Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Landscape Architecture, Horticulture and Crop Production Science

Relationships between Soil Management and Pathogen Suppressive Soils in Southern Sweden

An Interdisciplinary Analysis

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Relationer mellan Markbehandling och Jordens Förmåga att Motverka Patogener I Skåne
En Tvärvetenskaplig Analys

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Foreword

My first objectives when I started studying biology in Germany were to protect biodiversity and nature. However, protection of nature in a country like Germany can only work over the long term if one starts changing the major sector of land use: agriculture. Taking a look at the history of nature protection and agricultural development in Germany made clear to me that solutions can only be found if people work together.

The Agroecology Master's program was a very refreshing and inspiring period of my life. I have learned many things during the last two years, not only for my own profession, but also for life in general. Learning to analyze food production systems in a holistic way changed my view on the sustainability challenges of our century. Coming from a natural scientific background, I gained insight into social science and economy, which gave me an interdisciplinary understanding of food production systems. Analyzing ecological, social and economic aspects at the same time offered me a broad perspective on problem situations and a deeper understanding of how and why conflicts in problem solving processes appear and how they can be prevented. Brining people into the dialogue and working together to find constructive solutions for complex problems that are acceptable for the people involved is also an important step to a more democratic living environment.

We were given a number of highly valuable management and planning tools to start up from scratch and end up with feasible solutions. Systems thinking allows one to understand what is important to change, and skills in interviewing and problem analysis are valuable for finding out the key issues of a complex problem. These tools, among many more, enable me now to work on problems on the systems level. With the Agroecology Master Program, I obtained a guideline to tackle a multitude of complex situations ahead.

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Lastly, I want to thank the farmers who agreed to be interviewed and allowed me to use their soil for my experiments. A great deal of my inspiration and energy for this project came from them and the farm visits were a very positive and educational experience for me.

Summary

A holistic study on soil-borne pathogen management with suppressive soils was performed in Scania, Sweden. The study was designed to comprise both social and biological research to gain a systemic perspective on the real-life situation of Swedish farmers regarding plant pathogens and soil management. The social research comprised semi-structured interviews with a small number of farmers and an online survey, which could not be sent to farmers and therefore was without results. Possible reasons for the failure are discussed. For the biological research, soils from ten Swedish farms with different cropping and management regimes were assessed for effects on *Pythium ultimum* disease symptoms in wheat, physical and chemical soil parameters, and the soil nematode trophic community as identified at the family level.

Soil effects on *Pythium ultimum* disease symptoms were assessed in two categories: (1) biological or non-biological effects and (2) suppressive or conducive effects. Different soils had both conducive and suppressive effects, which were due to either the soil biotic community or chemical or physical properties of the soil. Management regimes with permanent plant cover had biological effects and management regimes with interrupted plant cover had non-biological effects. The nutrient balance was related to biological suppressiveness. Biologically conducive soils had either high or low nutrient content, while biologically suppressive soils had intermediate nutrient levels.

The total number of nematodes and the abundance of predators and omnivores were not related to the soil organic matter content. The abundance of hyphal-feeding nematodes was correlated with soil organic matter content. No relationship was found between the soil nematode trophic community, the soil management, and soil effects on *Pythium ultimum* disease symptoms. Therefore, nematode trophic guilds do not indicate soil effects on *Pythium ultimum* disease symptoms.

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1. Introduction

Agricultural food production is a highly complex and diverse process performed within our natural environment. Food production interacts with the local and global ecosystem, it directly and indirectly affects human societies and cultures and, conversely, agriculture is affected by social and cultural dynamics. Likewise, embedded in our political and cultural choices, economic factors of food production are directly linked to farmers' choice of crops and farming methods (Beddoe et al., 2009, Altieri and Nicholls, 2005, IAASTD, 2009, Brady and Weil, 2008).

During the last decades diversity of production on farms has decreased and field size increased to enhance economy of food production. Farming systems have been largely separated from the natural balance allowing higher yields with less manpower (Beddoe et al., 2009). Ecological regulative processes were replaced by machines and chemicals to deliver nutrients and to manage weeds, pests and pathogens (Foley et al., 2011). But intensive agriculture with high external inputs such as mineral fertilizers and pesticides and a high degree of mechanization has led to a number of serious problems (Hill, 1998) like loss of biodiversity (Le Feon et al., 2010, Luescher et al., 2014, Laliberte et al., 2010), increased greenhouse gas emission (Hoffmann, 2011) and pollution of coastal areas with nutrients (Howarth, 2008). Besides environmental damage the intensification of agricultural production and reduction of agrobiodiversity also lead to inadequate human nutrition leading to increased numbers of disease of civilization and vitamin and micro nutrient deficiency. The latter two in particular in developing countries (De Shutter, 2014).

The environmental and social problems connected to agricultural production create an increasing need for more sustainable production systems worldwide. Food production is embedded into a complex biophysical and social environment (Altieri and Nicholls, 2005). Our surroundings restrict agricultural systems by its physical and biological limits (Hill, 1998), but people also influence agricultural systems through cultural values, practices and regulations (Beddoe et al., 2009). These aspects define our biological, social and economic space of action when we perform or adapt food production.

A key issue for agricultural research is to reduce the application of chemical pesticides to a minimum and to find more resilient pest and pathogen management strategies. Therefore, ecological principles should be integrated in the farm management to prevent and control pests and pathogens (Wezel et al., 2014). Finding effective and resilient control methods for plant pathogens is one of the obstacles to solve for sustainable crop production to be realized. To address this need, I want to assess, how it could be possible to apply ecological management methods for the control of soil borne plant pathogens. Soils can have general pathogen suppressive characters (Chandrashekara et al., 2012) and different authors state that soil management is related to these suppressive effects (Alabouvette and Steinberg, 2006, Brady and Weil, 2008).

Based on this, I wanted to find out whether there are relationships between the soil management and effects of agricultural soils on plant pathogens. For farmers it is particularly important to be sure of a new pathogen management method. Therefore, easy measurable indicators are important tools to assess and evaluate soil effects for a reliable and efficient pathogen management. Soil nematodes possibly could be such an indicator. Soil nematodes can be found in high numbers in most soils, they are known to quickly react on changes in the soil environment and they are relatively easy to assess (Bongers and Bongers, 1998). Nematodes also comprise a wide range of trophic guilds and therefore represent a broad spectrum of ecological functions on different levels of an ecosystem (Yeates et al., 1993). Consequently, indicators like the maturity-index of nematode societies are used to assess functioning of soil ecosystems (Bongers and Bongers, 1998). Stirling et al. (2011) also found relations between the abundance of total number of free living nematodes, plant-feeding, bacterial-feeding, hyphal-feeding and predator nematodes and the suppressiveness of soils to plant parasitic nematodes. Therefore, this study also includes an assessment of the potential of using the structure of nematode trophic guilds as a bioindicator for soil effects on disease symptoms. In order to give the research project a systemic perspective and to give the performed work relevance I also included the views and opinions of the farmers. This allows setting the frame for future work to enhance the relevance of future research and adoption of technologies resulting from it.

1.1 Plant Disease Suppressive Soils

Suppressive soils are soils in which plant pathogens do not proliferate or disease symptoms do not occur despite presence of plant pathogens. For over 100 years, it has been known that some soils have disease suppressive characters (Chandrashekara et al., 2012). The idea of integrating suppressive soils in an effective plant disease management strategy is not new.

Already during the first congress on “ecology of soil borne plant pathogens, prelude to biological control” in 1963 different possible principles of ecology based management of soil borne plant diseases have been discussed (Baker and Snyder, 1965). However, since then, there have been many approaches to find ways to use suppressive soils for pathogen control, but in fact little progress has been made. Reasons for failure range from insufficient understanding of the underlying principles to infeasibility of methods (Alabouvette and Steinberg, 2006).

Cook and Baker (1983) describe two different mechanisms of suppressive soils according to the underlying ecological principle. Pathogen suppressive soils where the soil does not allow the pathogen to survive. And disease suppressive soils where the pathogen is present in the soil, but the disease does not occur or can be compensated by other effects. Suppression of disease and pathogens can be due to abiotic or biotic reasons. The underlying mechanisms range from abiotic soil conditions where the pathogens simply cannot survive to complex biological interactions (Brady and Weil, 2008).

Suppressive effects can be further separated into general and specific disease suppressiveness. General disease suppressive soils are characterized by high microbial activity. The biological mechanisms can include competition for nutrients, destruction of pathogen spores, production of antibiotics by other microorganisms, or the physical inability of the pathogen to reach the roots because they are densely colonized by beneficial microorganisms. Specific disease suppressiveness is caused by specific interactions of single soil organisms or small groups of organisms. Antagonist organisms either kill specific pathogens or prevent their growth (Cook and Baker, 1983).

Most suppressive soils become conducive after the soil biota has been destroyed, hence, plant disease occur and pathogens can proliferate (Alabouvette and Steinberg, 2006). Chen et al. (1987) and Chen et al. (1988) describes that composts with a core temperature higher than 60°C are *Pythium ultimum* conducive, but become suppressive within few days after cooling down to 25°C, when beneficial organisms from the cooler outer areas of the compost can recolonize the core compost. Hoitink et al. (1997) describes similar effects for compost core temperatures between 55 and 70°C.

Different biological factors are related to suppressive soils. The total microbial mass and activity seem to play an important role in general suppression of soil borne pathogens (Chen et al., 1988, van Os and van Ginkel, 2001). Soil biodiversity is suspected by many researchers to be related to general suppression of soil borne plant pathogens, but this is as yet difficult to assess (Reeleder, 2003, Nitta, 1991). The importance of these biological parameters becomes obvious when one considers that plants can actively change the composition of organisms in their rhizosphere to recruit beneficial microorganisms. In this way, the plant can react to changing conditions or pathogen occurrence, providing the necessary beneficial microorganisms are present in the soil (Berendsen et al., 2012).

Also, abiotic soil properties like pH, soil organic matter, clay content and nutrient availability can affect proliferation and pathogenicity of plant pathogens, but also affect the soil ecosystem. Hence, abiotic properties contribute indirectly to biological suppressiveness (Chandrashekara et al., 2012). Soil structure and moisture affect the suppressive potential of soils. In agricultural soils, the soil management directly influences abiotic properties of the soil as well as the biodiversity. Therefore, soil management is probably related to the suppressive potential of soils for soil-borne plant pathogens (Ghorbani et al., 2008).

Two different methods of implementation of soil suppressiveness for plant pathogens are known. The first is inoculation biological control. Specific suppressiveness is created by antagonist soil organisms. After identifying antagonists for plant pathogens, they are cultured and applied to the soil directly or as coated seeds (Alabouvette and Steinberg, 2006). For example, the bacterium *Pseudomonas flourescens* (Ganeshan and Kumar, 2005) and ascomycetes from the order *Trichoderma* (Vinale et al., 2008) are known to be able to generate specific suppressiveness in formerly conducive soils. However, the suppressive effects of single organisms are often pathogen specific, the persistence of the introduced organisms in the soil is low, and the market for beneficial microorganisms is too small to make the production profitable (Alabouvette and Steinberg, 2006).

The second possible implementation of soil suppressiveness is conservation biological control resulting in general suppressiveness. The idea is to adapt the soil management and the crop rotation in such a way that soil biodiversity and microbial activity increase, the survival of pathogens is reduced, and abiotic soil properties like soil structure, aeration and nutrient availability are optimized. The goal is to create a functional biodiversity that suppresses plant pathogens and diseases and to optimize parameters like soil organic matter content, pH, and fertility to support plant growth (Alabouvette and Steinberg, 2006).

1.2 Soil and Plant Pathogen Management

Doran et al. (1996) define soil health as "the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, maintain the quality of air and water environments, and promote plant, animal and human health". Soil biodiversity contributes to a large extent to the health of soil and its resilience. Diversity of soil organisms results in high functional redundancy which makes the soil less vulnerable to changes in the environment like for example climate change. Basic soil functions, such as structuring and stabilizing the soil and providing nutrients to plants, can be sustained, even when the ecosystem is disturbed. Organisms stabilize the soil by a multitude of physical, chemical and structural processes, plants have better conditions to grow and single opportunistic organisms are less likely to dominate (Brady and Weil, 2008).

It is evident that abiotic factors determine the basic structure of soil ecosystems. For example, low pH, as commonly found in forests, favors fungus-dominated soil ecosystems, while neutral pH, as found in prairies, promotes bacterial organisms (Brady and Weil, 2008). Management practices like extensive tillage and low crop diversity, on the other hand, favor fungus-dominated soil ecosystems despite the more prairie-like character of the environment (Brady and Weil, 2008, Alabouvette and Steinberg, 2006).

Due to the absence of light in the soil, vast majority of soil organisms are heterotrophic. Hence, microbial diversity and activity is largely affected by nutrient availability mainly in form of soil organic matter and the plants growing in the soil. Other factors like oxygen availability, moisture, temperature, pH, calcium levels, and soil disturbance are directly related to soil biodiversity and microbial activity (Brady and Weil, 2008). Therefore, abiotic soil parameters indirectly affect the potential for biological suppression of plant pathogens, as microbial activity is related to suppression of soil borne plant pathogens (Chen et al., 1988, van Os and van Ginkel, 2001) and similar relations are expected for biodiversity (Reeleder, 2003, Nitta, 1991).

The many different factors affecting microbial diversity and activity in the soil, such as plowing or the type of fertilizer, allow a number of adaptations within soil management in agricultural systems to enhance the pathogen suppressive potential. Commonly, these adaptations are double-edged, causing both positive and negative effects. For example, plowing reduces weeds and accelerates the breakdown of plant material on which plant pathogens can proliferate, but it also negatively affects the soil biodiversity, microbial activity and the soil structure, which reduces the general potential of plant growth (Brady and Weil, 2008). Plant disease management through soil management is mainly a preventive process building on the self-regulating capacity of a healthy soil. However, methods allowing such conditions often conflict with other more common soil management methods (Brady and Weil, 2008). While some benefits and disadvantages become obvious within short time, others take longer periods of time to become noticeable. The management of an ecosystem is very subtle and always demands a viable balance between pros and cons, both in long term and short term (Abrol and Shankar, 2012).

Therefore, pathogen management strategies always need to be integrated methods that considers complex interactions within the management system. During the last decades, we have seen promising progress in ecosystem management with integrated pest management above ground. The underlying principle is to adapt ecosystems based on ecological principles in order to promote positive effects and minimize negative effects. The overall goal is to minimize inputs, in particular of chemicals which are potentially harmful for humans (Guyton et al., 2015) or the natural environment, and to establish a functional biodiversity that provides persistent ecosystem services. It is important for this management system, to notice humans and their needs as an interactive part of the ecosystem itself (Abrol and Shankar, 2012).

However, there is a lack of understanding of the basic underlying ecological principles of soil ecosystems needed to make predictable adaptations for resilient pathogen management. Nonetheless, Stirling (2013) and Stirling et al. (2011) showed that increased soil organic matter and integrated management of plant pathogenic nematodes through adaptation of ecological processes can be more effective and productive than conventional strategies based on pesticides, chemical fertilizers, and extensive tillage. With organic amendments, mulching with crop residues, and crop rotation, it is possible to increase soil biodiversity and to create a balanced soil food web that effectively reduces the number of plant pathogenic nematodes to an economically viable level (Stirling, 2014). Although Stirling is aiming on nematodes the principles are very general and can possibly be also applied for control of filamentous pathogens.

To test this theory, for this study the oomycete *Pythium ultimum* was used. *Pythium ultimum* is one of the most common agricultural soil-borne pathogens that is pathogenic on many crop plants and can cause different diseases like for example damping-off and root rot diseases in wheat that especially affect plants in the seedling stage (Hendrix and Campbell, 1973). A lot of research has been done on *Pythium ultimum* disease suppressive compost media leading to the conclusion that suppression is mainly biologically mediated and related to microbial activity (Scheuerell et al., 2005, Chen et al., 1988, Chen et al., 1987). The ubiquitous character of the pathogen and the wide host spectrum make it a good model organism to represent soil-borne pathogens in this research.

1.3 Agroecology

The term agroecology has been defined in a number of ways, which can vary across areas of the world. Depending on place and context, agroecology can be framed as a scientific discipline for holistic agricultural research, a social movement for democratization and sustainability, or a practice for improvement of rural livelihood and sustainability. Generally, agroecology comprises all methods and tactics to overcome problems with sustainability and resilience of food systems using a holistic perspective (Wezel et al., 2009).

