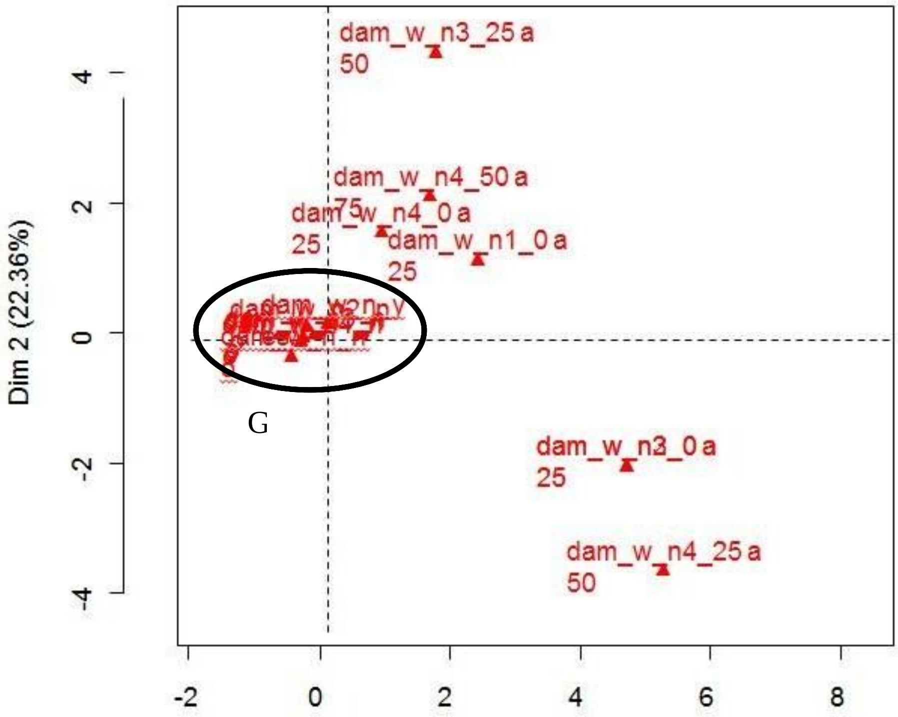


Figure 18: MCA factor map of wireworm damage in previous years (modalities)

Legend: dam_w: damage by wireworm; nX: year; G: group

Comparing this information with the individual diagram of the MCA analysis (cf. Figure 19), the first group contains the majority of the plots (G), individuals spread around are special cases.

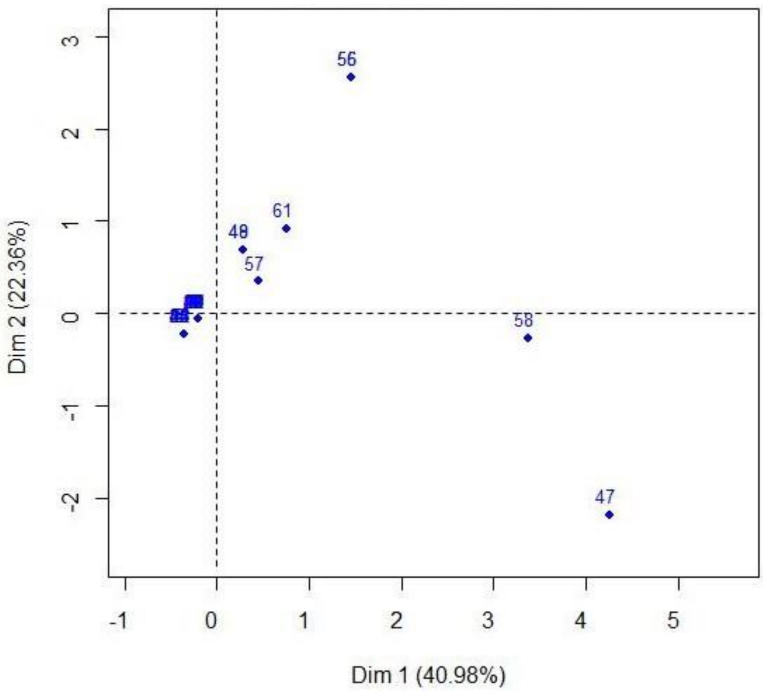


Figure 19: MCA factor map wireworm damage in previous years (individuals)

Legend: **Number**: plot representation

In the hierarchical cluster dendrogram (cf. Figure 20) plot distribution can be divided into three groups.

The first (G1) shows the plots where wireworm attacks were observed in the current year (when this survey was done) but not in the previous ones. The average wireworm damage on the harvest is 21. 4% .

The second group (G2) shows all the plots where no wireworm attack was observed over the previous four years.

The third (G3) contains all the plots showing wireworm attacks once or twice in the previous four years. With only five plots out of 58, these are considered as exceptions.

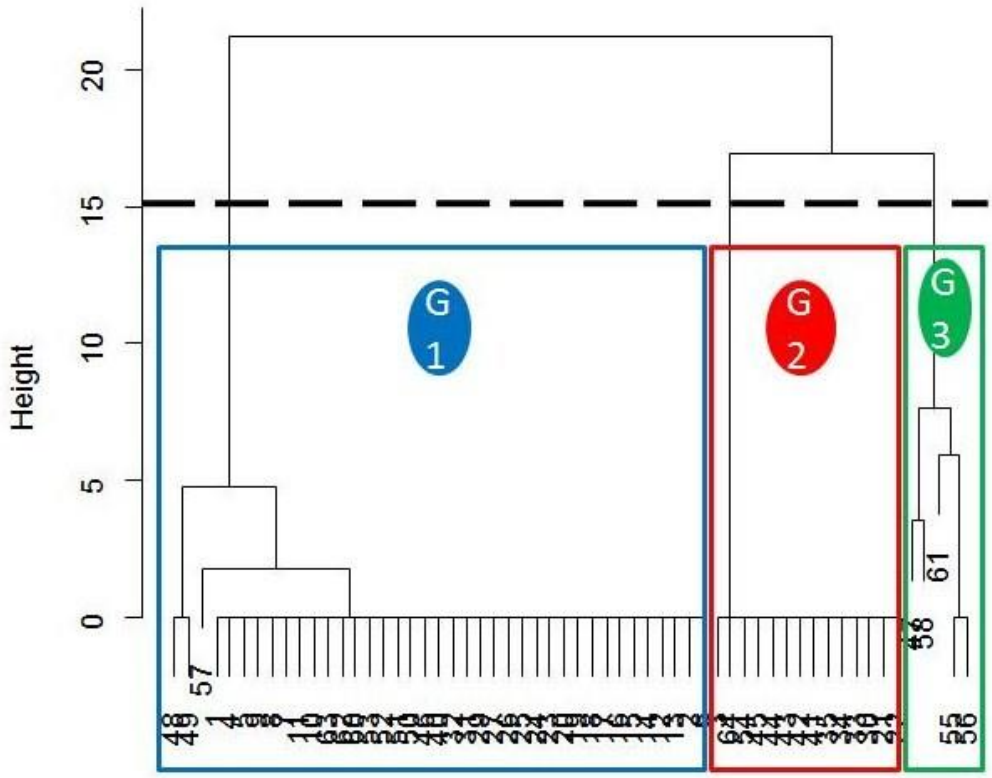


Figure 20: Cluster dendrogram of wireworm damages in previous years

Legend: G1: group one; G2: group two; G3: group three

The main observation here is that a majority of the plots were not showing any attack of wireworms in the previous four years. Wireworm attacks occurring in the survey year ("n") could not be predicted by observing previous years damage. No difference can be observed between the Alsace and Nord Pas de Calais region plots.

1.2. PCA and HCPC analysis

The second type of data we collected from my study was quantitative data. Using the same method as I did with the qualitative data, I chose to focus my analysis on two themes: chemical application frequency, and frequency of mechanical passes.

With the PCA, the goal was to highlight similarities between variables. We obtained an individual typology and a variable typology according to the theme I wanted to work on. The results of individual typology are shown here (variables typology data not shown). Once I got the typology I applied HCPC in order to homogenize and group plots according to their dimensions.

1.2.1. Use of chemicals

Chemical application frequency over the previous four years was observed. Chemicals considered are: insecticide, herbicide, fungicide, top-killing products and products which prevent germination.

The individual PCA analysis diagram (cf. Figure 21) shows that plots are spread out over the dimension identified. The clustering approach allows the identification of trends of chemical application frequency.

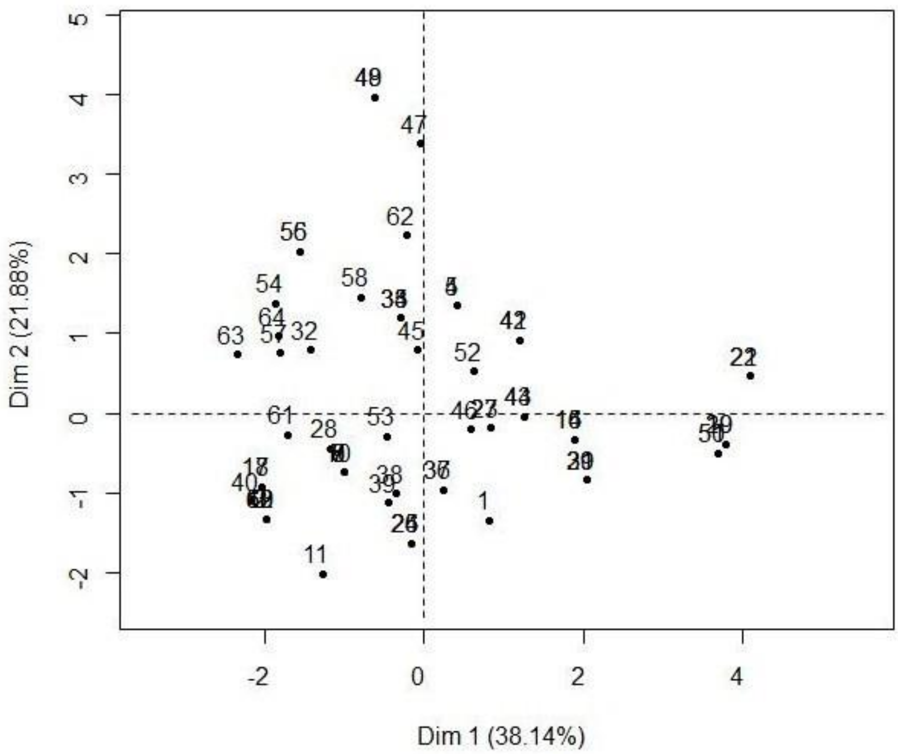


Figure 21: PCA factor map of chemicals (individuals)

Legend: **Number**: plot representation

In the hierarchical cluster dendrogram (cf. Figure 22) three groups can be identified.

The first (G1) contains the plots where many insecticides were applied at least once each year and where all other chemicals were also applied at least once. 68.75% of the plots showed wireworm attacks (11 plots out of 16). The average wireworm damage on the harvest is 19.8%.

The second group (G2) contains all the plots which had few applications of insecticides and other chemicals (no more than once each year), including the current year "n" (when the survey was done). 72.7% of the plots showed wireworm attacks (16 plots out of 22). The average wireworm damage on the harvest is 30%. It should be highlighted in this case that many surveys did not mention the percentage of harvest damage. This average has to be viewed with caution.

The last group (G3) presents the same trend as the second one: few chemicals applied, except at least two insecticides were applied in the current year "n". 76.9% of the plots had wireworm attacks (20 plots out of 26). The average wireworm damage on the harvest is 21%.

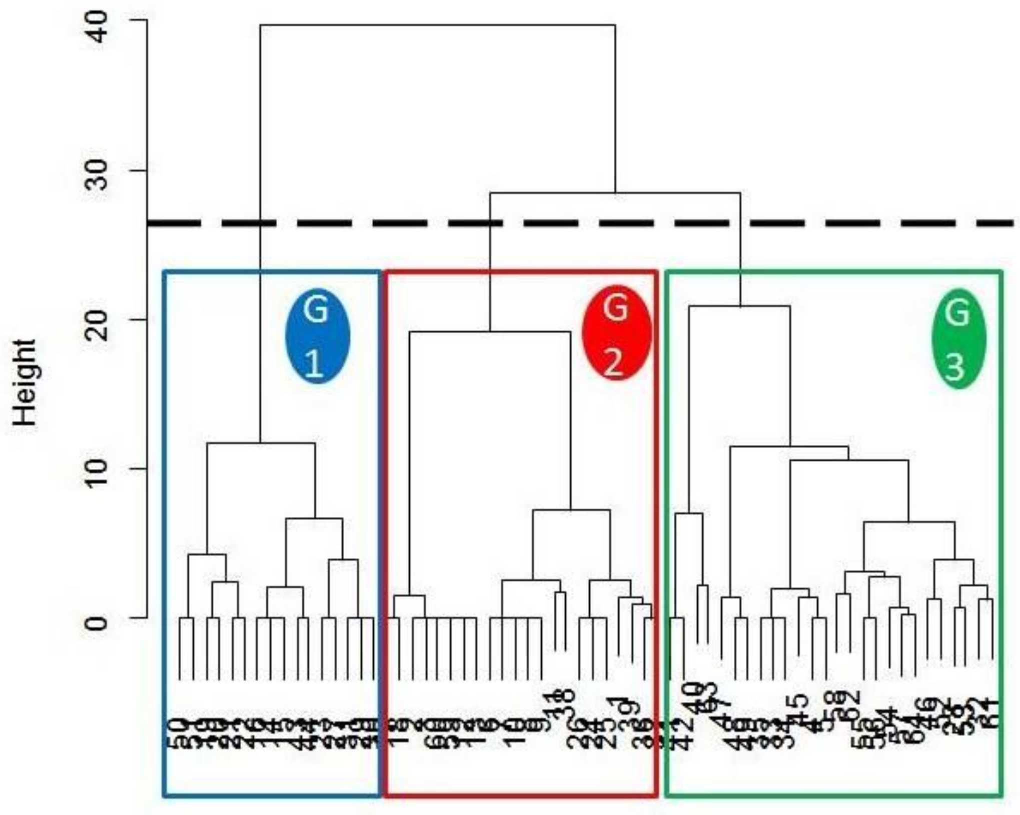


Figure 22: Cluster dendrogram of chemicals.

Legend: G1: group one; G2: group two; G3: group three

Both the first and third group (G1 and G3) are comparable for wireworm attacks. They show the same rate of attacks, meaning that application of insecticide can be compared (whether it was applied during the previous four years or only in current year). In the second group (G2), where fewer insecticides were applied, the rate of wireworm attacks is 10% higher. Both regions, Alsace and Nord Pas de Calais, show the same characteristics through the three groups.

1.2.2. Mechanical passes frequency

The frequency of mechanical passes performed on the soil in the previous four years is analysed here.

The individual PCA analysis diagram (cf. Figure 23) shows that plots are spread out over the dimension identified. The clustering approach allows the easy identification of trends of the mechanical passes topic.

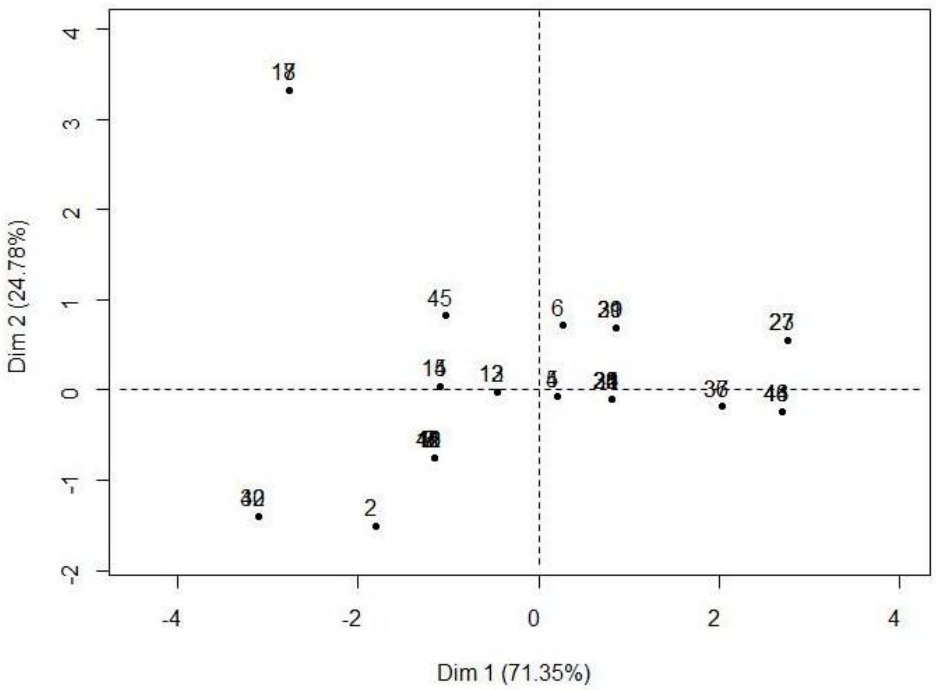


Figure 23: PCA factor map of mechanical passes (individuals)

Legend: **Number**: plot representation

In the hierarchical cluster dendrogram (cf. Figure 24) three groups can be identified. The first (G1) contains plots where at least one mechanical passes was done each previous year. 71.4% had wireworm attacks (five plots out of 7). The average wireworm damage on the harvest is 27%.

The second group (G2) presents plots where at least two mechanical passes were done each previous year. 50% were attacked by wireworms (6 plots out of 12). The average wireworm damage on the harvest is 32%.

The plots of both the Alsace and Nord Pas de Calais regions were mixed in these two groups.

G3 is a special case. One farmer made 6 mechanical passes each year.

The last group (G4) contains all plots where no more than one mechanical pass was done each previous year. 82.3% of the plots were attacked by wireworm (14 plots out of 17). The average wireworm damage on the harvest is 20.1%. Except for one plot, all the others in this group were from the Alsace region.

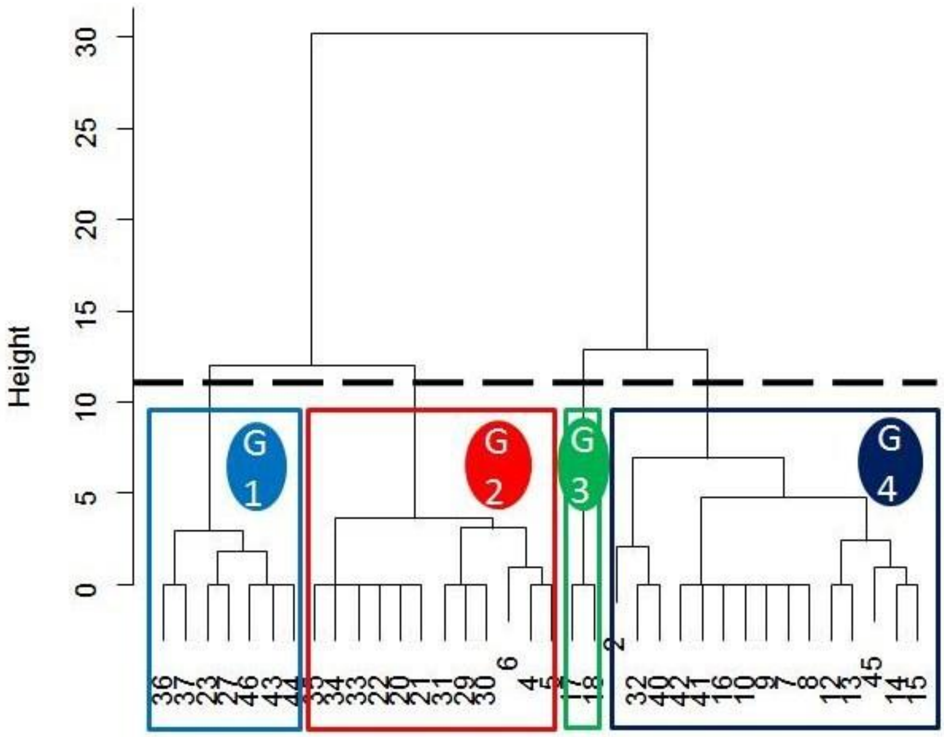


Figure 24: Cluster dendrogram of mechanical passes

Legend: G1: group one; G2: group two; G3: group three; G4: group four

Less wireworm damage was observed where fewer mechanical passes were carried out. However, it must be highlighted that these mechanical passes were carried out to different depths, up to 30 cm deep, which had no real impact on wireworm population. These results should be taken with caution.