Agroecology offers an alternative approach to food and fiber production based on holistic analysis of complex situations in farming systems with the goal of finding viable resilient solutions that are adapted to the local farming systems (Altieri and Nicholls, 2005). In terms of research and development, agroecology is the interdisciplinary study of food systems that includes ecological, social and economic elements. People who are affected by certain problems are involved in research and development to collaboratively work to overcome them. The involvement of stakeholders enables researchers to find the roots of a complex problem, rather than its symptoms. The application of the research results in a real life situation is already part of the process. Solutions are built on local knowledge and traditional practices in combination with scientifically based improvements and adaptations (Francis et al., 2003).

The holistic perspective on agroecosystems is a key to finding resilient solutions for problems in food and fiber production. The systemic view of agroecology emphasizes that human actions, whishes, and needs form an integral part of the agroecosystem and states that human interaction with nature is shaped by this. Thus, agroecosystems are interdisciplinary and to include social and economic interactions, even when dealing with a biological problem analysis, is key to successful implementation of research to enhance sustainability and resilience of food production. It is important to analyze the perspective, practice, culture, and economic situation of the people who are affected by changes so they are able and willing to adapt their production methods (Francis et al., 2003). Agricultural production practices, social standards, wishes and ideals, economic goals, and research activities need to co-evolve to overcome systemic problems with sustainability and resilience (Beddoe et al., 2009).

Because of the diverse definitions of agroecology, Wezel et al. (2009) recommend defining the context in which the term agroecology is used. Here I will use agroecology according to the definition of Francis et al. (2003) as the ecology of food systems. Agroecology is defined as the fusion of ecology, agronomy, environmental science, sociology, anthropology, ethics and economics and emphasizes the uniqueness of places and bioregions including the people living there as well as society and nature around. For this, a broad interdisciplinary view that comprises the whole system of food from the farm to the consumer is demanded.

1.4 Systems Thinking

Understanding the complex interactions of agricultural systems to find appropriate solutions without causing new problems elsewhere in both space and time demands a systemic methodology that can identify and handle all the aforementioned important aspects (Checkland, 2000). Systems thinking provides a useful concept to change the researchers view in a way that displays the nature of agroecosystems in a more holistic way (Schiere, 2004).

When studying the individual elements, or subsystems, in isolation, systemic dynamics are not captured and awareness of interactions between subsystems becomes very limited. Finding solutions for systemic problems becomes difficult, because the researcher is focusing on subsystems at a too early stage in the research process. For example, while the direct cause of a biological problem like increasing plant diseases in a crop production system are plant pathogens, the ultimate cause could be due to factors such as economic limitations or lack of knowledge, leading to inappropriate management. Agricultural research needs to cover the different disciplines that interact in the agroecosystem and consider both productivity and impact of new methods in short and long term (Bawden, 1991). Systems thinking is holistic. The observer tries to analyze a system as a whole, including the complex interactions between its elements. The holistic assessment of a problem in a complex system allows distinguishing causes and symptoms on an interdisciplinary level including ecological, social and economic aspects in order to solve the ultimate cause of an agronomic problem (Checkland, 2000).

In order to gain a fuller understanding and take the most appropriate action to approach a problem situation, it is important to determine what is important or unimportant in a system to limit the amount of information that the researcher must deal with to a feasible level. An initial appraisal can be done using a rich picture (Checkland, 2000) or a mind map done as a group brainstorming exercise with the people involved in the problem (Bell and Morse, 2013). Having obtained a broad overview of the problem situation, the researcher is able to zoom in into certain areas of interest to find practical solutions for specific causes of the problem. After this, one can place the solutions in the systems context and find applicable actions to make a change (Ackoff, 1971).

2. Aims and Objectives of this Research

The overall aim of this research was to further the understanding of the topic of suppressive soils by performing an interdisciplinary study based on agroecological principles. It was based on the assumption that there is a relationship between pathogen suppressive soils and soil management (Alabouvette and Steinberg, 2006, Brady and Weil, 2008). The research was made up of a preliminary assessment of whether there is a relationship between soil effects on *Pythium ultimum* disease symptoms and soil management regimes, and a social survey with Swedish farmers on how it may be possible to implement findings in real life farming in Sweden. The research questions were:

- Does soil management affect plant disease suppression of soils?
- Is the trophic structure of the soil nematodes a possible bioindicator for soil effects on plant diseases?
- How do Swedish farmers see the problems of plant pathogens?
- What can be changed in Swedish farming systems to improve ecological pathogen control?

3. Methodology

The research was structured around a series of research activities (figure 1). After a first literature review on suppressive soils and soil borne pathogen management, I made a mind map of the ecological, social and economic factors involved and interacting with soil pathogen management. With the mind map as a guide, I worked out the important themes for this research project. Then, I made a first project plan, which described the aims and objectives of the project and further structured the information to work out specific points of interest for the biological and the social research sections.

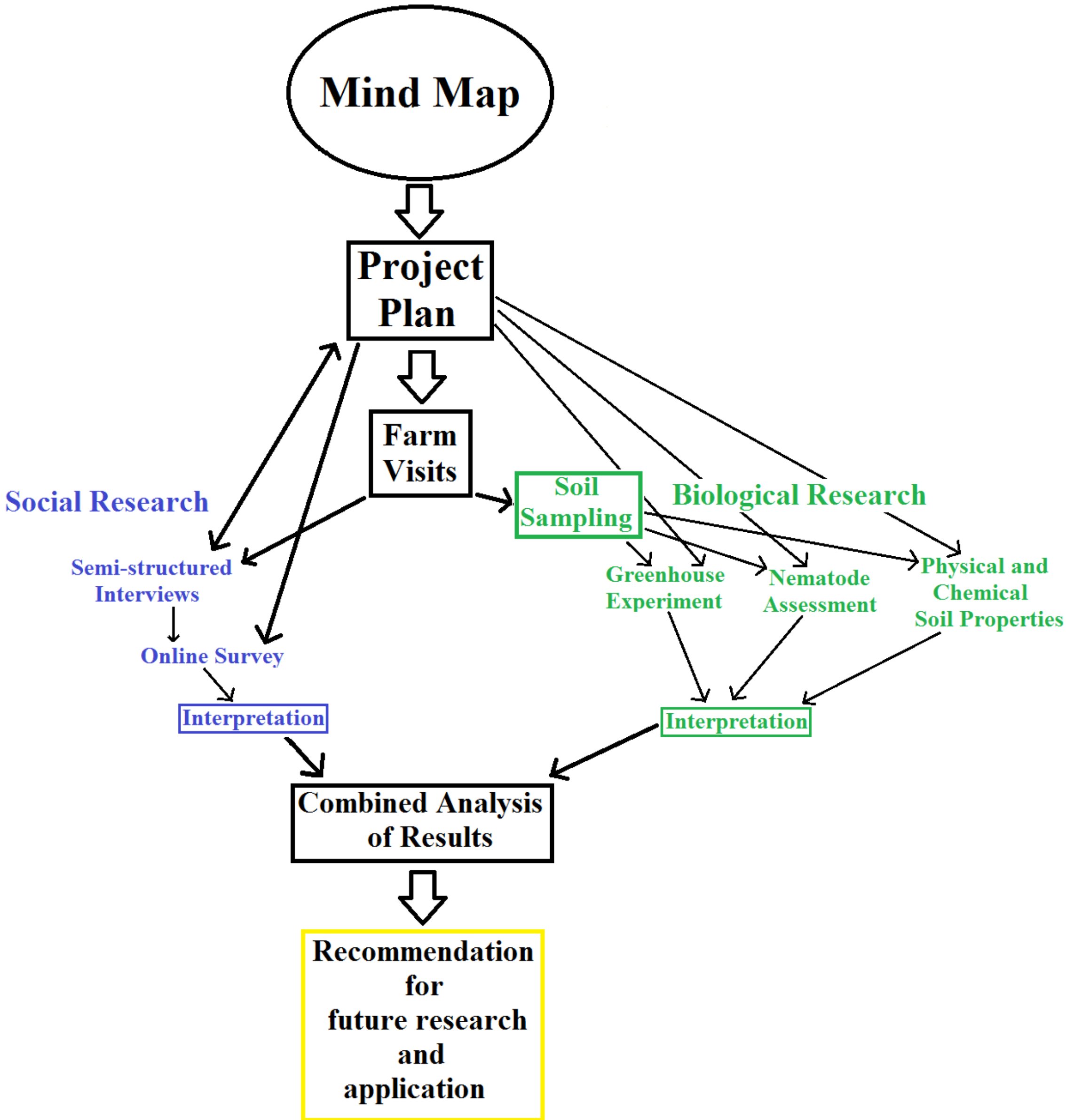

Figure 1: Model of the working progress of the interdisciplinary research for the master's thesis.

To address the biological aspects, I compared different soil management regimes and physical and chemical soil parameters with suppressive and conducive effects of the soils. As a model system, I chose the plant pathogen *Pythium ultimum*, the usual organism of damping-off and root rot on wheat (Hendrix and Campbell, 1973), because symptoms of the plant disease appear during the early growth period. I also assessed and evaluated soil nematode trophic communities for their potential as indicator of soil suppressive or conducive effects, because of their good properties as soil biodiversity and soil health indicator (Bongers and Bongers, 1998).

For the social research, I performed semi-structured interviews with the farmers managing the sites where I collected soil to get information on the management methods of the farm sites and their perceptions, feelings, and knowledge about plant pathogen management. Using the mind map and the gained information on farmers' perspectives from the interviews, I designed an online survey for farmers in Sweden to address the social aspects. After performing and interpreting the biological and social research, I combined the results to work out recommendations for further research and implementation of the results in real farming situations.

4. Material and Methods

4.1 Selection of Sites and Sampling

4.1.1 Site Selection and Classification

We chose farms that differed as much as possible in their methods of production, with special regard to soil management. For each management system, two farms were chosen to be able to compare farms using similar techniques and farms using very different management. However, only one pasture was included to compare the active farming systems with a passive agricultural soil use and only one strip tillage farm was included. Due to the interdisciplinary character of the study it was necessary to keep the number of sites low, but still high enough to get representative results. Ten sites with three replicates per site were regarded both feasible and sufficiently representative for this study. The choice of farms for this research was driven by four basic criteria:

1. The cropping sequence: permanent culture or crop rotation with or without interrupted soil cover.

2. The physical disturbance: frequency and depth of tillage and harrowing.

3. The fertilization: organic or mineral.

4. The chemical soil treatment: direct and indirect contact with synthetic or organic certified pesticides.

Most farms used for the project were visited by the agroecology master students during their courses. Therefore, it was easier to contact them and it was likely that they would be willing to have a researcher visit them to conduct interviews and take soil samples. The two apple orchards in Österlen, Apple Conventional 1 and Apple Organic 1, and the Strip Tillage farm in Gylle were not visited by agroecology courses, but were recommended by colleagues.

To compare the permissiveness of the soil to *Pythium ultimum* with the soil management and the trophic guilds of soil nematodes, I classified the farms according to physical treatment, chemical treatment and fertilization (table 1). The classification does not display a functional separation of the data based on research results, but the high differences between the management systems and the preliminary character of this study allow me to summarize the treatments in few groups.

Table 1: Definition of the soil management criteria to group the ten farm sites used for the biological experiments of the master's thesis.

Physical treatment	
None	No physical treatment - No disturbance of the soil but cutting the grass or human and animal body weight.
Low	Low physical treatment - Harrowing or equivalent to less than 10 cm only once a year and soil compression when harvesting (no sugar beets).
Medium	Medium physical treatment - Plowing and harrowing no deeper than 15 cm and maximum twice a year each, or harrowing to 4 cm more than four times a year
High	High physical treatment - Plowing deeper than 15 cm and harrowing more than two times a year, or harrowing to 10 cm more than four times a year.
Chemical treatment	
None	No chemical pest control.
Low	Little use of herbicides and pesticides - Application only if necessary.
High	Regular use of herbicides and pesticides - Application more than two times a year.
Applied fertilizer	
Organic	Organic fertilizer.
Mineral	Mineral fertilizer.

4.1.2 The Sites

To get information on the management systems of the sites I performed semi-structured interviews with most of the farmers. In two cases face-to-face interviews could not be conducted. Instead, I got the information via email and phone. The information is focused specifically on the fields that were used for the sampling, so the description might not represent the whole farm. The GPS coordinates of the ten different sites were recorded (Appendix 1).

Apple Conventional 1 (AppConv1 / AC1)

Källagården is a conventional apple orchard in Österlen, east Scania, and is situated about 6 km north-west of Kivik. The soil is not mechanically disturbed, and weeds are managed with application of glyphosate several times a year. The trees are fertilized with mineral fertilizers on the ground and on the leaves. There is a regular application of pesticides.

Physical treatment:	None
Chemical treatment:	High
Fertilizer:	Mineral

Apple Conventional 2 (AppConv2 / AC2)

Solnäs Trädgård is a conventional apple and pear producer east of Bjärred, close to the west coast of Scania. The production is 16.5 ha apples and 0.5 ha of pears. For weed management, there is application of glyphosate several times a year, so there is no major mechanical soil disturbance. Mineral fertilizers are applied to the soil and on the leaves and there is a regular application of pesticides.

Physical treatment:	None
Chemical treatment:	High
Fertilizer:	Mineral

Apple Organic 1 (AppOrg1 / AO1)

Kivik Musteri Trädgård is an organic apple orchard, which belongs to the Swedish juice company Kivik Musteri close to the town Kivik. The soil under the apple trees is ploughed several times a year to a depth of six to ten cm to reduce weed growth. Organic certified pesticides are applied regularly and organic fertilizer is applied. During sampling the soil was freshly ploughed, so the disturbance was only a few days old.

Physical treatment:	High
Chemical treatment:	High
Fertilizer:	Organic

Apple Organic 2 (AppOrg2 / AO2)

Dammstorp is an organic nursery plant producer with one ha of additional apple production situated at the north of Malmö. The soil under the apple trees is ploughed several times a year to a depth of about 4 cm for weed management. There is regular spraying with sulfur for pathogen control and to fertilize they use organic fertilizer pellets. During the sampling, fertilizer pellets were lying under the trees and, despite taking care to avoid getting them into the samples, there might be contamination from the pellets. Hence, soil parameters could be affected.

Physical treatment:	Medium
Chemical treatment:	High
Fertilizer:	Organic

Crop Conventional 1 (CropCov1 / CC1)

The farm near the village Annelöv is a conventional crop farm. The crop rotation is sugar beet, barley, winter wheat and winter rape. During sampling, winter wheat was growing. The soil is ploughed once a year, usually to 15 cm of depth, but after the sugar beets up to 25 cm to loosen the soil after the compression during the harvest. The soil is also harrowed twice and then rolled down. The farmer uses mineral fertilizer. There is a regular use of pesticides and herbicides, but the farmer tries to avoid the use of insecticides.

Physical treatment: Medium

Chemical treatment: High

Fertilizer: Mineral

<u>Lönnstorp Research Station</u>

The two sites crop conventional 2 and crop organic one belong to the research station Lönnstorp. The research station is used for agricultural research and it is operated so that the fields mimic on-farm production practices. It belongs to the Department of Biosystems and Technology of the Swedish University of Agriculture (SLU) in Alnarp and the Swedish Infrastructure for Ecosystem Science (SITES) and is mainly used for research from SLU. Situated near Lomma and on the university campus of Alnarp, it comprises 60 ha of conventional farmland and 18 ha farm land which is certified organic since 1993 (Kangro, 21 April 2015). For this project, I collected soil samples from one conventional (Crop Conventional 2) and one certified organic (Crop Organic 1) cropping field of the farm. The soil management has been classified according to a short interview with the field trial manager Erik Rasmusson.

Crop Conventional 2 (CropConv2 / CC2) is situated close to the research farm east of Lomma. The crop rotation is spring barley, winter wheat, sugar beets, faba beans, winter wheat with grass sown in spring, 2 years of grass with clover and winter oilseed rape. Before the soil was taken, oil seed rape was grown. During the sampling there was no ground cover except some very small and spread out weeds. Since 1992 (22 years) the field has not been ploughed, but it is cultivated to 12 cm of depth several times before sowing. The field is fertilized with mineral fertilizers and there is a regular application of pesticides and herbicides.

Physical treatment: Medium

Chemical treatment: High

Fertilizer: Mineral

Crop Organic 1 (CropOrg1 / CO1) is situated on the campus of Alnarp close to research facilities of SLU. The crop rotation during the last five years was oats, two years of ley, winter rape, winter wheat and during the sampling there was winter rape growing on the field. Before that period there was probably also ley and before that the field was grassland. However, the farm manager was not sure about the entire history. The field is cultivated two times to prepare the seedbed, and then it is plowed to 20 cm of depth. Before sowing, it is cultivated twice again. The field is fertilized with organic certified Biofer 10-3-1 fertilizer once a year. There is no use of pesticides.