2. System approach results

While answering the question **"How to manage the wireworm population within potato cultivation?"** the interviewed farmers determined and classified elements they had to consider. Three types of elements were chosen: actors, resources and dynamics (ARDI method; ETIENNE M., 2009). Elements could be simply quoted by the farmer during the interview without being selected and classified in the end.

2.1. Actors

Farmers determined and classified five categories of actors on the question "How to manage the wireworm population within potato cultivation?" They are classified with marks ranging from one (lowest mark) to five (highest mark). As explained previously, farmers were allowed to mention one actor during the interview without putting it in the final selection. In this case no mark was given to the element. That is why we differentiate "mark" from "quotation".

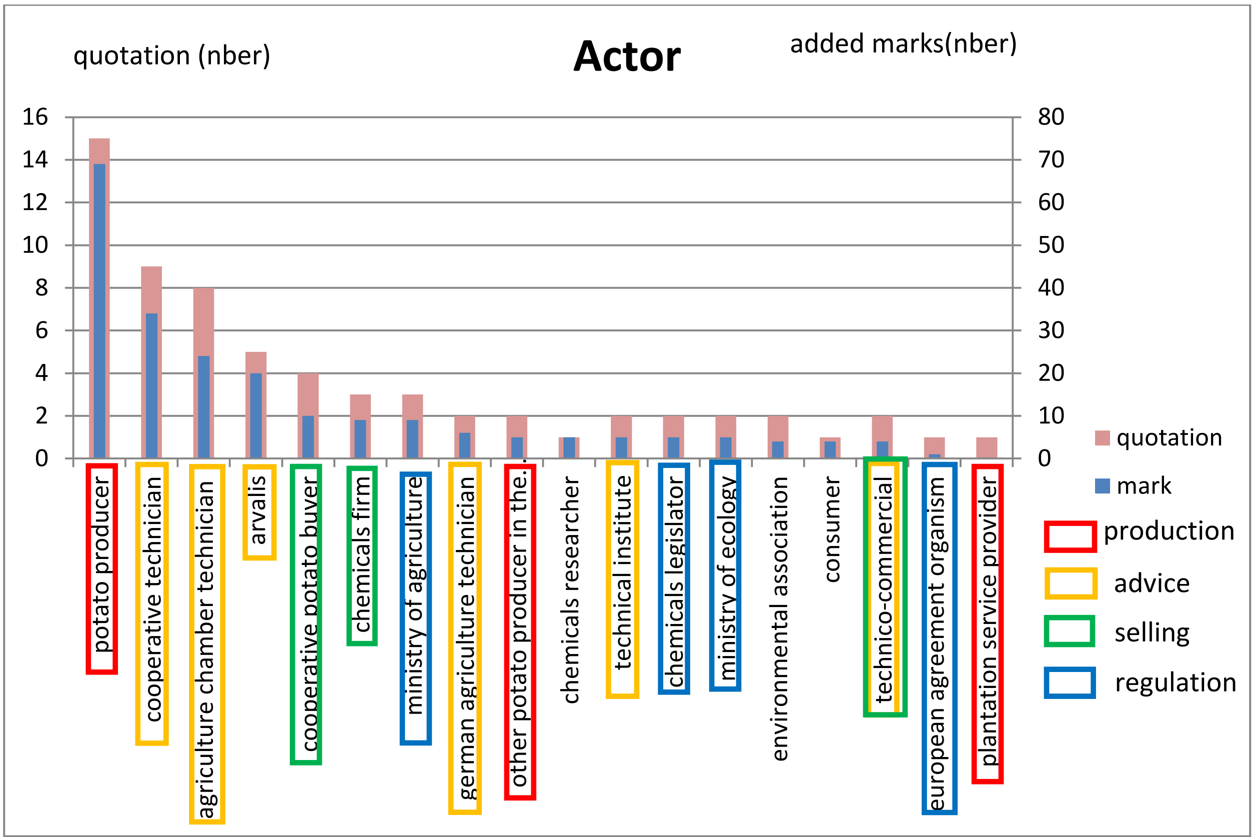


Figure 25: Added marks and quotation for Actors identification

In this study, most of the elements were also in the final selection. Farmers' vision of this problem was focused on a small number of actors. These actors were clearly identified and considered in the same way by all farmers.

The Actors (cf. Figure 25) can be divided in four categories :

- Advice
- Production
- Selling
- Regulation

The main actors with the highest marks are in the production and advice categories. The Production category is the first and most important one for all the interviewed farmers. Many different kinds of technicians (cooperative, agriculture chamber, German, commercial) and technical institutes are described, showing their importance in the farmers' mind. The Selling category elements are ranked tenth amongst the most important elements. The Regulation actors, such as agriculture or ecology ministry, come behind the Selling actors. This information is connected with other resource elements identified.

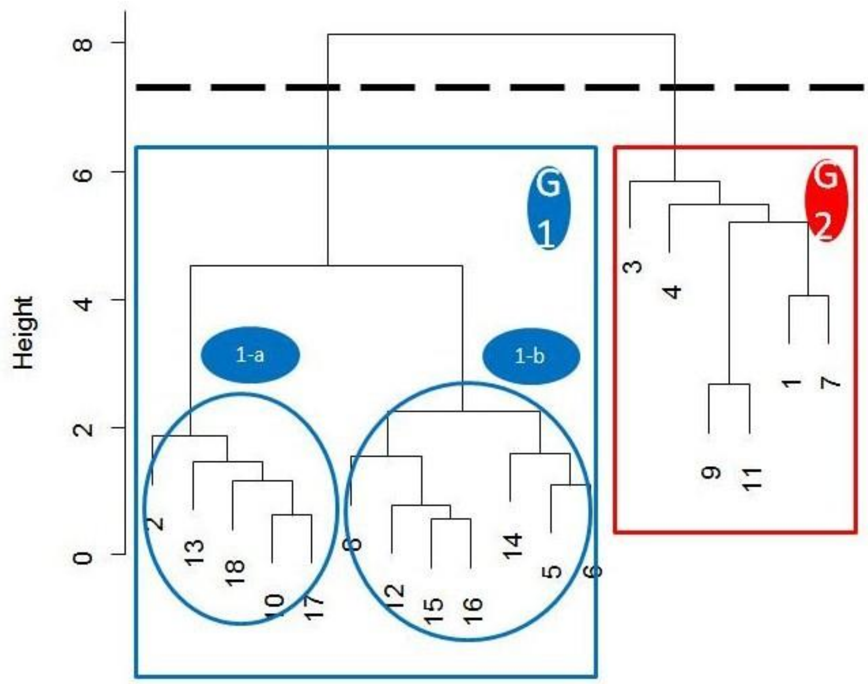


Figure 26: Cluster dendrogram of Actors

Legend: G1: group 1; G2: group 2; number: one person interviewed

The hierarchical cluster dendrogram (cf. Figure 26) shows three groups. The first two are concentrated on the same elements (G1-a; G1-b), whereas the last group (G2) has the most diversified range of elements.

The first group (G1a) is concentrated almost exclusively on “potato producer” and “technician” elements. The second group (G1b) includes other elements such as “ministry”, “consumer” or “technical institute”. The third group (G2) does not contain a trend between the identified actors.

2.2. Resources

Farmers determined and classified five resources (cf. Figure 27) on the question “How to manage the wireworm population within potato cultivation?” They are classified with marks ranging from one (lowest mark) to five (highest mark). As explained previously, farmers were allowed to mention one resource during the interview without putting it in the final selection. In this case no mark was given to the element. That is why we differentiate “mark” from “quotation”.

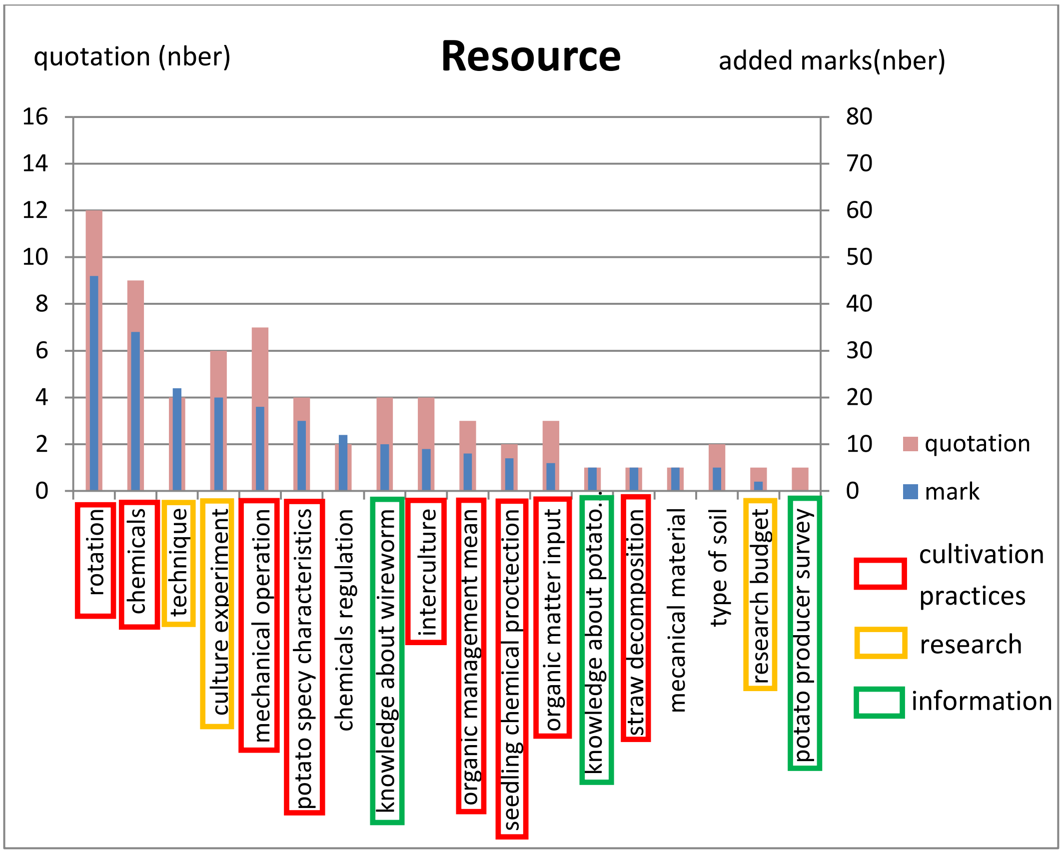


Figure 27: Added marks and quotation for Resources identification

Once again most of what was quoted was also in the final classification. However, compared to the identification of the actors, resources classification is more diversified with lower marks for each element. The farmers’ awareness of the resources involved in the management of the wireworm population question is less shared.

Some of the resources identified can be classified in three categories:

- cultivation practices
- information
- research

Considering the six first elements, the main part of resources quoted are cultivation practices (“crop rotation”, “chemicals”, “mechanical operation”, “potato specie characteristics”). These practices are known by agriculture professionals, although they are not systematically applied. Crop rotation and chemicals application are the two main resources used by the farmers.

“Technique” and “cultivation experiment” are two elements with important marks that do not depend on farmers. They must be linked with the actors identified previously, the technicians.

We observed “regulation” is quoted as a resource needed to manage wireworm population through the “chemicals regulation” element. This is the second time this notion appears in this survey. Several actors were identified previously and are directly linked to this resource. Farmers do consider it as a mean for managing wireworm population.

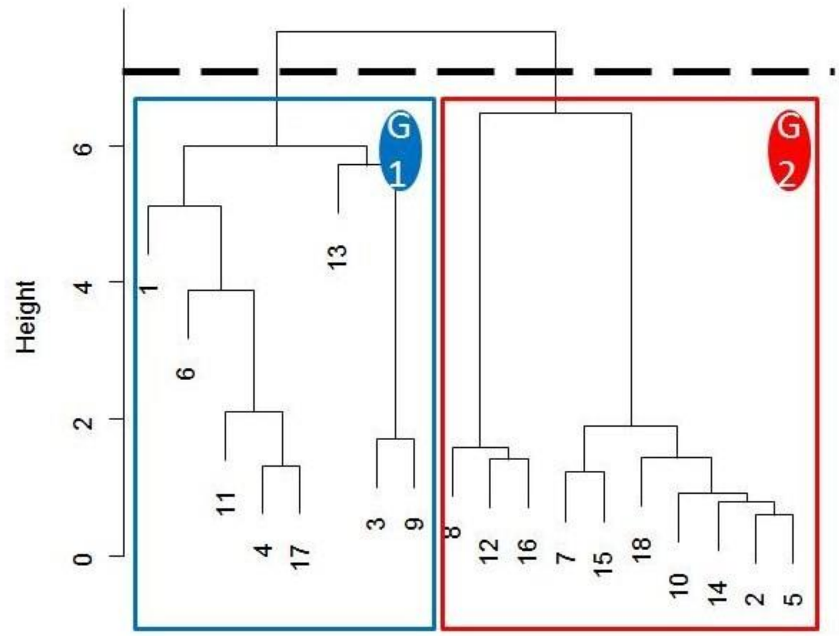


Figure 28: Cluster dendrogram of Resources

Legend: G1: group 1; G2: group 2; number: one person interviewed

The hierarchical cluster dendrogram (cf. Figure 28) shows two groups. As observed in the actor dendrogram, the second group (G2) is concentrated on same elements whereas the first group (G1) has the most diversified range of elements.

The second group (G2) is concentrated on elements such as "crop rotation", "mechanical passes" and "chemicals". In the first group (G1) it can be observed that most of organic farmers are grouped there.

2.3. Dynamic

Farmers determined and classified three dynamics (cf. Figure 29) on the question "How to manage the wireworm population within potato cultivation?" They are classified with marks ranging from one (lowest mark) to three (highest mark). As explained previously, farmers were allowed to mention one resource during the interview without putting it in the final selection. In this case no mark was given to the element. That is why we differentiate "mark" from "quotation".

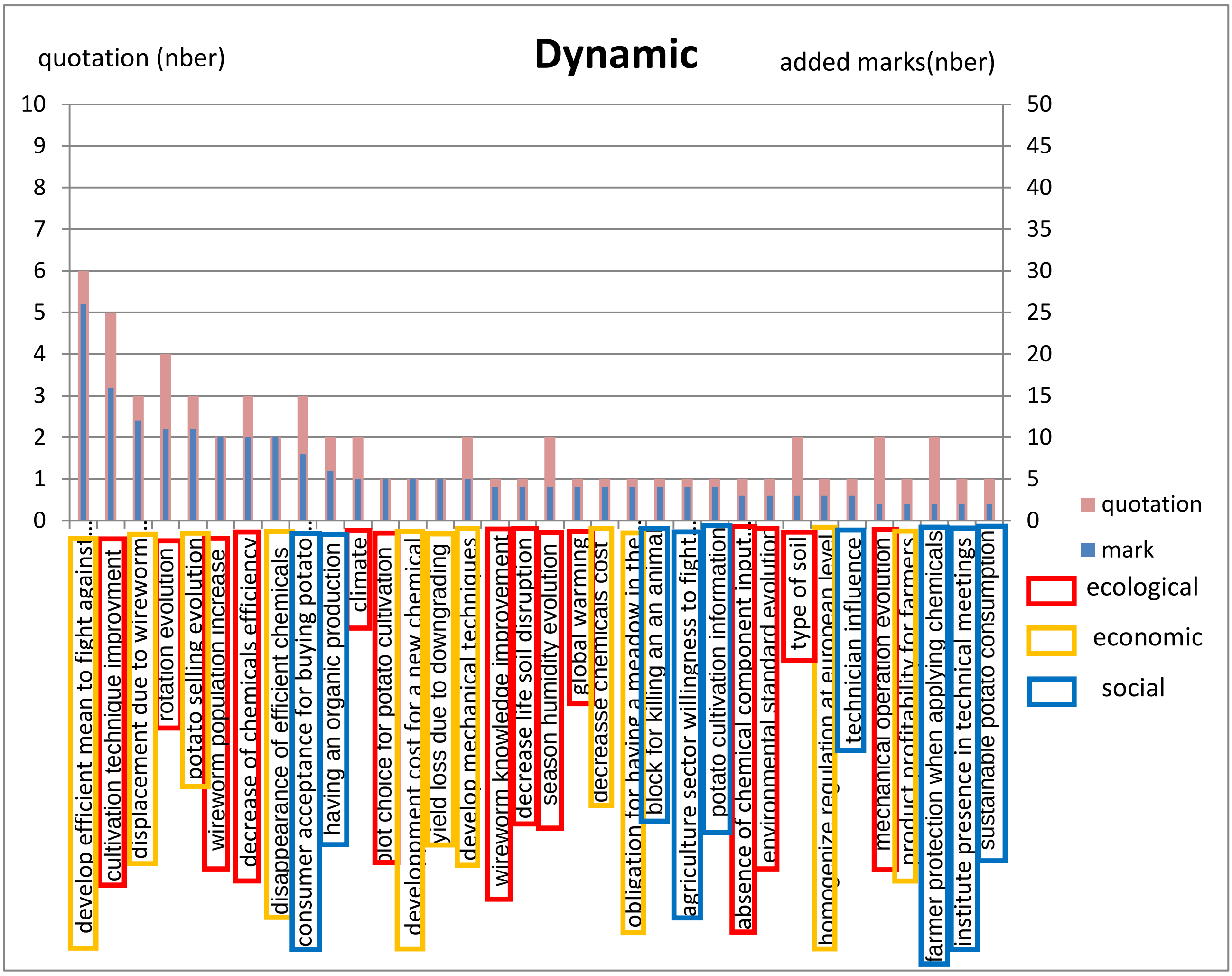


Figure 29: Added marks and quotation for Dynamic identification

Three categories can be identified: ecological, economic and social dynamics. Most of the dynamics mentioned by farmers were present in the final classification. No clear shared vision of dynamic-influencing system of wireworm management was identified. The main vision shared by the farmers was "developing solutions for managing the wireworm population".

Information to be added is that most elements categorized by farmers as ecological are closely linked to the economic category such as "cultivation improvement techniques".