Physical treatment:	High
Chemical treatment:	None
Fertilizer:	Organic

Crop Organic 2 (CropOrg2 / CO2)

Situated east of Malmö, Hagavik farm produces organic vegetables and crops and also runs a biogas station. The crop rotation in the sampled field is winter rape, winter wheat, beet root, faba beans, winter wheat, oats, white clover sown into the oats for seed production and then oil seed radish which had been ploughed under shortly before sampling. The field had small hills with very moist, uncultivated spots in some places. Soil was only taken from areas that were ploughed and not from the wet spots. The soil is ploughed once every year to about 18 to 20 cm of depth, except when the white clover stays on the field after oats. Further, the soil is cultivated one or two times a year to ten cm of depth and in some crops more often between the rows for weed management. The fields are fertilized with the residues of the biogas plant. No pesticides are applied.

Physical treatment:	High
Chemical treatment:	None
Fertilizer:	Organic

Strip Tillage (StripTill / STC)

The strip tillage farm is a conventional crop farm situated near the village Gylle north of Trelleborg. The sampled field has not been ploughed for at least eight years, when the farmers rented the field. The crop rotation is flexible according to demand and possibilities, but includes grass and clover, winter barley, green peas, winter rape, winter wheat and spring wheat. The field is managed in a way that growing plants always cover the soil. When the samples were taken, there was winter wheat growing on the field. The mechanical treatment of the soil is reduced to a minimum and only where the crops are sown (strip tillage). Soil cores were taken from both, in and between the wheat rows, and thus combines the tilled and untilled areas. The farmers use mineral fertilizer and there is a regular application of pesticides.

Physical treatment:	Low
Chemical treatment:	High
Fertilizer:	Mineral

Pasture (PO)

Tofta farm is an organic dairy farm close to Höör. The farm produces fodder for the cows and has a planned nutrient circulation on the farm. The only external inputs are some straw and some concentrated fodder for the cows. As the farm has got its own crop production, it was included into the interview section, but soil was only taken from a permanent pasture (at least 100 years). The pasture is situated in a small rather moist valley with a ditch in the middle for drainage. Besides cutting the grass, there is no disturbance of the soil except the cows grazing. The only fertilizer that comes on the pasture is manure from grazing cows.

Physical treatment:	None
Chemical treatment:	None
Fertilizer:	Organic

4.1.3 Soil Sampling

All soil was collected between 11 and 21 November 2014. On each farm, one field was chosen for the assessment. Each field was divided into three areas, which were sampled separately as replicates for that site. In all the fields, the soil was sampled using a 2.0 cm diameter soil bore to a depth of 30 cm. For each replicate sample, about three kg of soil in form of about 20 to 30 soil cores was taken in a W-pattern on an area of about 10x20 meter. This method would have been neither meaningful nor feasible in the apple orchards because only the soil under the trees is managed and tree rows were difficult to pass through. Instead, the soil cores were taken from under the trees, where the soil was actively managed. The soil from each sample was mixed in a bucket and then put into labeled plastic bags. After every replicate, the soil bore was carefully cleaned with paper tissues, and before taking the first soil cores for the next replicate, several soil cores were made without adding them to the sample, to further clean the instrument. After taking the samples, they were transported to the department on ice in a Styrofoam box. Samples were stored in a cool room at 4°C in darkness until they were processed.

4.2 Chemical and Physical properties

On 24 March 2015 about 5dl of soil from each replicate sample was sent to Eurofins soil testing lab (Lidköping, Sweden) for texture and nutrient analysis. The assessment includes the pH, phosphorus, potassium, magnesium and calcium content, the potassium-magnesium quotient, soil organic matter (SOM), clay and sand content, the cation (CEC) and anion (AEC) exchange capacity and the base saturation.

4.3 Nematode Assessment

4.3.1 Nematode Extraction

To extract the nematodes from the soil, I used the elutriation method and equipment described by Seinhorst (1962). The elutriator (figure 2) separates particles according to density, shape and size in a water column with steady water upstream. Sand and other heavier particles sink to the bottom of the column while smaller particles are held further up by the water flow. The water is finally separated into three parts by two tabs in the column. The upper part contains smaller nematodes (above the first tab), the middle part contains larger nematodes (above the second tab) and the lowest part contains the heavier particles and virtually no nematodes (under the second tab).

I washed 250 g of soil with tap water through a conventional kitchen sieve into a 2 L Erlenmeyer flask to remove large particles and stones from the soil. After filling the Erlenmeyer flask to the top, the opening was closed with a pipe funnel and a plug. Then the bottle was inverted several times to properly mix the contents before it was put onto the elutriator. After switching on the water flow of the elutriator I removed the plug from the funnel and the soil was separated for nine minutes with 80ml/minute water flow. After this, the water pressure was reduced to 50 ml/minute for another eleven minutes. Finally, the soil was further separated for 10 minutes without water flow. The remaining water-soil suspension was finally removed from the water column in two parts, the first and second tab.

Figure 2: Elutriater after Seinhorst (1962) as it was used for the extraction of the nematode from the soils.

I washed 250 g of soil with tap water through a conventional kitchen sieve into a 2 L Erlenmeyer flask to remove large particles and stones from the soil. After filling the Erlenmeyer flask to the top, the opening was closed with a pipe funnel and a plug. Then the bottle was inverted several times to properly mix the contents before it was put onto the elutriator. After switching on the water flow of the elutriator I removed the plug from the funnel and the soil was separated for nine minutes with 80ml/minute water flow. After this, the water pressure was reduced to 50 ml/minute for another eleven minutes. Finally, the soil was further separated for 10 minutes without water flow. The remaining water-soil suspension was finally removed from the water column in two parts, the first and second tab.

Figure 3: Sieve tower with seven 100 µm width sieves to clean the nematode extract from the elutriator.

The first compartment with the smaller nematodes was sieved with seven special 100 µm sieves (figure 3) while the second compartment was sieved with five 250 µm sieves. The sieves were washed out with tap water through a container with an open bottom covered with two filter papers with the grade 2601. This container was left standing for 24 hours in darkness in a petri-dish with 20 ml of tap water. During that time, the live nematodes moved through the filter paper into the water. The container was removed and the water was then stored in 50 ml falcon tubes in the cool room at 4°C in darkness until they were identified.

4.3.2 Nematode Identification

The soil extract described above was carefully concentrated from about 50 ml to about 10 ml by allowing the solution to settle, then collecting the supernatant with a pipet. Care was taken to minimize the risk that nematodes were removed during this process. During the first few times this was done, the removed water was checked for nematodes. No nematodes were found in these collections.

Concentrated extracts were carefully homogenized and then one ml of the liquid was collected and inspected with a Leitz stereomicroscope with 10x to 63x magnification. The nematodes per ml were counted and the nematodes were placed onto a drop of water on a glass slide and covered with a cover slip. In some cases the cover slip was sealed with nail polish to preserve the nematodes in moist conditions for the next day. Between 60 and 70 nematodes per sample were put on glass plates of which the first 50 to be seen under a Leitz SM-Lux microscope with 25x to 1000x magnification were identified. The number of nematodes per ml was calculated from the average number counted and then rounded to the nearest 0.5 nematodes.

The identification of the nematodes to the family level was made using two different keys. The first key can be found in the Dutch book "De Nematoden van Nederland" of (Bongers, 1994). In unclear cases, especially in the beginning, I also used the key form the web page "The Nematode Plant Expert Information System" (Ferris, 15 October 2012). I had a training day with the nematode expert Maria Viketoft in Uppsala after three weeks of identification work.

Samples were identified in three rounds, following a randomized complete block design to further reduce variation due to misidentification or storage time. After identification to family level, nematodes were separated into trophic guilds according to Yeates et al. (1993).

4.3.3 Statistics for the Nematodes and Soil Properties

For the analysis we used the Statistical Analysis System version 9.4 (SAS Institute, Cary, NC). To analyze the data on the chemical and physical properties of the soil and the soil nematode trophic guilds, we performed two separate principal component analyses. The number of components was selected with the criteria of an eigenvalue higher than 1.0 as recommended by O'Rourke and Hatcher (2013) and according to the location of elbows on the scree plot. We plotted each data point in factor space and considered data appearing in clusters to be similar.

Further, we tested the effect of the chemical and physical properties on the number of hyphal feeding nematodes or the predators and omnivores (high trophic level nematodes) using a general linear model ANOVA. We selected models with forward-, backward- and stepwise selection from terms for the three factors and all their interactions. The number of hyphal feeding nematodes or high trophic level nematodes in each sample was also regressed against the soil organic matter content in a separate analysis.

4.4 Greenhouse Experiment

The greenhouse experiment was part of the course "practical research training", but the results were planned from the beginning to be part of the master's thesis. However, for all biological experiments the same soil was used. To get a better overview of this important part of the thesis I will give a description of the experiment. The original report can be received from the author on request.

4.4.1 Pythium ultimum

Prof. Beatrix Alsanius provided a culture of the oomycete *Pythium ultimum* var. *ultimum* that was isolated from prof. Wohanka at the University of Geisenheim from a tomato plant. Prof. Whohanka visually identified the *Pythium ultimum* and it was later determined with DNA analysis from Dr. André Leveque. The culture was stored on a sealed potato dextrose agar (PDA) petri dish at room temperature in darkness. I activated the *Pythium ultimum* by cultivating pieces from the steady culture on fresh PDA-petri dishes for three days at 25°C in darkness. Then I inoculated V8 liquid agar with PDA-agar pieces from the periphery of the fresh culture for eight days at 25°C in darkness. Wheat seeds were disinfected with silver nitrate after the method of Hoy et al. (1981) and then inoculated with homogenized *Pythium ultimum* mycelia. The wheat seeds where kept on wet filter paper in petri dishes for three days until wheat roots showed clear signs of infection to confirm that the *Pythium ultimum* strain is pathogenic on wheat. A test for zoospores was negative. Five brownish black infected wheat roots were cut of the seed with a sterile blade and put on a PDA-petri dish which was then kept at 25°C in darkness for three days. Dr. Sammar Khalil confirmed that the reisolated culture is *Pythium ultimum* by visual identification. The reisolated culture was multiplied on five PDA-petri dishes as described before and then 66 100ml bottles each with 20 ml V8-agar were inoculated as described before for nine days. Half of the bottles were autoclaved at 121°C for 20 minutes for the control replicates (‘not inoculated’).

4.4.2 The Wheat Seeds

Dr. Georg Carlsson provided certified organic spring wheat seeds of the variety Diskett. He purchased the seeds from Lantmännen in 2012 and the seeds were then stored in darkness at 8°C. Before the seeds were used, they were stored for several weeks at room temperature. The seeds used for the experiment were sorted by hand to remove damaged and very small grains. In a germination test, 20 sorted wheat seeds per dish were kept in ten replicate petri-dishes with wet filter paper on the bottom.

4.4.3 Soil Sterilization

Two trays from each of the 30 samples were heat treated in an oven in three intervals of 6 hours at 65°C with 24 hour resting time between the treatments and before planting. Between the heat treatments, hardy life stages of soil organisms such as spores should have time to germinate and then be killed in the next heat treatment. During the resting time of the heating process the soil was kept moist by adding water if necessary. The other trays were stored at room temperature so that the soil organisms could recover from the cool house period. At a temperature of 65 °C most soil organisms can be killed or substantially decreased in abundance, while there are still thermophile organisms surviving to support the plant growth (Chen et al., 1987).

4.4.4 Design of the Experiment and Working Steps

The experiment followed a factorial design with two levels of soil sterilization (unsterilized and heat sterilized) and two levels of *Pythium ultimum* inoculum (live and killed). To ensure a comparable distance of the wheat plants in all replicates I used a plastic plate (figure 4) with holes, as a guide to make holes into the soil for planting. This plate had 15 holes for the grains in five rows and one hole for the mycelium at one end. For every tray, I used the same plate.

To prevent cross-contamination especially of the heat-treated soils the plate was washed with a chlorine solution after every tray. Further the heat-treated soils were done before the untreated soils.

In order to prevent an overdose of the oomycete, the experiment was set up so the *Pythium ultimum* created a gradient from one end to the other (figure 5). The mycelium was only put into one place at one end of the plant tray, with the five rows of three seeds appearing at intervals between the inoculated and uninoculated sides of the tray.

As planting pots I used aluminum food trays of about 11x8.5 cm bottom size. For each replicate, four trays were filled with about two cm of soil and sealed with a paper lid to reduce evaporation of water during storage time.

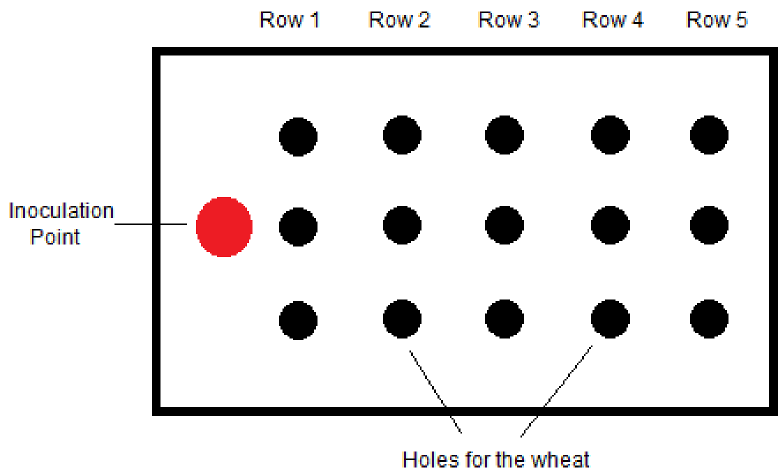

Figure 4: Top view of the design of the hole-plate for the greenhouse experiment to ensure equal position of the wheat grains in all plant trays.

Each 15 wheat plants were grown in sterilized and unsterilized soils and inoculated with one quarter of sterilized or fresh *Pythium ultimum* mycelia from one flask. The plants were watered with tap water when needed. Each of the 40 treatments (10 sites x 2 levels of soil sterilization x 2 levels of *Pythium ultimum*) was replicated three times. To minimize the effects of the position of the trays on the greenhouse bench, the trays were arranged using a split block randomization with three main blocks, each containing all four trays of one replicate of each site. Within the blocks, the four trays with soil from the same replicate were placed together in a random arrangement, so that the distance between the trays of one replicate was as low as possible. The split block system was chosen because the main focus of this experiment was to compare the growth between the different treatments in one replicate.

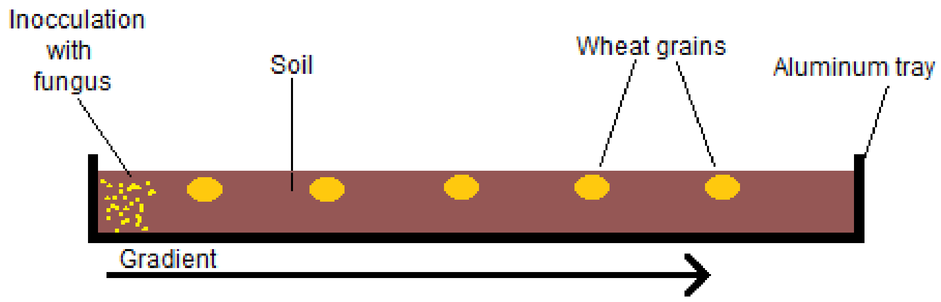

Figure 5: View from the side on the design of the greenhouse experiment. The wheat grains indicate the five rows, each with three seeds.

4.4.5 Determination of Plant Growth

In order to determine the effects of *Pythium ultimum* on plant growth, the fresh weight of the seedlings was measured 10 to 12 days after planting. It was not possible to weigh all 1800 plants on one day, so one block, containing all four treatments of one sample from each site, was measured each day. The four trays of each soil type in each replicate were weighed with as little time as possible between the trays to minimize the effect of plant growth during the sampling day. This way, the effect of further growth of the plants during the day was minimized. The seedlings were carefully dug up and cut off the grain as closely as possible with scissors. The plants were then cleaned with a brush to remove soil residues and then weighed to the nearest of 1/10,000 gram with a Samo Tronic Precisa 80A-200M weighbridge.