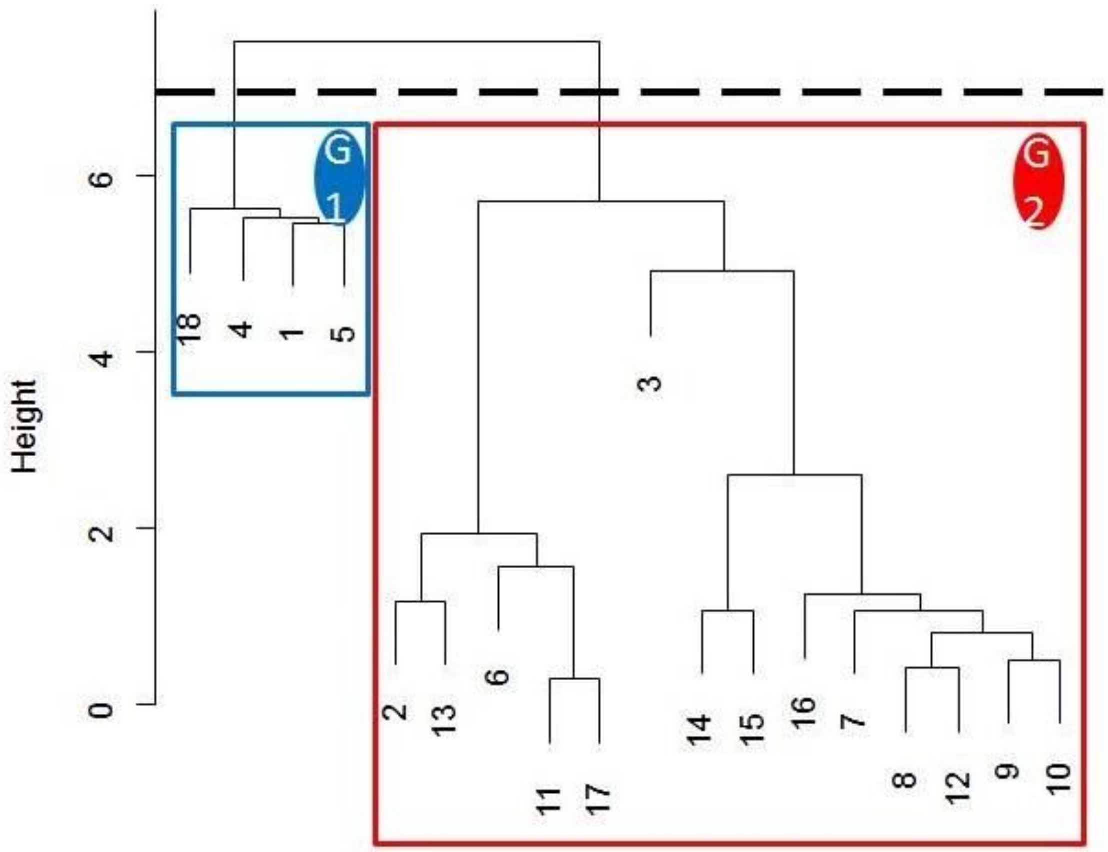


Figure 30: Cluster Dendrogram of dynamics

Legend: G1: group 1; G2: group 2; number: one person interviewed

The hierarchical cluster dendrogram (cf. Figure 30) shows two groups, one with clearly fewer farmers sharing that vision. As observed previously, group (G2) is more concentrated on a couple of elements than group (G1).

The second group (G2) is concentrated on elements such as "cultivation improvement techniques", "developing solutions for managing the wireworm population" and "crop rotation evolution".

Discussion

This survey mainly took place in two French regions (with several other special cases) where wireworm was reported as a pest issue. Those plots can therefore be considered as risk plots. The special cases represent only about 30 farms. For the moment, wireworm in French potato production seems to be a localised issue and not a generalized one.

1. **Plot characteristics and agronomic practices**

Wireworm damage in previous years

With wireworm having a five year life cycle (TAUPIN and BLOT, 2007), one would think its presence would be noticed at least once in the previous four years. However, most plots did not show wireworm damage at all within this period. Thus, farmers could not predict attacks for the 2012 season. As wireworms exist deep within the soil, it is also possible that its presence was just not noticed on other crops during the previous years.

Previous crops

Field rotation history is known to be linked to the presence of wireworms (WILLIS et al., 2010). I wanted to verify this information in my study by finding out about crop rotation trends in plots' surveys. There were two main crop rotation patterns observed: one had a dominance of maize (Alsace region), and the other of cereals (Nord-Pas-de-Calais region). The latter also showed evidence of plots with meadow.

Wireworm damage on the 2012 harvest was around 20% irrespective of the type of rotation. The same percentage was also observed previously in Western France on maize and cereal crop rotation (BLOT et al., 1999). This result contradicts other studies which have observed maize as a main risk factor in the rotation (WILLIS et al., 2010; GUESTEM, 2012). Indeed, most of the regions where wireworm was reported as a pest issue (in potato production), are also regions where maize represents the main added value crop (sparsely in Southern France, and Alsace region). Therefore, this risk must be taken into account in maize rotation.

More information to be also noted is that where there was meadow in the rotation, all the plots showed evidence of wireworm attacks. This observation can be linked to work done by previous studies (SHIRCK, 1945; PARKER and HOWARD, 2001; MADEC, 2006; BROUARD, 2012; GUESTEM, 2012), where meadow is shown to be a major factor in the occurrence of wireworm attacks, according to its position and duration in the rotation.

However, as in my case, there was not the same number of plots showing attacks and plots showing no wireworm attacks (as a blank sample) so any conclusion should be considered carefully.

Use of chemicals

As seen in the introduction, the efficiency of chemicals against wireworm is not completely successful. I wanted to identify the trends for chemical use during crop sequence management, including the previous years, and I wanted to find out if any variation in wireworm attacks could be observed between those trends.

Two types of application were identified. In one case there had been many chemical applications each year right throughout the previous four year period, especially insecticides. In the other case, chemicals such as insecticides were not applied systematically every year. In both cases, the same rate of attacks was observed (around 20%). The same information can be noted in plots where insecticide application was performed only during the current "n" year (when survey was done).

Applying higher amounts of chemicals in the previous four years does not seem to be linked with wireworm population decrease. The issue to be debated here would be their real efficiency on wireworm destruction. It would be relevant to find out if they were used at planting time or during potato cultivation.

This result can be linked with observations made in maize or wheat rotation in Western France, where insecticide-treated fields were, in spite of everything, showing 19% of wireworm damage (BLOT et al.,1999).

The moment of application is also a factor in controlling wireworm. The key moment for potato seedling protection is when planting them (from late March until early May). The application of insecticide for wireworm is supposed to be efficient until harvesting time (from August until late October) to avoid wireworm damage. The same issue was observed in wheat attacked by wireworm, with seed treatments (MADEC, 2006)

Mechanical passes on the plot

An alternative to chemical application would be mechanical passes. That is why I wanted to look at emerging trends on this theme, once again including what was done in previous years.

Less wireworm damage was observed in plots where there were fewer mechanical passes. However, as with the supply of organic matter theme, it was only the presence or absence of mechanical pass that was reported here. The type of pass done was not detailed. It would also be relevant to observe what dates, and to what depths they were used. Indeed, mechanical passes are efficient in managing wireworm population if they are done on the surface. Wireworm larvae can be located in soil from 5 to 30 cm deep, to avoid dryness. Generally the larvae will avoid all kinds of extreme temperature (PARKER and HOWARD, 2001).

Two efficient practices for reducing wireworm population are: decreasing irrigation frequency in the plot, and ploughing it at summer time, when temperatures are high (SHIRCK, 1945). In the context of my study, it would be interesting to analyse the date and depth of all mechanical passes done in the previous four years. It could be linked to previous wireworm damage in order to observe evolution of the population.

Supply of organic matter

In the plots where much organic matter was supplied, wireworm damage was 10% higher than in the other cases. A similar trend was noticed in a maize survey (GUESTEM, 2012) where high organic matter contents in the soil was thought to have helped wireworm attacks. In the context of my study, the quantity of organic matter spread was not analysed in detail. This study took into account only its presence or absence. A more detailed analysis would allow a more precise evaluation.

Plot environment

All plots surrounded by either a path, a road or a railway showed evidence of wireworm attacks. However, plots are normally surrounded by at least a small path permitting farmers to gain access. To clarify this pattern, it would be relevant to make the link between wireworm locations within the plot and surrounding environmental features.

Interculture

There was no clear difference of wireworm damage between plots with or without interculture. However this factor must be part of the general analysis of the problem situation, as there is a tendency to reintroduce practices such as intercrops and green manure. One of the goals of interculture is to increase biodiversity and richness of insect habitats. On the other hand, insects can also mean pests, e.g. wireworm. A balance must be made between the risk of having more pests we do not control and increasing the richness of our soil (JANSSON and LECRONE, 1991).

Filling in surveys.

An additional observation can be made about the filling in of the survey. Some of the surveys were done in 2010, filled in by several different people. A lot of information returned was incomplete. However, two topics were well answered all the time: the frequency of chemical application and the level of wireworm damage observed.

The farmers mainly focused on these topics and considered the rest of the information (such as rotation, mechanical passes) not as relevant to improving wireworm management. They clearly wanted to make agricultural professionals notice they had wireworm in their fields and that, even applying recommended chemicals, they could not control its population.

2. System approach part

A choice was made to interview only farmers in this survey. In the ARDI method, you normally interview as many different people from the sector as possible. The goal is to enrich the understanding of the system by gathering different worldviews. I firstly wanted to find out about the main trends in farmers' views of the wireworm problem. Out of all the farmers interviewed, 18 surveys were carried out using the ARDI method. Thus, I could only analyse here one point of view on the wireworm issue. Other agriculture professionals could have been interviewed on the wireworm topic such as technicians, managers of cooperatives, or researchers. They could have provided a different vision, enriching the system information.

Our common thread question was: "How to manage wireworm population within potato cultivation?"

The actors' part (A) of the results of our study (obtained by the ARDI interview guide) contains four categories grouping most of the identified elements: advice, production, selling, and regulation.

The first two categories (advice and production) have the highest marks. The majority of farmers interviewed placed potato producer and technicians as the main actors of the system. Indeed potato producers work directly in the field, and so are confronted with wireworm (or other pest) issues. Considering the higher proportion of technical actors, it shows that farmers strongly depend on technicians' advice in the management of their fields. They are not proactive in finding out their own methods of management without this information. They prefer to use the tried and tested methods of the technicians. We can link this information to the resource part.

The resource (R) part of the ARDI method reflects the resources needed by the actors identified previously to achieve their goals. Three resource categories were identified: cultivation practices, research and information. The main cultivation practices are crop rotation and chemical application. While the use of cultivation practices depends on the farmers, two other categories (research and information) depend completely on other actors (for example technicians). Chemical regulation is quoted once again, and considered as a resource to manage wireworm population.

Farmers are familiar with the cultivation practices recognized as a solution for limiting wireworm development (rotation, mechanical passes) and are supported by literature (SHIRCK, 1945). The question is why are they are not used? Why are farmers waiting for the "research", or the "cultivation trials" to come from technicians? This can be linked to the last part, dynamics.

In the dynamics' part (D) of the ARDI framework, the processes that significantly change system functioning are identified. In opposition to the Actors, and Resource parts, no obvious elements, agreed upon by all the farmers, could be identified. However in the notation system of the ARDI method, elements having the highest marks are mainly economical elements such as "developing an efficient solution for managing wireworm", "quality downgrading according to wireworm damage", "evolution of the potato market". These are the first elements farmers think about. Economy dynamics prevails over other elements, such as the consumer's point of view, and influence farmers in the management of the wireworm population.

3. Implications of the results at various levels and of the farming and food system from different perspectives.

The results of my study on wireworm management in potato cultivation require a discussion considering several levels of the problem and the several perspectives to it. The following discussion will go from field level (plot, first technical part of this study) to farm level (second system approach part of this study) and then to food system level of the potato sector, and the food system in general.

Field level

Within one plot, there are already several elements to take into account when considering wireworm management in potato cultivation. Firstly, in potato cultivation, wireworm is clearly not the only type of pest farmers have to manage in their rotation. The reason for considering the problem in this investigation is as follows: there is a decreasing use of some chemicals, and the ones in current use are less efficient. In my study, the products' efficiency is a redundant theme observed in the system approach using the ARDI method.

Until now, chemicals remain the most efficient short term management option when encountering a pest issue. However, it is known that repeated use of the same components are making insects resistant to them, and more chemicals are needed to maintain efficiency (GLIESSMAN, 2007), which becomes more costly for the farmer. In this case, a short cycle wireworm is also reported to develop in Southern France (TAUPIN and BLOT, 2007).

Nowadays, using chemicals is a standard practice in agriculture to manage pest whereas it should be reserved to special case management, when no other efficient technique could be found. It remains a limited short-term management technique. In the case of wireworm, these limits are tightening with more and more regulations. Moreover these regulations take into account the longevity of these products in the soil and build a legal frame to decrease it. In potato cultivation the critical moment to use efficient insecticide is at the planting stage. Thus, in order to be efficient, it should remain in the soil from April to September (harvesting time), which is contrary to the regulations objectives. That is one of the reasons why regulations are considered as a resource for pest management in agriculture, as observed in my system approach with the ARDI method. It became an important strategy for the professional agricultural sector. However, following the establishment of the Ecophyto 2018 plan (which plans to reduce chemical use by 50% in 2018; MINISTERE DE L'AGRICULTURE, 2013) in France, and throughout Europe, other alternative to chemical solutions should be experimented with.

Wireworm is not only concentrated in potato cultivation. Indeed, it was observed and analysed on many other crops with important added value, such as cereals and maize (MADEC, 2006; BROUARD, 2012; GUESTEM, 2012). Their feeding behaviour is not clearly identified for now, according to the locations where studies were done. The *Agriotes* species is considered predominately herbivorous while others feed on animal prey (TRAUGOTT et al., 2008). Another study also showed that wireworms prefer insects to maize seeds for example. (ROBERTSON, 1987).

Potato cultivation is traditionally considered as an up-keeping cultivation. A rotation of at least 4 years is recommended (ROUSSELLE et al., 1996). While yield is good, costs for infrastructure and material for this type of cultivation force farmers to favour shortening the crop rotation in order to recover expenses as quickly as possible. In some places it became a monoculture as did maize in other regions. Such rotation is known for increasing pest and risks of diseases (GLIESSMAN, 2007).

From the field to the packaging platform level…

The main concern for potato producers once harvest is done is the possibility of quality downgrading (potatoes are sorted, and those with too many defects will not be sold). If this happens, the farmers will be paid little or they will not be paid at all. Indeed, once a batch has been judged unsaleable by the packaging platform organization, there is no real way to increase its value. In most cases they are sold as animal feed (personal communication, 21.12.2012).

Criteria used to qualify wireworm damage on potato are different depending on the companies. Although a convention for potato damages has been adopted by potato professionals (commercial decree; CNIPT, 1998) each company and each packaging platform have their own rules which they adapt to the current market. The value-creation of potato and the regulations can change from one year to another. This is also a short term vision, impacting farmers' investments in potato cultivation every year.

Several studies (GRATWICK, 1989; PARKER and HOWARD, 2001) reported that wireworm damage can be easily confounded with slug damage even in professional agriculture sector. This observation was verified during my study when I made analysis for wireworm damage on potato.

On packaging platforms; wireworm damage is classified most of the time together with many other surface defects, making the setting up of a traceability of plots exposed to risks of wireworm very difficult.

Food system, researches and their oversights…

In the French agriculture sector, potato cultivation is not the main crop production, compared to wheat or maize. Wireworm does not currently represent a major problem compared to other pests or diseases.

This makes research and cultivation experiments difficult to set up, especially for financial reasons. As many different practices could be tested, experiment choices are made with short term and cheaper outcomes in mind.

This is the case for chemicals experiments. As certification for one product can take over 10 years before being sold on the market, chemical company would not invest in research if there is no financial returns guaranteed for them. This could explain why some potato producers, even if wireworm is not a big issue yet, are complaining strongly about it in order to encourage research on that topic. This idea is reinforced by the fact that in my study, I found only few farmers suffering from wireworm damage, despite the help of a technical institute social network. I managed to contact 28 farmers up from the five ones identified in 2010 by the institute.

A difference between short-term and long-term research can be highlighted here. It can be linked to fundamental research and applied research (which is the ARVALIS institute main field of work). Both types of research do not need the same financial investment and time duration. Short term research fits perfectly for testing chemical products, but not for the management of the whole rotation, which must last at least five to six years for only one study. Unfortunately financial resources for researches are available for three to five years maximum. That is the case of my study which is part of a four-year program aiming to build a wireworm risk scale on different type of crops.

Wireworm biology could be studied over ten years in order to understand completely its behaviour and feeding habits. However, one may wonder if wireworm issue is important enough to warrant such investments?

Although wireworm appeared in several other countries (PARKER and HOWARD, 2001; WILLIS et al., 2010), research is often directed on finding solutions to get rid of wireworm instead of understanding its biology.

Indeed many studies were performed on topics such as forecasting methods (PARKER, 1996 ; TOTH et al., 2003), use of pheromones (ESTER and VAN ROZEN, 2005; CHATON et al., 2007), biofumigation (RAMIREZ et al., 2009 ; MICHEL et al., 2007; FURLAN et al., 2010), flooding and temperature (VAN HERK and VERNON, 2006), microbial insecticides (ZACHARUK and TINLINE,1968 ; KABALUK et al., 2007 ; ANSARI et al., 2009) or resistant cultivars potato for some pests (JACKSON et al., 2012; PARKER and HOWARD, 2000).

On the opposite, few studies were carried out to understand the wireworm behaviour.

The Final observation will include the consumer role. Indeed, as in many other crops many chemical products are used on potatoes only for preventing some marks from appearing on them For example, the number of fungicides used involves to make from 10 to 15 passes and forces farmers to perform one treatment per week during the potato crop cycle. These marks can be easily removed most of the time by peeling them. Lastly, the wireworm is an annoyance as it makes galleries within the tuber, but no threat on human health was found until now.

Conclusion

This study aims to obtain a better understanding of wireworm risk within potato cultivation plots, and of the potato producers' approach to wireworm management.

For a greater part of France, wireworms do not yet represent a major problem for potato producers. The wireworm damage average on the harvest observed in this study was about 20% in attacked plots. No damage at all was observed in the four years preceding potato cultivation, making it hard for farmers to predict wireworm attacks. The same rate of damage (20%) was observed irrespective of the type of rotation, in both regions studied.

More attacks were observed on plots where fewer insecticides were applied. The same level of efficiency was identified on plots where many insecticides were applied during the previous four years, and the plots where many insecticides were applied in the current year only(2012, year of the survey). Less damage of wireworm was observed in cases where there were fewer mechanical passes applied in the plot for the period of five years leading up to and including the year of this study. 10% more wireworm damage was observed where a consequent supply of organic matter inputs was made (twice to five times in four previous years). The presence or absence of interculture over the previous four years did not show any significant difference.