4.4.6 Statistics for Greenhouse Experiment

Due to the set-up of the experiment with *Pythium ultimum*, the data was also separated by row (1-5) and position (middle or edge) in each plant tray. With the Statistical Analysis System version 9.4 (SAS Institute, Cary, NC) we performed a GLM ANOVA on the fresh weight of the seedlings, and selected the final model with backwards selection. We also forced the three way interaction of site*heat**Pythium* in order to compare our experimental treatments. The criteria for the backwards selection was $\alpha < 0.05$ for each term that remained in the model. The full model contained terms for the three experimental factors (site, soil sterilization, and *Pythium ultimum*), plus row and position within the seedling trays, with all interactions up to the five way interaction. After the final model was selected, individual contrasts were performed for the significant factors and evaluated at $\alpha < 0.05$.

4.5 Farmer Online Survey

The online survey contained 21 questions and was to be sent out to a large number of farmers throughout Sweden. The purpose of the survey was to gain insight into farmers' practices, knowledge and attitudes in relation to plant pathogens. The questions covered the following:

- Farmers management strategies
- Estimated crop losses due to pathogens
- Time spent on pathogen management (both work and reading/learnig)
- Perceived reliability of different pathogen management methods and their effects on people and the environment
- Farmers opinion about different pathogen management methods

The results should have been used to discuss the possibilities for implementation of the findings of the biological section. It transpired that the survey could not be sent to a representative amount of farmers. A discussion about the possible reasons for this and the implications for this part of the research not being done, can be found in the discussion. Nevertheless, the design of the questionnaire is presented here.

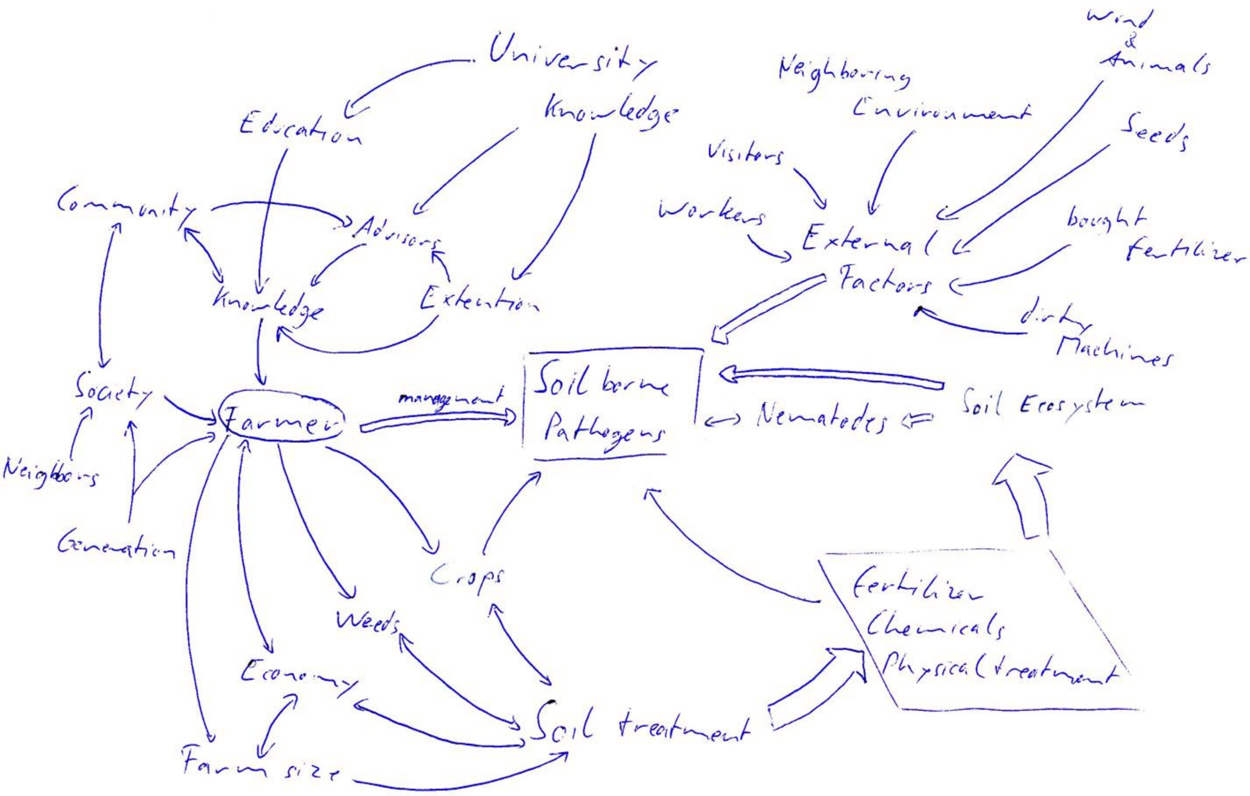

Figure 6: Mind map of factors influencing soil-borne plant pathogens in Swedish farms as it was used to structure and organize the research for the master's thesis.

As part of the initial analytic appraisal to designing the study, I made a mind map (figure 6) based on the literature review to display the systemic relationship between different factors affecting soil-borne pathogen occurrence and proliferation in Swedish farming systems. The focus of the mind map is on factors affecting soil-borne pathogens at the farm level, and was used for organization and coordination of the research.

Wider effects and interactions have been excluded in order to limit the study to a scale appropriate to the objectives of the research question. The mind map includes social interactions, the farmer's knowledge and farming practices, biological interactions on the farm level and some external factors.

The mind map shows a range of interrelated factors affecting soil-borne pathogens in a farming system. The soil ecosystem is an important part of ecological pathogen control mechanisms, and this is directly affected by the soil management practices, weed management, use of pesticides and herbicides and the physical disturbance (Brady and Weil, 2008). The soil management practices employed are, in turn, indirectly influenced by socio-economic factors such as the farmer's knowledge, standards, expectations and economic pressures and limitations.

According to the mind map, a table of interests was constructed (Appendix 3), representing possible topics to include in the study. The different topics were evaluated so that less relevant or not feasible parts could be excluded. This was mainly to keep the questionnaire short, in order to maximize the likelihood that the farmers would take their time to answer (Bernard, 2006). With help of the table of interests I then designed questions in order to answer the research questions. The questions were written in English and then translated into Swedish by myself with help of my co-supervisor and colleagues. I wrote the introduction letter in Swedish with major improvements from my co-supervisor. To publish the online questionnaire, I used SoSci Survey (Leiner, 2014), which is accessible on www.soscisurvey.de. The final survey (Appendix 4) was separated into seven sections:

1. General information
2. Information about the farm
3. How do farmers get information
4. Management methods for plant pathogens

5. Plant pathogens and farm economy
6. Development
7. Lastly

The first two sections covered general questions about the farmer and the farm to be able to classify the farms and the information. In section three, I intended to assess how farmers gain access to new information. Sections four and five constitute the main part of the survey, with detailed questions about pest management methods applied and what farmers think about different management methods. The economic aspect is very important here, because it is a major factor for outlining the working space for possible improvements. In the sixth section, I was interested in the personal opinion of the farmers regarding future developments and needs in the sector of plant pathogen management. The last section is not related to the actual research, but here farmers were given the possibility to independently propose research questions to researchers or to tell them what their interests are. In the long term, these research questions should have been used to work out a data base for researchers.

4.6 Semi-Structured Interviews

When the soil was collected, semi-structured interviews were carried out with some of the farmers. The intention of the interviews was twofold:

1. To gain detailed information on the production and management of the farms.
2. To gain information from farmers for designing the questionnaire.

The interviews lasted between 25 minutes and 1 hour 45 minutes, largely depending on the willingness of the farmers to talk or to go into details. Interviews were performed with eight persons on six different farms between 17 and 21 November 2014. Information regarding the farms Apple conventional 1, Apple organic 1 and Lönnstorp research station (Crop conventional 2, Crop organic 1) I gained via short interviews over email and phone, because the farmers did not have time for a longer interview.

The location for the interview was chosen by the farmers and was either in the living room, the dining room or their office. The language for the interview was English, but in some cases Swedish words were used to explain and describe. All interviews were recorded with a smartphone or laptop.

The semi-structured interview format was chosen because of its free and adaptive character. It is a rather interactive type of interview where the outcome depends on both the interviewee and the interviewer. The conversation is more personal and free than in a structured interview and it is possible to get additional information, which has not been considered before (Bernard, 2006). A prepared interview guide (Appendix 5) with key questions was used to ensure that important questions were not forgotten during an interesting and floating conversation (Kvale and Brinkmann, 2009). The interview guide was designed using the same guideline criteria as for the survey questions and was separated into three groups of questions. The first part included general questions about the farmer, the farm, and the work on the farm. In the second part, the focus was on the farm production and management, especially soil- and pest management, but also included the farmers' personal thoughts about different management methods like no-tillage or ecological pest and pathogen control and farmers' awareness of biota living in the soil and the effects of the management on soil organisms. In the third part, there were questions about the social environment like contact and relationship with neighbors. Despite structuring the interview guide, the interviewing was freely adapted to the situation, while the structure was only used sometimes to keep the conversation going.

5. Results

5.1 Greenhouse Experiment

During the germination test before the experiment 194 of the 200 seeds germinated within the first five days. Of the remaining six seeds, four got very moldy so that it was unclear whether they were germinating, and two seeds did not germinate at all. During the next five days there were no further changes observed. Hence, in the test 97% of the seeds germinated. Of the 1800 planted wheat seeds 164 seeds did not germinate at all or grew less than 0.5 cm from the seed without reaching the soil surface. 1636 seeds grew to plants of which the fresh weight could be measured. In total 90.89% of the sown seeds resulted in measurable plants.

5.1.1 Factor Interactions

The effects of all five factors of the experiment and all their interactions up to the five-way interaction on the plant fresh weight of the wheat were tested in an ANOVA model. The final model (table 2) was selected by backwards selection, including all factors that had a significant influence ($p < 0.05$). The three-way interaction soil*heat**Pythium* was included in the final model to allow contrasts between treatments, because it represents the purpose of the experiment.

Table 2: The factors included in the backwards-selected ANOVA model for the analysis of plant fresh weight in the greenhouse experiment and their degrees of freedom, F-values and p-values.

Effect	Num DF	Den DF	F Value	Pr > F
Row	4	1751	1.26	0.2855
Position	1	1751	18.59	<0.0001
Soil	9	1751	76.76	<0.0001
Heat	1	1751	143.53	<0.0001
P. ultimum	1	1751	33.60	<0.0001
Row*Position	4	1751	3.26	0.0112
Soil*Heat	9	1751	2.07	0.0295
Soil*Heat*Pythium	19	1751	1.03	0.4163

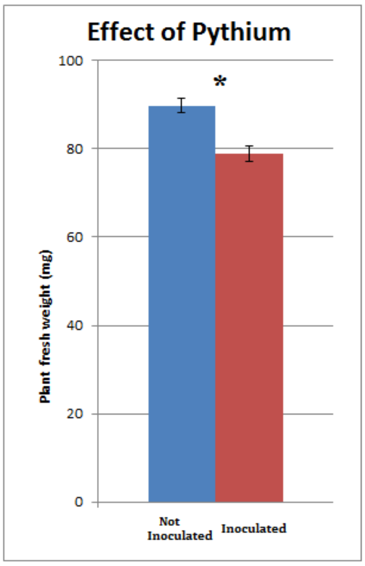

Figure 7: The average plant fresh weight of all non-inoculated trays compared with all inoculated trays from the greenhouse experiment. * = p<0.05

The *Pythium ultimum* var. *ultimum* strain had a significant effect (table 2) on the growth of the wheat variety. On average, the weight of plants exposed to live *Pythium ultimum* was with 10.9 mg significantly lower than the average plant weight of 89.8 mg observed in the uninoculated trays (figure 7).

The position of the plants in the tray had a significant effect on the growth of the plants (table 2). However, the detected differences in growth did not affect the significance of the results, as all plant trays were design in the same way and the statistical model accounted for the position effect.

5.1.2 Effects of the soil

To determine effects of the biological, chemical and physical properties of the soils on disease symptoms, I compared the mean plant fresh weight of the inoculated and uninoculated plants separately for the natural and heat-treated soil from each site. The four different patterns (table 3) show different effects of the soils on disease symptoms. In Scenario 1 can be seen that the soil is suppressive on *Pythium ultimum* disease symptoms and that the effect remains after heat treatment. This means that there is a non-biologically mediated suppressive effect on the pathogen. However, the experiment cannot exclude a biological suppressive effect in addition to the non-biological effect. Scenario 3 is conducive for non-biological reasons, and similar to scenario 1 it is not possible to exclude biologically conducive effects. For scenarios

2 and 4, the detected effects of the natural soil do not occur after partial sterilization of the soil by heat. Hence, in scenario 2 soil organisms generate suppression of disease symptoms, while in scenario 4 soil organisms reverse a non-biological suppressive effect of the soil on disease symptoms. It can be assumed that in scenario 2 and 4 biological effects dominate over possible non-biologically derived effects of the soil on the disease symptoms caused by *Pythium ultimum*.

Table 3: The four possible scenarios for the interpretation of the greenhouse experiment. N = No statistically significant difference; S = statistically Significant difference.

	Natural soil	**Heat treated soil**	**Effect**	**Reason**
1	N	N	Suppressive	Non-biological
2	N	S	Suppressive	Biological
3	S	S	Conducive	Non-biological
4	S	N	Conducive	Biological

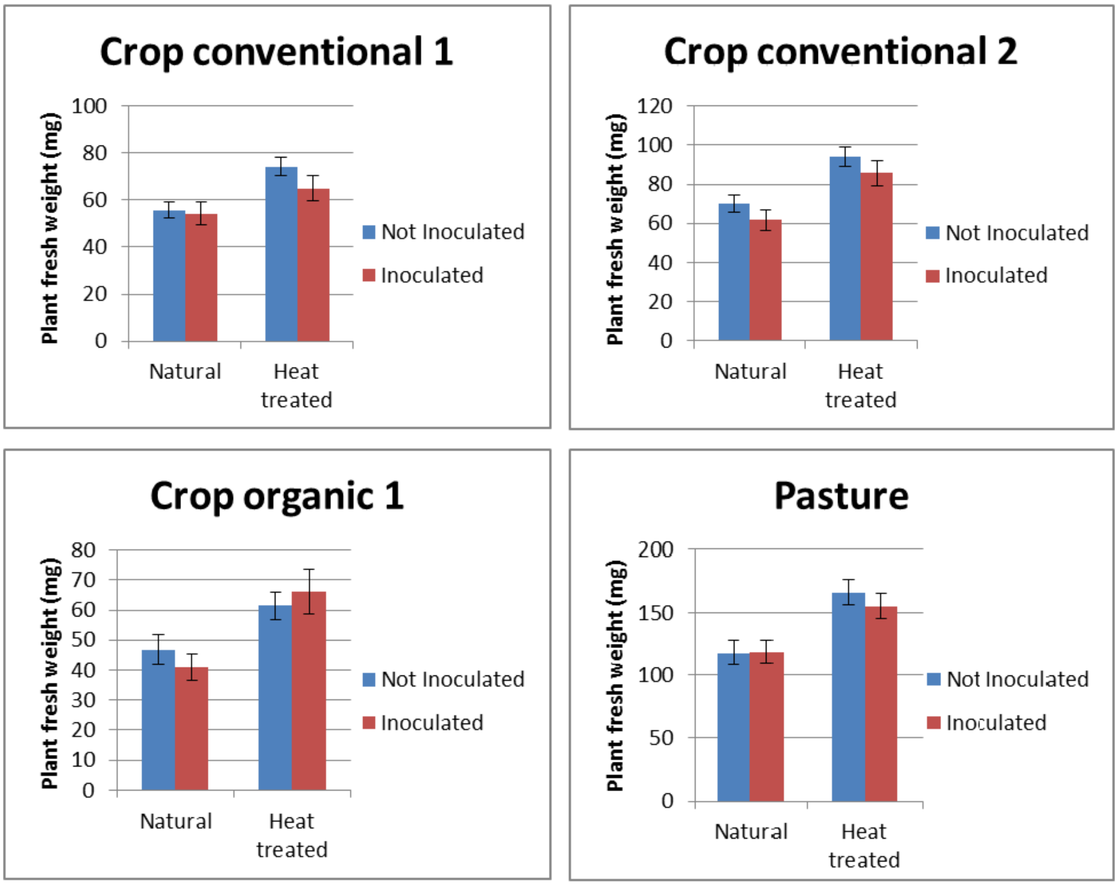

Figure 8: Differences in plant fresh weight of wheat plants grown in heat-treated and untreated soil from the sites CropConv1, CropConv2, CropOrg1 and Pasture with and without *Pythium ultimum* inoculation. * = $p < 0.05$.

For the four farm sites crop conventional 1, crop conventional 2, crop organic 1 and the pasture (figure 8), there was no significant difference (table 4) in plant fresh weight, neither for the natural nor for the heat treated soil. Hence, for these four farm sites can be assumed a suppressive effect of the soil on disease symptoms due to non-biological effects.