Farmers identify the main actors for wireworm management through four categories: advice, production, selling, and regulation. They focus on the two former elements. Resources are grouped under three categories: cultural practices, research, and information. Farmers are familiar with alternative cultural practices to chemicals, but they don't use them. This could be explained by the dynamics identified. They are mainly economic elements and prevail in farmers' views about the food and cultivation system.

These conclusions were observed in the case of potato cultivation. However, wireworm damage is not specific to only this crop. Maize, wheat and other different cultivation can encounter this wireworm management problem. Therefore, comparing similar studies on other crops would improve determining risk factors for wireworm attacks. This is what Arvalis institute aims to do. Indeed, data processed in this study will serve to inform future studies where several types of crop data can be combined**.**

References

AGRESTE ; 2011.Campagne de pomme de terre 2009/2010. Agreste conjoncture-grandes cultures. Synthèse 2011/148.

ANSARI M.A., EVANS M., BUTT T.M. ; 2009. Identification of pathogenic strains of entomopathogenic nematodes and fungi for wireworm control. Crop protection, 28, 269-272.

ARVALIS INTITUT DU VEGETAL ; 2004. Principaux ravageurs de la pomme de terre.

ARVALIS INSTITUT DU VEGETAL ; 2012. Protection des cultures. Pomme de terre. Lutte contre les maladies, mauvaises herbes, défanage et ravageurs 2012.

BLOT Y., BRUNEL E., COURBON R. ; 1999.Enquête sur l’infestation de parcelles de blé et de maïs par les larves de taupins des genres Agriotes et Athous dans l’Ouest de la France (Coléoptères : Elaterides). Annales de la société entomologique de France, 35, 453-457.

BROUARD A. ; 2012. Etude du risque taupins sur cultures de maïs dans l’Ouest de la France. Rennes : Agrocampus Ouest CFR.

CHATON P.F., LEMPERIERE G., TISSUT M., RAVANEL P. ; 2007. Biological traits and feeding capacity of Agriotes larvae (Coleoptera : Elateridae) : A trial of seed coating to control larval populations with the insecticide fipronil. Pesticide biochemistry and physiology, 90, 97-105.

CNIPT, DGCCRF; 1998. Commerce des pommes de terre de primeur et des pommes de terre de conservation. Arrêté du 3 mars 1997 et son interprétation (octobre 1998), 32 p.

DEDRYVER C.A., ROBIN N., TAUPIN P., THIBORD J.B. ; 2009. Lutte contre les taupins : Etat des recherches et des connaissances techniques en France et dans l’U.E., voies de recherche à privilégier. INRA, ARVALIS.

ERICSSON J.D., KABALUK J.T., GOETTEL M.S., MYERS J.H. ; 2007.Spinosad interacts synergistically with the insect pathogen Metharhizium anisopliae against the exotic wireworms Agriotes lineatus and Agriotes obscurus (Coleoptera : Elateridae). Journal of economic entomology, 100, 31-38.

ESTER A., VAN ROZEN K. ; 2005. Monitoring and control of Agriotes lineatus and A. obscurus in arable crops in the Netherlands. Insect pathogens and insect parasitic nematodes : Melolontha IOBC/wprs Bulletin, 28, 81-85.

ETIENNE M.; 2009. Co-construction d'un modèle d'accompagnement selon la méthode ARDI : guide méthodologique.

ETIENNE M. ; 2010. La modélisation d'accompagnement. Une démarche participative en appui au développement durable.

FAO. Global production and consumption of roots and tubers. [online] Localised on http://www.fao.org/wairdocs/tac/x5791e/x5791e0q.htm. Refered to 15.10.2012

FAO. Potato 2008, Année internationale de la pomme de terre. Le monde de la pomme de terre. [online]. Localised on http://www.potato2008.org/fr/monde/index.html. Refered to 10.09.2012

FAOSTAT. Potato production. [online]. Localised on http://faostat3.fao.org/home/index.html?#VISUALIZE_BY_DOMAIN. Refered to 10.09.2012

FURLAN L., BONETTO C., FINOTTO A., LAZZERI L., MALAGUTI L., PATALANO G., PARKER W., 2010. The efficacy of biofumigant meals and plants to control wireworm. Industrial crops and products, 31, 245-254.

GHESTEM A. ; 2012. Evaluation du risque taupins en culture de maïs et céréales à pailles dans les exploitations du grand ouest. Lille : ISA.

GLIESSMAN S. ; 2007. Agroecology : The ecology of sustainable food systems. 2nd edition.

GRATWICK M.; 1989. Potato pests. MAFF Reference book 187. London.

GRAVOUEILLE J-M. ; 2012. La pomme de terre, marchés et qualités. Formation culture de la pomme de terre. March 2012

JACKSON D.M., HARRISON H.F., RYAN-BOHAC J.R.; 2012. Insect resistance in sweetpotato plant introduction accessions. Journal of economic entomology, 105 (2), 651-658.

JANSSON R.K., LECRONE S.H. ; 1991. Effects of summer crop management on wireworm (Coleoptera :Elateridae). Abundance and damage to potato. Journal of economic entomology, 84, 581-586.

KABALUK J.T., VERNON R.S., GOETTEL M.S. ; 2007. Mortality and infection of wireworm, Agriotes obscurus[Coleoptera :Elateridae] , with inundative field applications of Metarhizium anisopliae. Phytoprotection, 88, 51-56.

LARROUDE P. ; 2013. Lutte contre les taupins. Réunion technique pomme de terre ARVALIS-Institut du végétal. Informations techniques et bilan des expérimentations. Paris : 30.01.2013.

MADEC B. ; 2006. Evaluation du risque parcellaire de dégâts de taupins (Coleoptera, Elateridae) dans l'Ouest de la France. Clermont-Ferrand : ENITA de Clermont.

MICHEL V., AHMED H., DUTHEIL A. ; 2007. La biofumigation, une méthode de lutte contre les maladies du sol. Revue suisse viticulture, arboriculture, horticulture, 39, 145-150.

MINISTERE DE L'AGRICULTURE DE L'AGROALIMENTAIRE ET DE LA FORET. Ecophyto [online] http://agriculture.gouv.fr/ecophyto Refered to 25.02.13

PARKER W.E. ; 1996. The development of baiting techniques to detect wireworms (Agriotes spp. Coleoptera : Elateridae) in the field, and the relationship between bait-trap catches and wireworm damage to potato.

PARKER W.E., HOWARD J.J. ; 2000. Assessment of the relative susceptibility of potato cultivars to damage by wireworms (Agriotes spp.). Tests of Agrochemicals and cultivars no.11. Applied biology Suppl.

PARKER W.E., HOWARD J.J. ; 2001. The biology and management of wireworms (Agriotes spp.) on potato with particular reference to the U.K. Agricultural and Forest Entomology, 3, 85-98.

RAMIREZ R.A., HENDERSON D.R., RIGA E., LACEY L.A., SNYDER W.E. ;2009. Harmful effects of mustard bio-fumigants on entomopathogenic nematodes.Biological control, 48, 147-154.

ROBERTSON L.N.; 1987. Food habits of pasture wireworm, Conoderus exsul (Coleoptera: Elateridae). New Zealand journal of zoology, 14, 535-542.

ROUSSELLE P., ROBERT Y., CROSNIER J.C. ; 1996. La pomme de terre.

SHIRCK F.H.; 1945. Crop rotations and cultural practices as related to wireworm control in Idaho. Official organ American association of economic entomologists, 6 (38), 627-633.

TAUPIN P., BLOT Y.; 2007. Dossier taupins. Perspectives agricoles. 339, 20-31.

TOTH M., FURLAN L., YATSYNIN V.G., UJVARY I., SZARUKAN I., IMREI Z., TOLASCH T., FRANCKE F., JOSSI W. ; 2003. Identification of pheromones and optimization of bait composition for click beetle pests (Coleoptera : Elateridae) in Central and Western Europe. Pest management science, 59, 417-425.

TRAUGOTT M., SCHALLHART N., KAUFMANN R., JUEN A. ; 2008.The feeding ecology of elaterid larvae in central European arable land : New perspetives based on naturally occurring stable isotopes. Soil biology and biochemistry, 40, 342-349.

UNPT ; 2012. Rapport d'activité 2011.Congres UNPT 2012. 02/02/2012.Reims.

VAN HERK W.G., VERNON R.S. ; 2006. Effect of temperature and soil on the control of a wireworm, Agriotes obscurus L. (Coleoptera : Elateridae) by flooding. Crop protection, 25,1057-1061.

WILLIS R.B., ABNEY M.R., HOLMES G.J., SCHULTHEIS J.R., KENNEDY G.G.; 2010. Influence of preceding crop on wireworm (Coleoptera:Elateridae). Abundance in the Coastal Plain of North Carolina. Journal of economic entomology,103 (6), 2087-2093.

WILLIS R.B., ABNEY M.R., KENNEDY G.G.; 2010. Survey of wireworms (Coleoptera : Elateridae) in North Carolina sweetpotato fields and seasonal abundance of Conoderus vespertinus. Journal of economic entomology, 103 (4), 1268-1276.

ZACHARUK R.Y., TINLINE R.D., 1968. Pathogenocity of Metarhizium anisopliae, and other fungi, for five Elaterids (Coleoptera) in Saskatchewan. Journal of invertebrate pathology, 12, 294-309.