Table 4: Degrees of freedom, t - values and p - values of the contrasts between inoculated and non-inoculated trays for the ten assessed sites of the greenhouse experiment.

Site	Natural soil			Heat treated soil		
	DF	t - value	p - value	DF	t - value	p - value
Crop conventional 1	1751	0.18	0.8576	1751	1.08	0.2782
Crop conventional 2	1751	0.98	0.3289	1751	1.01	0.3128
Crop organic 1	1751	0.69	0.4872	1751	-0.56	0.5738
Pasture	1751	-0.11	0.9105	1751	1.29	0.1961
Apple conventional 2	1751	0.32	0.7507	1751	2.35	0.0190
Apple organic 1	1751	1.68	0.0940	1751	2.11	0.0349
Crop organic 2	1751	2.61	0.0092	1751	2.05	0.0401
Apple conventional 1	1751	2.28	0.0226	1751	0.19	0.8460
Apple organic 2	1751	3.28	0.0011	1751	0.87	0.3843
Strip tillage	1751	2.26	0.0240	1751	1.36	0.1726

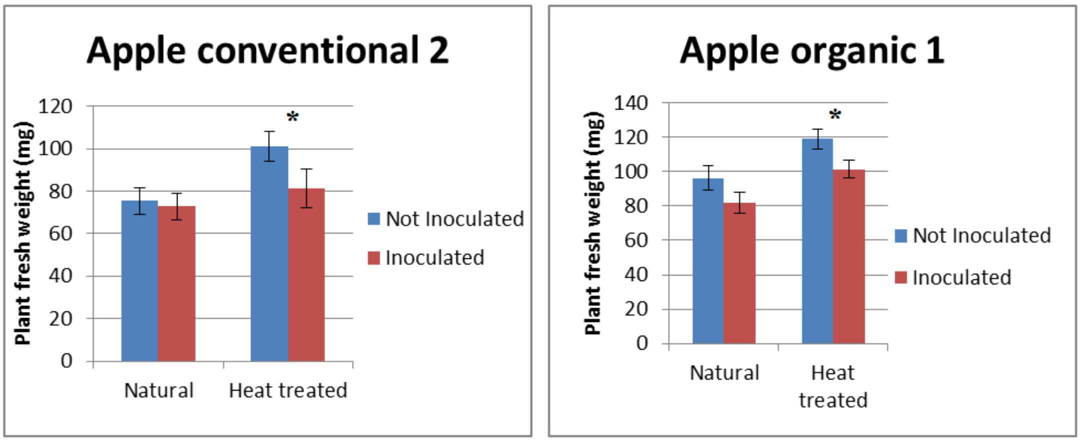

Figure 9: Differences in plant fresh weight of wheat plants grown in heat-treated and untreated soil from the sites AppConv2 and AppOrg1 with and without *Pythium ultimum* inoculation. * = p < 0.05.

For the sites apple conventional 2 and apple organic 1 (figure 9), the difference in plant fresh weight from the natural soils was not statistically significant, while the difference in the heat treated soils was statistically significant (table 4). This means that both apple conventional 2 and apple organic 1 have a suppressive effect on disease symptoms due to biological reasons.

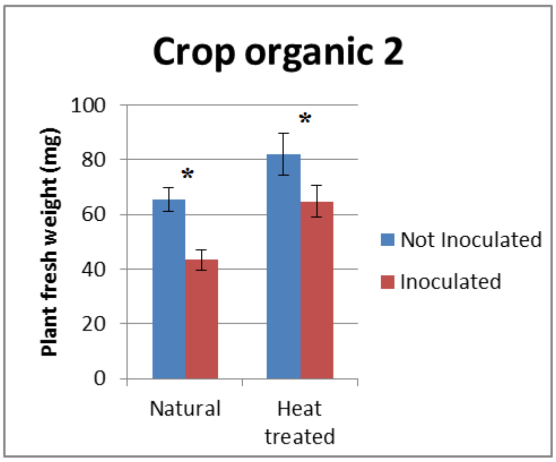

Figure 10: Differences in plant fresh weight of wheat plants grown in heat-treated and untreated soil from the site CropOrg2 with and without *Pythium ultimum* inoculation. * = p < 0.05.

The crop organic 2 farm of the study (figure 10) shows a significant difference in plant fresh weight in both the natural soils and the heat treated soil (table 4). The soil can be classified as conducive due to non-biological reasons.

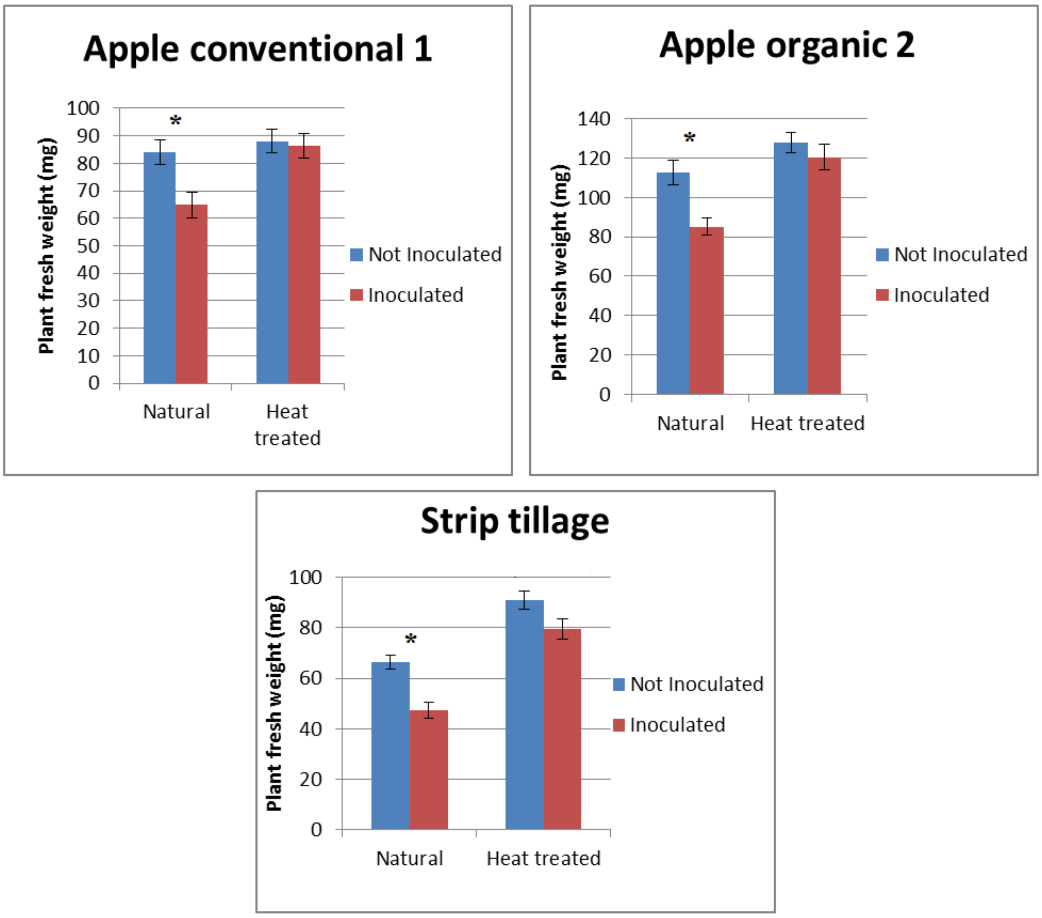

Figure 11: Differences in plant fresh weight of wheat plants grown in heat-treated and untreated soil from the sites AppConv1, AppOrg2 and StripTill with and without *Pythium ultimum* inoculation. * = p < 0.05.

For the three tested farm sites apple conventional 1, apple organic 2 and strip tillage (figure 11), a significant difference in plant fresh weight for the natural soil could be found. For the heat treated soils there is no significant difference in all three cases (table 4). Hence, all three sites can be considered conducive to disease symptoms due to biological reasons.

All possible effects were found in the assessed soils (table 5). Six of the ten tested sites had soil that was suppressive to disease symptoms associated with *Pythium ultimum*, four sites due to non-biological reasons and two sites due to biological reasons. Three sites were conducive due to biological reasons and one site was conducive due to non-biological reasons. The majority of the suppressive effects was due to non-biological reasons.

Table 5: Summary of the effects of the soils from the ten assessed farm sites of the Greenhouse experiment.

	Effect	**Reason**
AppConv1	Conducive	Biological
AppConv2	Suppressive	Biological
AppOrg1	Suppressive	Biological
AppOrg2	Conducive	Biological
CropConv1	Suppressive	Non-Biological
CropConv2	Suppressive	Non-Biological
CropOrg1	Suppressive	Non-Biological
CropOrg2	Conducive	Non-Biological
StripTill	Conducive	Biological
Pasture	Suppressive	Non-Biological

5.2 Soil Chemical and Physical properties

In table 6 below can be found the data gained from the soil analysis of Eurofins soil testing lab.

Table 6: Physical and chemical soil parameters from the laboratory assessment of each three replicates from the ten assessed farm sites. AC = Apple conventional, AO = Apple organic, CC = Crop conventional, CO = Crop organic, STC = Strip tillage, PO = Pasture.

sample	pH	P mg/ 100g	K mg/ 100g	Mg mg/ 100g	K/Mg	Ca mg/ 100g	SOM %	Clay %	Sand %	CEC mekv/ 100g	AEC mekv/ 100g	Base saturation %
AC1-1	7.0	19	17	12	1.4	130	2.3	8	71	9.4	7.9	80
AC1-2	6.2	15	15	8.0	1.9	59	2.7	5	76	7.3	4.0	54.9
AC1-3	6.3	16	15	9.5	1.6	77	1.9	8	70	8.6	5.0	58.0
AC2-1	7.0	33	41	16	2.6	200	2.7	14	60	12.3	12.3	80
AC2-2	6.8	15	49	16	3.1	190	2.3	19	56	13.5	12.1	80
AC2-3	6.8	23	57	17	3.4	190	2.5	16	54	12.7	12.4	80
AO1-1	6.7	22	42	11	3.8	110	3.0	10	64	10.7	7.5	70.0
AO1-2	6.9	16	49	18	2.7	120	2.9	13	56	12.2	8.7	71.3
AO1-3	7.1	20	37	13	2.8	140	2.7	9	66	10.4	9.0	80
AO2-1	7.7	63	48	24	2.0	870	4.7	13	65	15.0	15.0	80
AO2-2	7.0	72	46	14	3.3	320	3.3	13	67	12.9	12.9	80
AO2-3	7.4	78	53	18	2.9	470	3.6	13	66	13.3	13.3	80
CC1-1	7.3	6.5	7.9	6.4	1.2	150	1.6	13	63	10.2	8.2	80
CC1-2	7.8	5.1	9.9	8.0	1.2	190	2.0	14	63	11.2	10.4	80
CC1-3	7.3	27	16	6.9	2.3	140	1.9	8	79	8.7	8.0	80
CC2-1	8.1	11	12	9.2	1.3	600	3.0	17	54	13.9	13.9	80
CC2-2	6.4	8.3	14	6.8	2.1	190	2.5	15	58	12.7	10.4	80
CC2-3	6.1	20	29	6.0	4.8	130	2.7	12	66	11.5	7.7	66.9
CO1-1	7.2	7.5	15	12	1.3	340	3.6	27	43	18.6	18.4	80
CO1-2	6.5	11	10	10	1.0	240	3.1	18	57	15.4	13.1	80
CO1-3	7.7	15	10	6.5	1.5	300	2.8	16	60	13.3	13.3	80
CO2-1	8.0	16	11	7.1	1.5	460	2.3	19	50	13.6	13.6	80
CO2-2	7.8	15	11	7.3	1.5	330	2.8	18	53	14.0	14.0	80
CO2-3	6.9	9.1	9.6	8.6	1.1	320	5.4	14	52	16.5	16.5	80
STC-1	6.8	14	14	5.9	2.4	130	2.1	12	61	10.4	7.3	70.0
STC-2	6.5	11	14	6.0	2.3	120	2.2	12	64	10.6	6.9	65.0
STC-3	6.2	7.1	13	8.1	1.6	100	1.9	11	66	9.9	6.0	60.8
PO-1	6.6	7.1	21	61	0.3	1000	36.1	33	5	82.5	71.7	80
PO-2	6.1	6.1	25	22	1.1	800	36.4	21	3	78.5	55.0	70.1
PO-3	6.4	13	31	26	1.2	450	13.4	19	29	33.7	25.6	75.9

5.3 Clustering of Soil Properties

Principal Component Selection

In addition to the nematode trophic guilds also the physical (content of sand, clay and soil organic matter) and chemical (pH, CEC, AEC, Ca, Mg, Ca/Mg, P and K) soil parameters were analyzed with the principal component analysis in order to find possible patterns for the different management regimes.

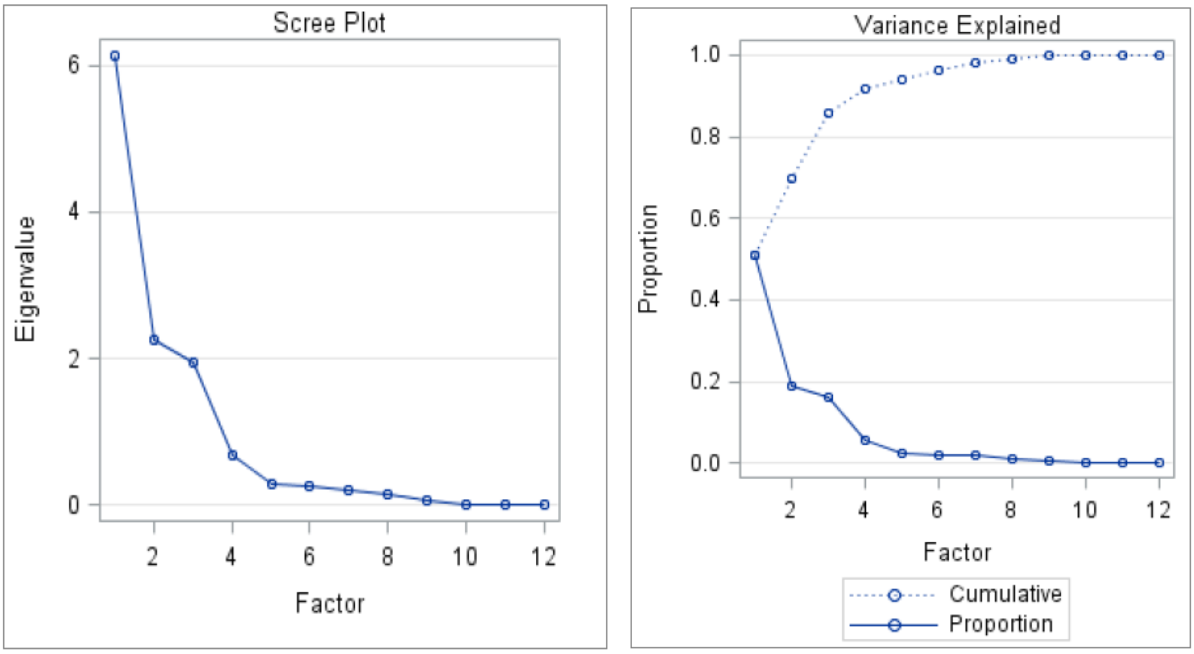

Figure 12: Scree plot and proportion of variance of the PCA-analysis of the chemical and physical soil parameters from the laboratory analysis.

The Scree plot for the soil parameters (figure 12) shows the proportion of variance of the twelve possible components for the PCA. The left graph has two elbows, one at the second principal component and another at the fourth. For the further analysis we chose to use the first three components, all of which had Eigenvalues over 1.0. The cumulative proportion of the variance of the first three components is 85.99% of the total variance.

Loading of Components

Table 7: Weighings of three chosen components for the final PCA model of the soil parameters.

	Component 1	Component 2	Component 3
pH	-0.09248	0.33026	0.87349
P	-0.18664	0.85797	-0.06107
K	-0.01985	0.84637	-0.41515
Mg	0.82912	0.30957	-0.19745
K/Mg	-0.52363	0.51870	-0.48869
Ca	0.83587	0.30609	0.19872
SOM	0.93658	-0.05873	-0.25795
Clay	0.83039	0.03098	0.25098
Sand	-0.94773	0.09387	0.05954
CEC	0.96312	-0.05373	-0.19986
AEC	0.98604	0.02263	-0.08672
Base Saturation	0.24227	0.47153	0.70363

Principle component 1 (table 7) has positive loadings for proportions of magnesium, calcium, clay, soil organic matter (SOM), the cation-exchange-capacity (CEC) and the anion-exchange-capacity (AEC). Negative loadings are related to sand content and potassium-magnesium quotient. Principle component 2 has positive loadings for all parameters except the soil organic matter content and the cation-exchange-capacity. Main influence comes from phosphorous, potassium, potassium-magnesium quotient and the base saturation. Sand, clay anion-exchange-capacity, cation-exchange-capacity, and the soil organic matter content are negligible. Principal component 3 has positive loadings for the pH and base saturation. Negative loadings are due to the potassium-magnesium quotient, potassium, soil organic matter content, cation-exchange-capacity and magnesium content.

Clustering of Soil Parameters

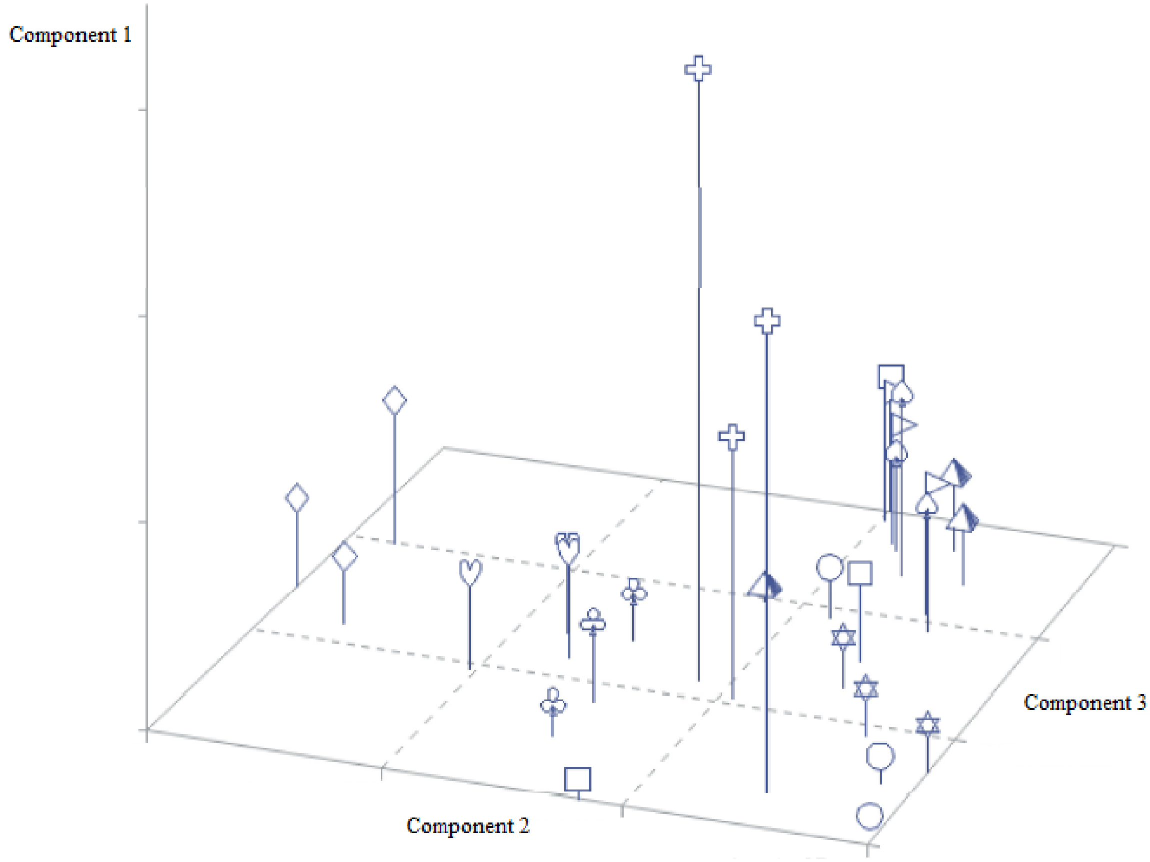

Figure 13: Placement of the individual samples on the 3 principal components describing chemical and physical soil properties. AppConv1 = balloon, AppConv2 = heart, AppOrg1 = club, AppOrg2 = diamond, CropConv1 = pyramid, CropConv2 = square, CropOrg1 = spade, CropOrg2 = flag, StripTill = star, Pasture = cross.

At first glance it is noticeable that component 1 separates samples from the pasture from the rest of the dataset (figure 13). Due to the generally very high sand content and low soil organic matter and clay content in most of the assessed soils compared to the pasture.

Three distinct clusters can be identified in the graph. The first cluster in the upper right corner includes all three samples of Crop organic 1 and Crop organic 2 as well as two samples of Crop conventional 1 and one sample of Crop conventional 2. Three of these four sites showed non-biological suppression on disease symptoms and Crop organic 2 was conducive for non-biological reasons (table5, p. 47). Hence, both suppressive and conducive effects were related to non-biological factors. The low values in the cluster for principal component 2 indicate low proportions of cations in the soil. A high principal component 3 shows high pH values and base saturation and low potassium and potassium-magnesium quotient.

Cluster 1

Non-Biological Effects

High:	**Low:**
- Sand	- Potassium
- Clay content	- Potassium-magnesium quotient
- pH	- Phosphorous

The second cluster can be found in the lower right corner of the graph with each three samples of Apple conventional 1 and Strip tillage and one sample of Crop conventional 2. App conventional 1 and Strip tillage are both conducive for biological reasons, while Crop conventional 2 is suppressive due to non-biological reasons. As the sample of Crop conventional 2 is very close to the first cluster and all three samples of this site are spread out over the graph it will be neglected in the further analysis. The second cluster is associated with low magnesium, calcium, phosphorous, potassium, soil organic matter, clay, pH, cation- and anion-exchange-capacity while the sand content is high.

Cluster 2

Biological Conduciveness

High:	**Low:**
- Sand content	- Magnesium
	- Potassium
	- Calcium
	- Phosphorous
	- Cation exchange capacity
	- Anion exchange capacity
	- pH
	- Clay
	- Soil organic matter

The third cluster is situated in the middle of the graph. Here we can find all samples of Apple conventional 2 and Apple organic 1. Both sites were suppressive due to biological reasons. The cluster also has samples from Apple organic 2 (conducive due to biological reasons), which is situated further to the left, the highest values for principal component 2 and similarly low values for component 3. Component 1 is similar to the average. The phosphorous content is very different between the replicates of the two sites, but the potassium and the potassium-magnesium-quotient are consistently high. The base saturation is in two samples under 80%, but generally over the mean. The soil organic matter and clay content is not conspicuously low, but the cation and anion-exchange-capacity is lower than the average.

Cluster 3

Biological Suppression

High:	Low:
- Potassium	- Cation exchange capacity
- Potassium-magnesium quotient	- Anion exchange capacity
- Base saturation	

Sites with biologically derived effects on disease symptoms, either conducive or suppressive, have high concentration of potassium and magnesium and high potassium-magnesium quotient, soil organic matter and cation exchange capacity. Sites with non-biological effects have high values for pH, base saturation and clay content. The sites with biological suppression are further separated from sites with biological conduciveness. Very high and very low proportions of cations, in particular phosphorus and potassium are associated with conducive effects while intermediate cation content seems characteristic of suppressive effects. The pasture, which is located close to the biological suppressive replicates in components two and three has high proportions of potassium and rather low proportions of phosphorus.

5.4 Soil Nematode Trophic guilds

In the nematode assessment of the soils, 1174 nematode individuals were classified to 38 different families (Appendix 2). The families were then sorted in the 6 trophic guilds predators, omnivores, bacterivores, hyphal-feeding, eukaryote-feeding and plant-feeding according to the classification of Yeates et al. (1993). Seven families accounting for 7.5% of the total nematodes had heterogeneous feeding habits and were assigned to the heterogenic group “unclassified”.

5.3.1 Relations between soil organic matter and nematode trophic guilds

In order to test whether the abundance of the total nematodes, the higher trophic level nematodes (predators and omnivores), or hyphal-feeding nematodes is related to the soil organic matter content, the abundance of each of the three groups was regressed against the soil organic matter content. In most samples, the soil organic matter content was with 1.9% to 3.6%, very low compared to the pasture. Furthermore, there were many samples without any hyphal feeders or predators.

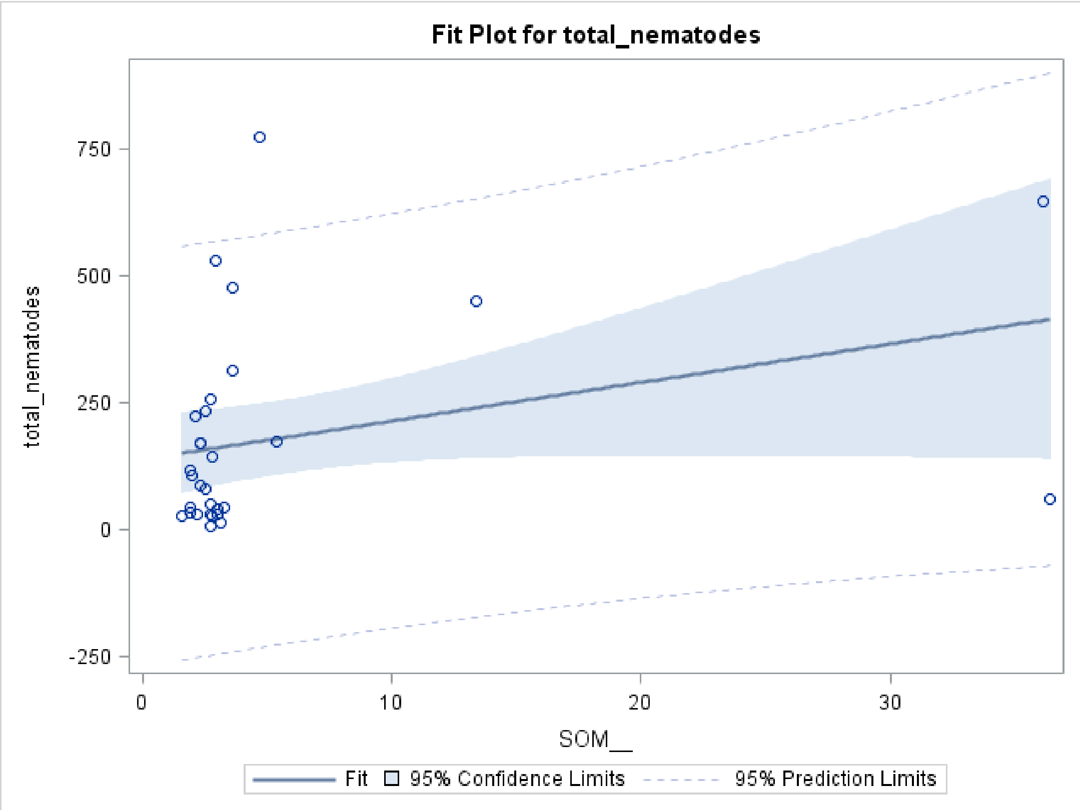

Figure 14: Fit plot of the total nematode abundance found in the 30 soil samples compared to the soil organic matter content.

The t-test whether the slope of the linear regression of the total nematodes is not significantly different from zero (figure 14, slope = 7.5808, t = 1.81, p = 0.0809, R2 = 0.1048). Therefore, we can assume that the abundance of nematodes in soil from southern Swedish farmland is not related to the soil organic matter content.

There was no significant relation between soil organic matter and higher trophic level nematodes (figure 15, slope = -0.1117, t = -0.20, p = 0.8447, R2 = 0.0014).

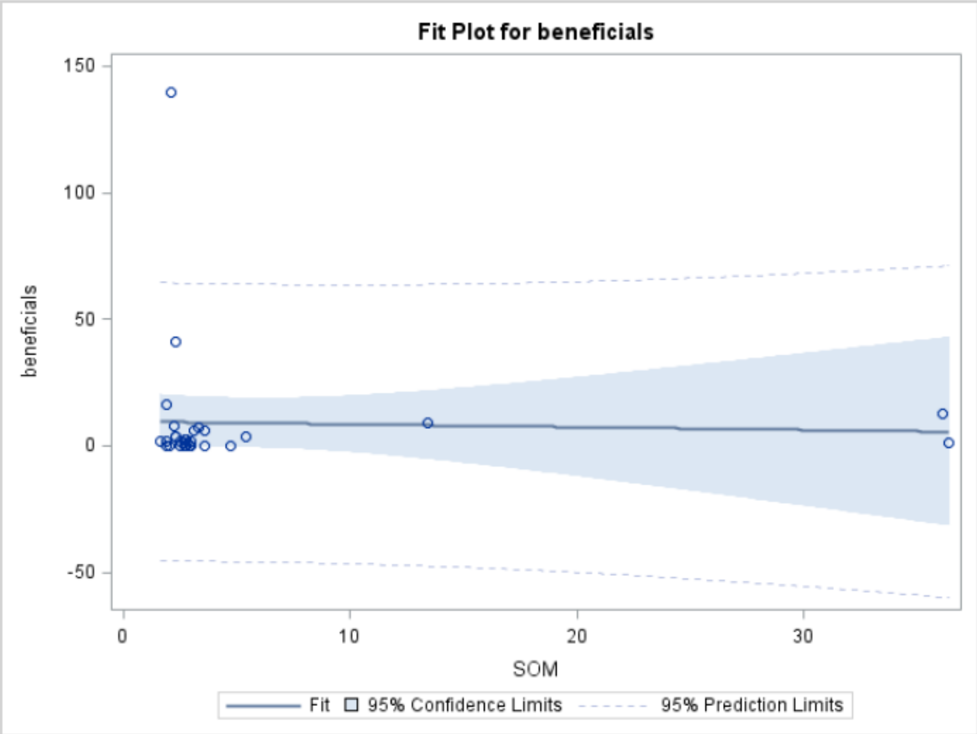

Figure 15: Fit plot of the higher trophic level nematode abundance (predators and omnivores) found in the 30 soil samples compared to the soil organic matter content.

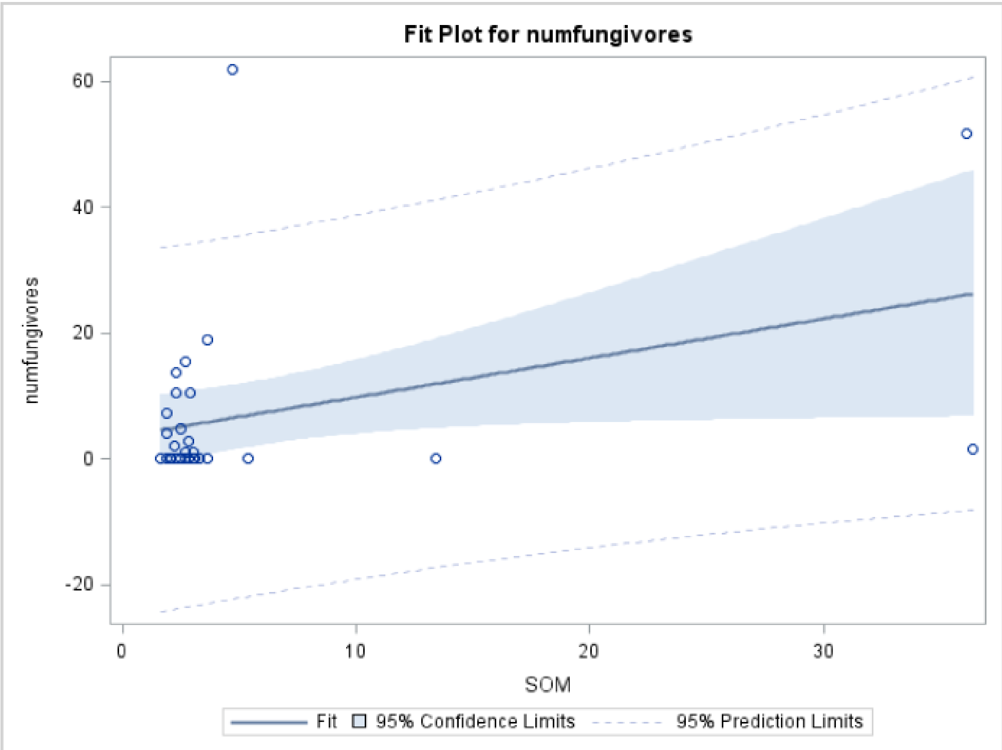

Figure 16: Fit plot of the hyphal-feeding nematode abundance found in the 30 soil samples compared to the soil organic matter content.