Appendixes

Appendix 1- Plot characteristics and agronomic practices survey (French)

Appendix 2-System approach survey

Appendix 1: Plot characteristics and agronomic practices survey

Projet Casdar Taupins	**Questionnaire d'enquêtes parcellaires TAUPINS**	**Fiche 1**

Date enquête : / /

CODIFICATION (CP parcelle / Init. enquêteur / N°parcelle / Année de l'enquête) : / / /

Enquêteur		
Nom :	Prénom :	Tél. :
Agriculteur		
Nom :	Prénom :	Tél :
Adresse :	Code postal :	Ville :
PARCELLE		
Commune :	Nom parcelle (facultatif) :	Surface (ha) :
Code postal parcelle :	Coordonnées GPS * Latitude X=	
Poste météo représentatif :	Longitude Y=	

Appendix

CARACTERISTIQUES DE LA PARCELLE

Type de sol (dénomination locale) :

Profondeur d'enracinement (cm) :

Texture du sol : (connaissance agriculteur)
Argileux ☐ Argilo-limoneux ☐ Limoneux ☐ Sablo-limoneux ☐ Sableux ☐ Argilo-calcaire ☐
Autre :

%cailloux (estimation) : < 5% ☐ 10-15% ☐ > 15% ☐

Sensibilité du sol à :

- l'excès d'eau : parcelle saine non drainée ☐ parcelle saine drainée ☐ parcelle hydromorphe ☐

selon vous comment est la parcelle ?

hydromorphe 0 → 100 bien drainée

- la sécheresse (RU) : > 170 mm ☐ 120-170 mm ☐ 70-120 mm ☐ < 70mm ☐

- la battance : oui ☐ non ☐

Analyse de sol (à minima granulométrie 5 fractions, pH eau, %matière organique)

Parcelle de Niveau 1 avec distinction de la zone attaquée : Prélèvement par enquêteur : oui ☐ non ☐
date : / /

Résultats d'analyse (< 5ans) : oui ☐ non ☐

%Argile	%Limons fins	%Limons grossiers	%Sables fins	%Sables grossiers	%MO	pH eau

Si non : Prélèvement par enquêteur : oui ☐ non ☐ date : / /

Zone de prélèvement	☐ zone attaquée (ZA)	☐ zone non attaquée (ZNA)	☐ zone aléatoire
Codifications :			

Position dans le paysage Plane ☐ Pente ☐ préciser le % de pente : %
exposition : N ☐ S ☐ E ☐ O ☐

Appendix

ENVIRONNEMENT DE LA PARCELLE

Périmètre de la parcelle			% périmètre concerné	Vent dominant (cocher la case si le vent vient de l'environnement considéré)
Chemin enherbé	Non ☐	Oui ☐		
Fossé	Non ☐	Oui ☐		
Bande enherbée	Non ☐	Oui ☐		
Cultures adjacentes (sans séparation)	Non ☐	Oui ☐		
Cultures adjacentes (avec séparation)	Non ☐	Oui ☐		
Prairies adjacentes (sans séparation)	Non ☐	Oui ☐		
Prairies adjacentes (avec séparation)	Non ☐	Oui ☐		
Haie végétale (< 3 m hauteur)	Non ☐	Oui ☐		
Haie boisée / Bois	Non ☐	Oui ☐		
Autre préciser :	Non ☐	Oui ☐		

Total = 100 %

HISTORIQUE DE LA PARCELLE **Année N (année récolte) =**

La parcelle a-t-elle été reprise récemment ? Non ☐ Oui ☐ Si oui, année de reprise : _ _ _ _

Cette parcelle a-t-elle déjà été exploitée ? Non ☐

en prairie permanente ☐ en prairie temporaire ☐ en jachère ☐ ou autre ☐ préciser :

Préciser l'année de destruction de la prairie / jachère : _ _ _ _ la durée : _ _ ans

Appendix

Rotations des cultures sur les quatre dernières campagnes							
Récolte	Culture (0)	Inter-culture (implantée après récolte) (1)	Apports organiques (2)	Travail du sol (3)	Protection insecticide au semis (4)	Dégâts ravageurs des jeunes plantes (5)	Lutte en végétation Ravageurs cibles (6)
Année N – 1 : _ _ _ _							
Interculture N-2 / N-1							
Année N – 2 : _ _ _ _							
Interculture N-3 / N-2							
Année N – 3 : _ _ _ _							
Interculture N-4 / N-3							
Année N – 4 : _ _ _ _							
Interculture N-5 / N-4							

(0) Si prairie préciser le mode d'exploitation : 100% pâture (P) / pâture et fauche (PF) / 100% fauche (F)

(1) CIPAN (préciser espèce) / mulch de résidus / repousses / sol nu / prairie ou jachère / autre (préciser).

(2) préciser le type d'apport et la quantité

(3) préciser : labour (L) / techniques culturales sans labour (TCS) / semis direct (SD) précisez les mois

(4) Préciser le produit ou le type de traitement insecticides (semences).

(5) Indiquer le (s) ravageur (s) des jeunes plantes présents et préciser le niveau de nuisibilité (faibles dégâts, dégâts significatifs ou dégâts très fortement préjudiciables)

(6) Indiquer le ravageur ayant fait l'objet d'une lutte en végétation ainsi que la période d'application.

Appendix

DE LA CULTURE N-1 A LA CULTURE N

Précédent Rappel du précédent : Date de récolte du précédent : / /

Gestion des résidus de culture

☐ Résidus laissés sur place non broyés

☐ Pailles exportées

☐ Broyage sous cueilleurs (à la récolte)

☐ Broyage après récolte date : / /

Inter-culture ☐ Sol nu ☐ Prairie / Jachère ☐ CIPAN espèce ☐ Repousses

date semis : / / date destruction : / / mode chimique ☐ mécanique ☐

Préparation du sol

Labour ☐ Techniques culturales sans labour ☐ Semis direct ☐

Préciser les interventions mécaniques pour la préparation du sol de la récolte du précédent jusqu'au semis de la culture enquêtée

Outil	Date	Profondeur (cm)
	/ /	
	/ /	
	/ /	
	/ /	
	/ /	
	/ /	
	/ /	

Chaulage

Non ☐ Oui ☐ Type de produit : Quantité (/ ha) : Date : / /

Apports de matières organiques

Non ☐ Oui ☐ Type de produit : Quantité (/ ha) : Date : / /

Appendix

CULTURE de POMME de TERRE

Plantation **Variété :** **Date de plantation :** / / fécule ☐ frais (lavée, entière) ☐ primeur ☐ transformation (frites chips, purée…) ☐ plant ☐ **Densité** : Plants/ha **Date de récolte :** / / Ecartement : 75 cm ☐ 80cm ☐ 90cm ☐ billons ☐ **Levée** : jours après plantation Condition de plantation : sèche ☐ bonne ☐ humide ☐ Matériel de buttage : Date de buttage **:** / /	
Protection du plant Plant certifié : oui ☐ non ☐ Protection du plant : oui ☐ non ☐	Produit (s) utilisé (s)
Traitement du sol ☐ anti nématodes en plein ☐ en localisé ☐ date : / / Produit(s) x Dose (unité) :	
☐ anti taupins en plein ☐ en localisé ☐ date : / / Produit(s) x Dose (unité) :	
☐ anti limaces en plein ☐ en localisé ☐ date 1 : / / date 2 : / / Produit(s) x Dose (a unité) :	
Protection insecticide en végétation Nombre d'application : période d'application : Produit(s) x Dose (unité) : cibles : (D) ☐ (P) ☐ (T) ☐ **Ravageur(s) visé(s) : doryphore (D), pucerons (P), teigne (T)**	
Désherbage : date : / / chimique ☐ mécanique ☐ si mécanique nombre de passages :	
Défanage : date : / / chimique ☐ mécanique ☐ si mécanique nombre de passages : Récolte en vert : Non ☐ Oui ☐	
Antigerminatif : Produit(s) x Dose (unité) : date : / /	

Irrigation :

Date début :   /   /   date fin :   /   /   nombre de passages :   quantité moyenne : mm

Protection fongicide en végétation

Nombre d'applications de produits fongicides :

Remarques :

Avez-vous déjà eu des dégâts de taupins sur tubercules les années précédentes

Année :   variété :   Dégâts : oui ☐   non ☐

Année :   variété :   Dégâts : oui ☐   non ☐

Année :   variété :   Dégâts : oui ☐   non ☐

Année :   variété :   Dégâts : oui ☐   non ☐

OBSERVATIONS DES DEGATS DE TAUPINS SUR POMME DE TERRE

Localisation des dégâts de taupins :

Plutôt en bordure ☐   caractérisation de la bordure (boisée, chemin…): ________________________________

Plutôt au centre ☐   Pas de zone particulière ☐

Sur zones séchantes ☐   sur zones hydromorphes ☐   pas de zone particulière ☐

Sur zones tassées ☐   sur zones meubles ☐   pas de zone particulière ☐

Répartition   Homogène ☐   Foyers/ taches ☐   Dispersée ☐

Appendix

OBSERVATIONS DES DEGATS DE RAVAGEURS SUR TUBERCULES

Notation faite : ☐ au champ avant récolte après récolte ☐ sur table de triage ☐ en caisses

Echantillonnage effectué par : ☐ agriculteur ☐ technicien ☐ enquêteur

Si effectué par le technicien : nb de tubercules observés : ________

% de tubercules touchés par le taupin : ______ (formulaire de suivi qualitatif)

Si effectué par agriculteur/enquêteur :

Comptage de dégâts de taupins sur tubercules après prélèvement (100 à 150 tubercules par point de piégeage PL/CB ou d'échantillonnage post récolte R)

	Date des observations	**Nombre tubercules observés**	**Nombre tubercules sains**	**<u>Dégâts profonds</u>** **Nombre tubercules présentant au moins 1 trou ou 1 galerie**	**<u>Dégâts superficiels</u>** **Nombre tubercules présentant des morsures < 3.5 mm**
PL / CB ou R1					
PL / CB ou R 2					
PL / CB ou R 3					

Appendix 2 : System approach survey

Farmer name : **Date :**

"How to manage the wireworm population within potato cultivation?"

Actors :

Resources :

Dynamics:

*Ecological :

*Economic :

*Social :