The linear regression model of the number of hyphal-feeding nematodes against soil organic matter is statistically significant (figure 16, slope = 0.6226, t = 2.10, p = 0.0450, R2 = 0.1359), showing a correlation between the soil organic matter content and the number of hyphal-feeding nematodes. Hence, the soil organic matter content in southern Swedish agricultural soils is positively related to the number of hyphal-feeding nematodes.

5.3.2 Clustering of Nematode Communities

Principal Component Selection for Nematode Trophic Guild Analysis

The proportions of the population made up of the six nematode trophic guilds and unclassified nematodes, and the total number of nematodes were analyzed in a principal component analysis. The objective of the analysis is to find out whether there are patterns in the structure of nematode trophic guilds. Patterns can then be compared to the results of the greenhouse experiment to find out whether the structure of nematode trophic guilds could be a potential indicator for soil effects on disease symptoms. The SAS program calculated eight principal components for the PCA of the nematode trophic guilds (figure 17).

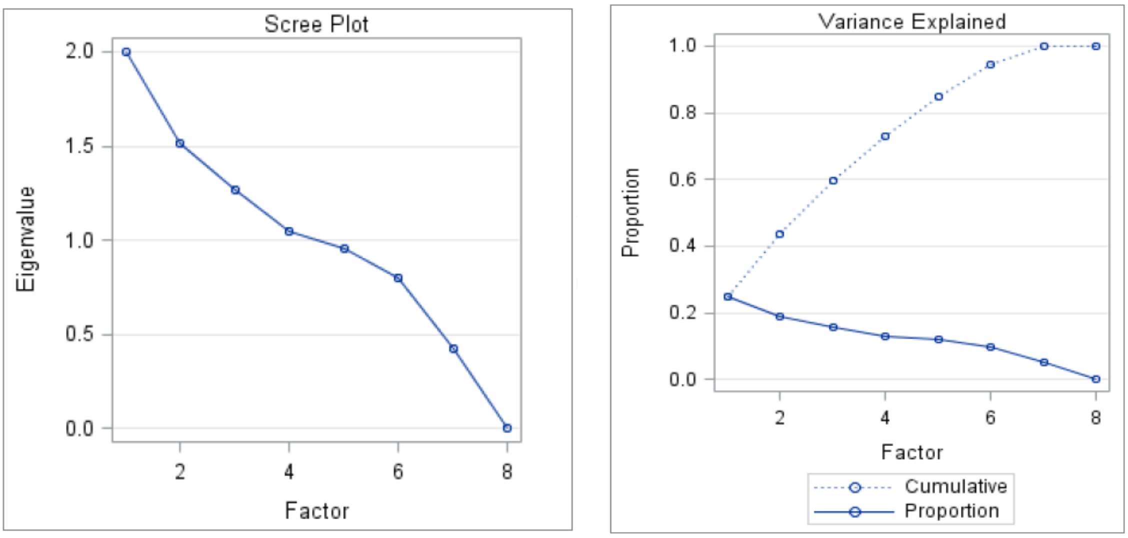

Figure 17: Scree plot and proportion of variance of the PCA-analysis of the nematode trophic guilds.

The eigenvalue of the fourth component is slightly above the common eigenvalue threshold of 1.0 (O'Rourke and Hatcher, 2013) the fifth component is below. The cumulative proportion of the variance of the first four components is 72.8%. Because of the Eigenvalue threshold of 1.0, the first four principal components were chosen for the following analysis. The proportion of 72.8% of the variance was considered sufficient for this preliminary assessment.

Loading of Principal Components

Table 8: Weighings of four chosen components for the PCA-analysis of the nematode trophic guilds.

	Component 1	Component 2	Component 3	Component 4
Total nematodes	0.46919	0.65458	0.07429	0.20491
Plant-feeders	0.84539	-0.29730	-0.32828	-0.13387
Hyphal-feeders	0.39485	0.14536	0.40350	0.00524
Bacterivores	-0.67788	0.68705	-0.05920	-0.23509
Predators	-0.41018	-0.38810	-0.03660	0.81265
Eukaryote-feeders	0.49489	0.40834	0.27366	0.41947
Omnivores	-0.17704	-0.04146	0.73511	0.03936
Unclassified	0.03765	-0.42655	0.60878	-0.31076

Principal component 1 (table 8) had negative loadings for proportions of bacterivore and predator nematodes and positive loadings for the proportions of hyphal-feeders, plant-feeders and eukaryote-feeders as well as the total number of nematodes. Hence, nematodes feeding on autotrophic organisms and filamentous organisms show a positive response on the component, while those feeding on heterotrophic organisms show a negative response. For principal component 2, positive loadings are related to proportions of the total number of individuals, bacterivores and eukaryote-feeders, while negative loadings are due to proportions of predators, plant-feeders and unclassified nematodes. Positive loadings for principle component 3 are due to proportions of omnivores and unclassified nematodes and to a lower extent due to hyphal-feeders and eukaryote-feeders. The component only has negative loadings for plant-feeders. Principal component 4 mainly shows positive loadings for proportions of predator nematodes followed by eukaryote-feeders. Negative loadings are due to proportions of unclassified nematodes, bacterivores and plant-feeders, but all to a very low extent.

Clustering of Nematode Trophic Guilds

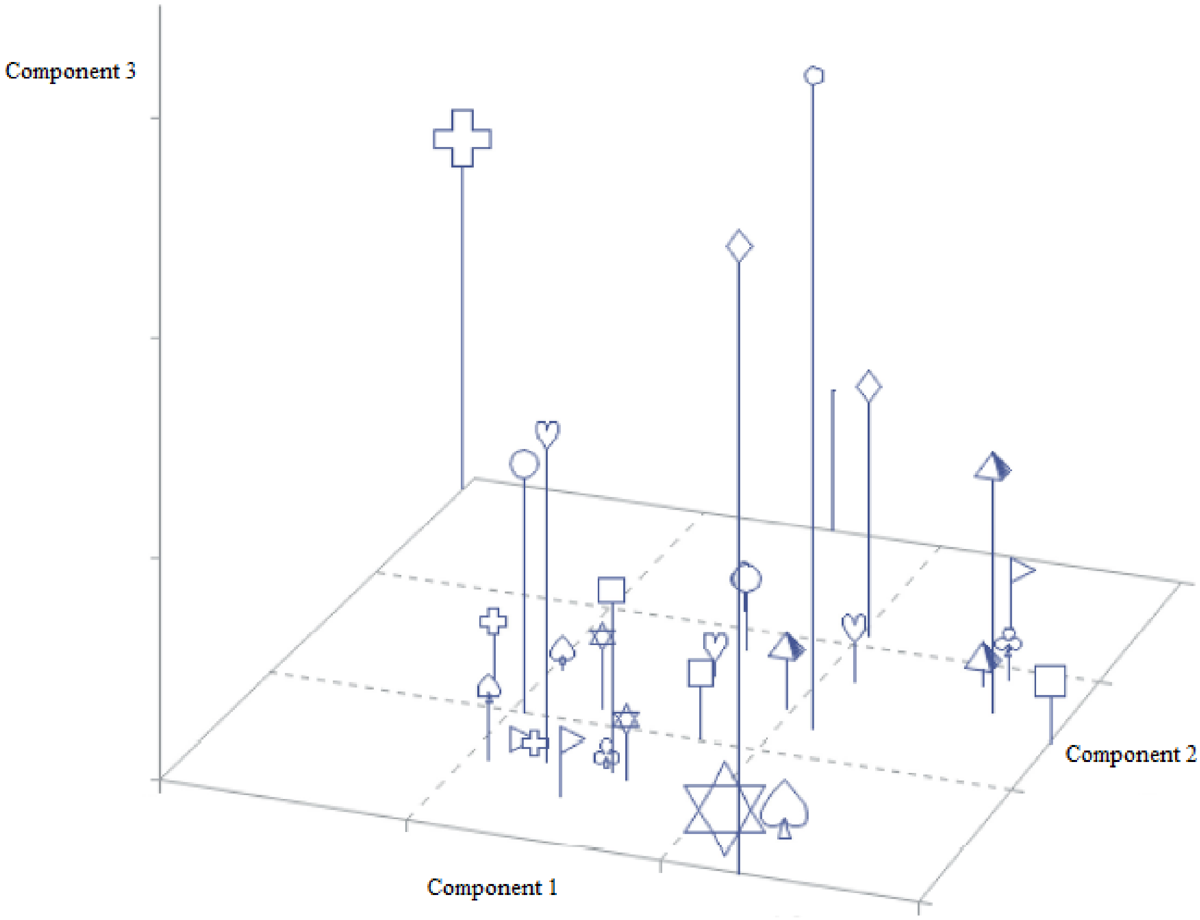

Figure 18: Four dimensional graph of the structure of the trophic guilds from the 30 soil samples resulting from the PCA analysis with components 1-3 on the x-, y- and z axes and component 4 represented by the size of the figures. AppConv1 = balloon, AppConv2 = heart, AppOrg1 = club, AppOrg2 = diamond, CropConv1 = pyramid, CropConv2 = square, CropOrg1 = spade, CropOrg2 = flag, StripTill = star, Pasture = cross.

The samples are well distributed over the four components (figure 18), but most samples have negative values for principal component 3, which indicates a high ratio of plant-feeders to other groups. There are two very small and one slightly bigger cluster. The first small cluster on the right side includes four samples from four different sites (Crop conventional 1 and 2, Crop organic 2 and Apple organic 1). The second small cluster is located in the middle with five samples (Two samples of Apple conventional 2 and one sample from each Apple conventional 1, Crop conventional 1 and Crop conventional 2).

The third, more obvious cluster is located left of the middle of the graph. The cluster includes samples from the Pasture, each two samples from Crop organic 1 and 2, two samples from

Strip tillage and each one sample from Apple organic 1 and Crop conventional 2. The management regimes in this cluster range from pasture over apple to field crops, both organic and conventional. It also includes all kinds of soil management, from very low physical disturbance (Pasture) to very high physical disturbance (Apple organic 1, Crop organic 1 and 2), from no agrochemical use (Pasture) to very high agrochemical use (Strip tillage) and from organic fertilizer (all organic farms) to mineral fertilizer (Strip tillage).

While all replicates from the second cluster are under conventional management neither of the other two clusters have interesting patterns regarding management regime. Furthermore, there are only single replicates from a total of three replicates per site in cluster one and two, except for two samples of Apple conventional 2. Hence, the inter- and intra-field variation were similar and the clusters do not correlate to any of the factors interesting for this study.

5.4 Farmer Online Survey

The on-line questionnaire was sent to a total of eleven farmers of which ten replied within short time and gave detailed answers to the questions. However, due to the small amount of surveyed farmers the results are not representative. Nevertheless, to get a short overview on the value of the social study I will present here the findings from the on-line questionnaire.

All farmers were from Scania, male and age ranged from 40 to 78 years with an average age of 56 years. Six farms were conventionally managed and four farms had both conventionally and organically managed parts. The total farm size ranged from 12ha to 2800 ha but was in general very large with an average of 824.6 ha. The predominant production form of the farms was crop production followed by forest, ley and pasture. Two very small farms (12 and 13 ha) had only pasture.

The ten farmers described different ways of pathogen management on their farms, but in general strategies were combinations of methods including fungicides, crop rotation, certified seeds and pathogen resistant varieties. All ten farmers were relying on fungicides and certified seeds and nine farms outlined crop rotation as one of their main pathogen management strategies. Six farmers relied on pathogen resistant varieties and one farmer outlined hygiene as an additional pathogen management strategy. One farmer with both organic and conventional management crossed among several management strategies also “no pathogen management”.

The estimated loss of yield due to plant pathogens ranged from 0% to 10%, with as many as six farmers described 10% loss. Average estimated loss of yield was 8.13%. More difference was found in the estimated working time needed for pathogen management. Farmers spent very different amount of working time for pathogen management ranging from 0 to 150 hours per year with an average of 76 hours. The additional reading time per year to get new knowledge or information on pathogen management ranged from 3 to 40 hours per year with an average of 15. The total estimated time spent for pathogen management (work and reading) ranged from 10 to 190 hours per year with an average of 91 hours. Farmers generally perceived that both costs and time spent for pathogen management has increased over the last ten years.

The rating of the reliability of different pathogen management methods showed clear trends among the ten farmers. Fungicides was rated as very reliable. Crop rotation, resistant varieties and certified seeds were rated as reliable. Hygiene and biological control methods are seen as rather not reliable and copper is seen as unreliable with the worst ratings. The specific rating questions for the reliability of specific pathogen control methods revealed similar tendencies. All farmers think that fungicides are a generally good pathogen management method. Crop rotation was also rated very positive, but less than the fungicides. Spraying with copper and biological control methods were rated in average neutral with a negative tendency. On the question which pathogen management farmers think is best four farmers named crop rotation. In the additional text field they described that crop rotation works very well and that it is best developed. Four farmers think it is best to apply a combination of methods. One farmer specified in the text field, that combining methods is best in the long term. Each one farmer outlined copper or resistant varieties as best method. Generally the farmers did not observe resistances of pathogens against pesticides in their fields although some farmers perceived a little resistance.

In the questions on whether fungicides can harm people or nature farmers showed very different responses. On average farmers had little concerns about influences of fungicide use on human health or nature. Influence of fungicide use on farmers' health was rated neutral. In the specification whether fungicides can harm people or nature if applied correctly farmers had positive rating. Conventional farmers rely to a large extent on the regular use of pesticides for pathogen control and perceive pesticides as a good and sustainable method if applied correctly.

The question on what could be improved in pathogen management methods also showed very different opinions among the assessed farmers. Three farmers see a big problem in the restricted access to pesticides in Sweden. Two farmers see potential in breeding of more resistant varieties. Further each one farmer sees potential for improvement in inoculation biological control, better prognoses, improved combination of methods or cleaning techniques for seeds.

5.5 Semi-Structured Interviews

Six semi-structured interviews with eight farmers were performed. The length of the interviews varied depending on the interviewees' willingness to talk and lasted between 24 min and 1h 42 min. The pathogen management varied between the different farms. In the apple farms farmers were cutting off infected branches and put them on the ground whenever they have time, but they mainly relied on spraying conventional or organically certified pesticides. Pathogen management strategies in crop production systems included Crop rotation, resistant varieties, plowing down of crop residues, adaptation of sowing time to the weather condition and the use of fungicides. The organic crop farmers mainly relied on crop rotation and plowing activity to control pathogens.

The estimated loss of yield because of pathogens in the apple farms was around 5%. Both the organic and the conventional grower pointed out the risk of high loss of yield in organic farming when conditions are favorable for some pathogens. However, according to the farmers insects represent a higher potential for crop loss in apple production than pathogens. The crop farmers estimated their loss of yield due to pathogens to be around 10%. There were only two organic crop farms included in the social research results, but no difference was found between the estimated loss of yield due to pathogens in conventional or organic management. All farmers emphasized the importance of keeping an economic threshold between loss of yield and pathogen management, as working time, pesticides and diesel use for plowing are costly activities.

Most conventional farmers perceived fungicides as a reliable and sustainable pathogen management method. Nevertheless most conventional farmers were aware of the importance of correct application of pesticides to prevent resistances and tried to reduce the amount of pesticides by applying combined strategies to reduce costs and minimize possible risks for humans and nature. Considerably farmers perceived almost no resistances of pathogens against pesticides. The organic growers on the other hand had concerns about the long term reliability of pesticides and possible effects on human health and nature. However, organic growers also expressed concerns because of the higher needs of diesel for plowing.

Most farmers were not very convinced about the effectiveness of ecological pathogen management approaches, but the organic farmers expressed during the semi-structured interviews large interest in this. Organic farmers seemed to be very restricted in their possibilities for pathogen control. Main strategies are crop rotation and plowing. Considerably, organic farmers seem to rely more on ecological control methods than conventional growers.

6. Discussion

The analysis of the nematodes did not reveal a significant relationship between the total number of nematodes or the higher trophic nematode guilds (predators and omnivores) and the soil organic matter content in agricultural soils in southern Sweden. Stirling (2014) describes that soil organisms in agricultural soils are mainly dependent on carbon inputs and that sufficient inputs of organic matter can increase the soil biological activity and diversity, including the nematode community. However, Stirling is mainly referring to organic inputs in form of crop residues and mulching, while most site assessed in this study used chemical fertilizers or processed organic certified fertilizers instead of manure or plant material. Therefore, the input of carbon and organic material may be too low to see a response in the nematodes. The abundance of predator and omnivorous nematodes is related to the abundance of prey organisms (Stirling, 2014), hence, it is not surprising, that they as well are not related to the soil organic matter content. For the hyphal-feeding nematodes, there was a positive relationship between abundance and the soil organic matter content.

The structure of the nematode trophic guilds of the different farming systems did not reveal any relation to soil management, the types of crops, or the cropping sequence. The variation within the different sites was very high and did not show any logical pattern. A possible reason for this might be that the nematodes were only classified at the family level. Bongers and Bongers (1998) state that a determination at the family level usually provides enough information to study soil functioning. However, in this study, the diversity of families was not used as parameter, but rather the nematode trophic guilds were determined at the family level. While it was possible to classify most families to one trophic guild according to Yeates et al. (1993), some families have less consistent feeding behavior or there are reported contradictory observations. Therefore, about 7.5% of the nematodes could not be assigned to a single trophic guild. The lack of classification for this group may have affected the final results. Further, the soil was taken late in the year and little is known about seasonal fluctuations of soil nematode societies. However, one publication (Renco et al., 2010) indicates that soil nematode societies vary seasonally over the year. Measuring nematode abundances and trophic guilds in Czech hop gardens between May and October over three years, they found a significant relation of the abundance of nematodes to temperature and precipitation. They also found differences in abundance of plant feeders, hyphal feeders, root fungal feeders, predators and omnivores, but not in the abundance of bacterivores during the measured period. The different trophic guilds had different fluctuations over the year, so the composition of the soil nematode trophic community changed as well. Therefore, studies at different times of the year may lead to different results. However, according to the findings of this research the structure of nematode trophic guilds determined at the family level does not correlate with the soil management or soil effects on *Pythium ultimum* disease symptoms and is therefore not a useful indicator of soil suppressive effects.

The greenhouse experiment revealed that the majority of suppressive effects on *Pythium ultimum* disease symptoms was assigned to non-biological effects. Many authors describe suppressive effects on soil-borne plant pathogens in general (Alabouvette and Steinberg, 2006, Chandrashekara et al., 2012, Brady and Weil, 2008) or specifically for composts and *Pythium* spp. (Sullivan, 2004, Hoitink et al., 1997, Chen et al., 1988, Chen et al., 1987) as almost solely biological effects that can be reversed by heat treatment.

This study, however, performed with real farm soils, only found two biologically suppressive soils and four soils suppressive due to non-biological reasons. It cannot, however, be excluded that the samples suppressive due to non-biological reasons have an additional biological effect, but the non-biological effects were sufficient to suppress the disease symptoms without biological effects involved. The general assumption that pathogen suppression is related to ecological processes makes an additional biological effect likely. However, an alternative explanation for these results would be that the heat treatment of the soils was insufficient and the suppressive soils attributed to non-biological effects had biological effects due to recolonization by beneficial organisms within short time after the heat treatment. Chen et al. (1988) described that *Pythium ultimum* conducive core compost heated over 60°C became suppressive within three to four days after inoculation at 25°C and addition of lower tempered edge composts. However, this experiment included inoculation with un-sterilized soil and the experiments of Chen et al. (1987) and Chen et al. (1988) showed that heat treatment of composts over 60°C for five days resulted in *Pythium ultimum* conducive composts while samples from the edge of the same composts with lower temperatures were suppressive. During the whole experiment it was taken care to prevent cross contaminations between the trays, in particular with the heat-sterilized soils and the wheat seeds were planted 24 hours after the last heat-treatment. Hence, it is unlikely that mesophilic soil organisms were growing after the heat-treatment.

While both suppressive and conducive effects did appear in all types of cropping and management regimes, the biological and non-biological effects were related to the cropping sequence. Non-biological effects appeared on all sites where the crop rotation included times in which the soil was not covered by plants (‘Crop’-sites). Biological effects appeared on the ‘Apple’-sites and the strip tillage site with a permanent soil cover. However, two samples with non-biological effects had plants growing on the fields during sampling as well, hence, the observed effect seems to be only related to a permanent plant cover of the soil. The strip tillage site was the only crop farm of a total of five that had a biological effect. The management of this site includes sowing directly after harvesting, hence, as on the ‘Apple’-sites, there is no long period without soil cover. The pasture soil was suppressive due to non-biological reasons despite a permanent cover of the soil. However, the experimental design used does not allow excluding that the pasture had an additional biological suppressive effect on *Pythium ultimum* disease symptoms. Van Elsas et al. (2002) described permanent grasslands as the sites with highest biodiversity, functional diversity and suppressiveness on *Rhizoctonia solani*. The plant fresh weight from all treatments of the soil from the pasture was the highest of all replicates. Therefore, it is likely that the pasture has both biological and non-biological suppressive effects. The results of this study indicate that there may be a connection between cropping sequence and biological effects on *Pythium ultimum* disease symptoms. A possible reason could be the permanent availability of plant roots to sustain soil organisms. Further research is necessary to confirm these results on a larger scale and to draw more detailed conclusions.

Correlation was found between soil effects on *Pythium ultimum* disease symptoms and chemical and physical soil parameters. Sites with high pH, base saturation and clay content showed non-biological effects on *Pythium ultimum* disease symptoms while high potassium, magnesium, potassium-magnesium quotient, soil organic matter and cation exchange capacity were characteristic for soils with biological effects. Sites with biologically conducive effects had either very low cation content, particularly for potassium, magnesium and calcium, or very high cation content, especially of phosphorous, magnesium and calcium. Sites with biologically suppressive soils had intermediate cation contents compared to the biological conducive sites. It is known that high nutrient supply, in particular nitrogen supply, promotes plant pathogen growth and that nutrient depletion makes plants more susceptible to pathogens (Ghorbani et al., 2008). However, due to the long storage time of the soil it was unfortunately not possible to measure the nitrogen content, but similar relations to other plant nutrients could be found. Hence, the nutrient balance and the soil organic matter content probably play a crucial role in the creation of biological suppressiveness.

The results correlate with the general recommendations for soil health management from Brady and Weil (2008), Ghorbani et al. (2008) and Alabouvette and Steinberg (2006). They propose integrated soil-borne pathogen management strategies through soil management that leads to general suppressive soils over the long term. The management should include organic fertilizers and mulching to increase and maintain the soil organic matter content and to create a balanced nutrient supply based on active and diverse soil organisms like beneficial fungi and bacteria. Reduced physical soil disturbance from tillage and a diverse crop rotation that is planned in a way that host plants for the same pathogens are not planted after each other. With the results of this study can be added, that a permanent soil cover probably enhances biological effects.

Ideally, comparative long-term studies would determine whether and which of these practices are effective. However, such studies are both time consuming and costly. Studies similar to this one with real farms, including different management systems and farms that are currently changing their management, might be cheaper, less time consuming, and reflect real-life farming situations with different kinds of influences. Additional long-term experiments could be used to assess for example effects of extreme management regimes with no or very high organic inputs or to assess techniques that currently may not be used by farmers. Studies with real farm soils and farmers may also allow researchers to get additional insights from the farmers themselves on problems and benefits of the processes during the time when they happen. The experience gained would be of high value for further research as well as for the application of the results. A reliable, economically viable protection of crop plants against soil-borne pathogens through suppressive soils could be a large contribution to reduce fungicide use and enhance sustainability.

The strip tillage site is the only crop farm in the experiment with a confirmed biological effect on *Pythium ultimum* disease symptoms. Hence, a future study should compare different conservation tillage, strip tillage and no-tillage systems with different fertilizers and cropping sequences. According to the strip tillage farmer, who is also selling related machinery, Swedish farmers are rather reluctant to apply reduced or no tillage technologies. However, a study of Sattler and Nagel (2010) found that, for north-east German farmers, several factors were important for the implementation of agricultural conservation measures. In addition to economic factors and investment costs, farmers were also concerned about associated risks, effectiveness, time, and effort for the implementation of the methods. Similar opinions might be found in Sweden.

The online questionnaire that was designed to be sent to a large number of Swedish farmers had unfortunately too few participants to be representative and the semi-structured interviews were not in depth enough to be viable for case studies. The semi-structured interviews were intended to supplement the larger survey and be used in conjunction with the information from this and as such were never designed to be sufficient by themselves. The main reason for the failure of the on-line survey was probably miscommunication. As a first approach to find possibilities to send the questionnaire to farmers via mail, an agricultural organization generously offered their help. However, when we contacted the organization after designing and testing the questionnaire for sending it to the farmers, it transpired that they could not send the survey to a larger number of farmers. I attempted to get help from other agricultural organizations to reach more farmers, but was unsuccessful. This issue was realized rather late and unfortunately it was not possible to gain access to a large database of farmers in the time available. Similarly, it was too late to re-think the design of the research to for example, include more semi-structured interviews or conduct group discussions with farmers. Unfortunately, the missing results of the social research largely limit the holistic perspective and the possibility to discuss farmers' real-life situations beyond the anecdotal in this study. With results of the social research it would have been possible to answer the two social research objectives of this project:

- How do Swedish farmers see the problems of plant pathogens?
- What can be changed in Swedish farming systems to improve ecological pathogen control?

At the onset of this research it was envisaged that the results from the on-line questionnaire and farmer interviews would have made it possible to draw an explicit picture of real life farming practices for pathogen control and soil management in Sweden. More importantly, we hoped to gain important insights into their perspectives and priorities to add depth and relevance to the picture of the problem situation. This would have been helpful to design future research projects on disease suppressive soils according to farmers' possibilities, needs and wishes.

As mentioned, it is not possible to draw scientific conclusions from the data gained from the survey and the semi-structured interviews, but some trends were indicated in farmers working methods, opinions and perceptions. For example the described crop loss due to pathogens of about 10% by most farmers and the related high need of time for management would sufficiently justify research efforts towards improvement of pathogen management and development of new methods. Conventional farmers largely seem to rely on pesticide use and were very skeptic towards ecological control. Organic farmers seemed to have very limited possibilities to actually control pathogens. The interviewed organic farmers showed considerable interest in ecological pathogen management methods. Another key issue that many farmers were talking about was weed management.

Generally, the farmers responded very positively on being asked about their opinions and knowledge. Therefore it is likely, despite the little data collected in this study, that there is good potential for Swedish agricultural research to include growers in the research process to enhance both sustainable development and implementation of research results. Although not representative, the questionnaire and the semi-structured interviews led to some valuable insights and indicate both necessity and potential for application of ecological pathogen control methods. Organic farmers seem to be more likely to adapt ecology based approached for pathogen control, but also some conventional growers showed interest. As weed management turned out to be an important topic, ecological pathogen control methods need to be compatible with common weed management practices or new adapted weed management strategies need to be co-developed.

Hence, improved soil health and related disease suppression may contribute to improved pathogen control and increased yields in organic farming. This tendency was also reflected in the question about what farmers would like to improve in the current pathogen management. Many ecological growers mentioned the importance of improving ecological control strategies while many conventional growers saw a major problem in the government restrictions on pesticide use. Further areas proposed for improvement were crop rotation, more pathogen resistant varieties, inoculation biological control, prognoses, combination of methods and cleaning techniques for seeds.

The environmental and social problems connected to agricultural production have created an increasing need for more sustainable production systems worldwide. Food production is embedded into a complex biophysical and social environment (Altieri and Nicholls, 2005) and our surroundings restrict agricultural systems by its physical and biological limits (Hill, 1998). But also people influence agricultural systems through cultural values, practices and regulations (Beddoe et al., 2009). These aspects define our space of action when we perform or adapt food production and they need to be considered when developing new methods for improved production and enhanced sustainability. Therefore, Röling (2009) argues that, to make a change, it is not enough to only develop new ideas, but that researchers also need to take into account the pathways of knowledge and technology transfer into practice. Further he writes that society is confronted with systemic environmental and social challenges that demand interactive changes and adaptations both locally and globally. According to Reynolds et al. (2014) most farmers and stakeholders involved in food production respond very positively to being involved in research and development and similar experiences have been made with this research project. They argue that ecological participatory-research that includes the socio-economic environment is a very good way to improve local and global sustainability by strengthening the local economy while respecting the local limits of food, water and air sheds. According to them, including farmers and stakeholders in the research process reduces focus on economic growth and enhances sustainable development.

7. Conclusion

The structure of nematode trophic communities is not a useful indicator for soil effects on *Pythium ultimum* disease symptoms. The total number of nematodes and the number of high trophic level nematodes was not related to the soil organic matter content, but the hyphal-feeding nematodes were positively related to high soil organic matter content.

While no relationship was found between the soil management regime and soil effects on *Pythium ultimum* disease symptoms, the cropping sequence probably plays an important role. Biologically conducive and suppressive effects could only be found in management regimes with plants growing permanently in the soil including the apple farms, the strip-tillage farm with direct sowing and the permanent pasture. Biological effects could be assigned to high potassium, magnesium, potassium-magnesium quotient, soil organic matter and cation exchange capacity. Non-biological conducive and suppressive effects were found in sites with interrupted plant cover. Non-biological effects were related to high pH, base saturation and clay content.

Biological suppressive effects seem to be distinguished from conducive effects by a balanced nutrient supply and the soil organic matter content. Excessively high or low cation content in the soil was associated with conducive soils. More research is necessary to confirm the described relationships and to determine effects of cropping sequence, soil organic matter, nutrient supply and seasonality on pathogen permissiveness of agricultural soils. For this, studies with real farms including farmers' perspectives similar to this seem to be more appropriate and feasible than comparative long term filed studies on experimental sites.

Social research with farmers may add important information to natural scientific research to ensure purposeful research development and to ease implementation of the results. Particularly, promotion of agricultural practices with low economic returns could benefit from including farmers' perspectives and needs by adapting them to actual possibilities and needs in real life situations.

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Appendix 1: GPS Coordinates of the Ten Farm Sites

Apple Conventional 1	**1**	N 55º 43’ 11.1’’	E 14º 06’ 38.1’’
	2	N 55º 43’ 11.4’’	E 14º 06’ 40.6’’
	3	N 55º 43’ 09.2’’	E 14º 06’ 40.3’’
Apple Conventional 2	**1**	N 55º 43’ 25.4’’	E 13º 05’ 44.5’’
	2	N 55º 43’ 18.3’’	E 13º 06’ 00.5’’
	3	N 55º 43’ 19.6’’	E 13º 05’ 56.0’’
Apple Organic 1	**1**	N 55º 40’ 02.1’’	E 14º 15’ 26.4’’
	2	N 55º 39’ 59.6’’	E 14º 15’ 25.8’’
	3	N 55º 40’ 00.4’’	E 14º 15’ 29.7’’
Apple Organic 2	**1**	N 55º 36’ 03.3’’	E 13º 06’ 14.2’’
	2	N 55º 36’ 04.0’’	E 13º 06’ 16.0’’
	3	N 55º 36’ 03.5’’	E 13º 06’ 17.1’’
Crop Conventional 1	**1**	N 55º 50’ 04.3’’	E 13º 02’ 03.5’’
	2	N 55º 50’ 08.1’’	E 13º 02’ 09.5’’
	3	N 55º 50’ 14.6’’	E 13º 02’ 01.3’’
Crop Conventional 2	**1**	N 55º 39’ 59.2’’	E 13º 06’ 49.7’’
	2	N 55º 40’ 02.8’’	E 13º 06’ 50.7’’
	3	N 55º 40’ 04.1’’	E 13º 06’ 54.6’’
Crop Organic 1	**1**	N 55º 39’ 42.8’’	E 13º 04’ 49.6’’
	2	N 55º 39’ 39.3’’	E 13º 04’ 46.8’’
	3	N 55º 39’ 35.5’’	E 13º 04’ 49.8’’
Crop Organic 2	**1**	N 55º 33’ 41.5’’	E 13º 05’ 21.6’’
	2	N 55º 33’ 47.7’’	E 13º 05’ 12.4’’
	3	N 55º 33’ 43.9’’	E 13º 05’ 04.0’’
Strip Tillage	**1**	N 55º 22’ 35.3’’	E 13º 13’ 51.4’’
	2	N 55º 22’ 38.5’’	E 13º 13’ 48.6’’
	3	N 55º 22’ 41.7’’	E 13º 13’ 33.2’’
Pasture	**1**	N 55º 49’ 33.2’’	E 13º 29’ 46.0’’
	2	N 55º 49’ 35.5’’	E 13º 29’ 49.5’’
	3	N 55º 49’ 39.5’’	E 13º 29’ 48.7’’

Appendix 2: Nematode Families and Trophic Guilds Found on the Ten Sites.

	AC1	AC2	AO1	AO2	CC1	CC2	CO1	CO2	P	ST
Plant feeding	49	59	57	29	27	44	79	63	106	39
Belondiridae	0	1	0	1	0	2	2	0	0	0
Criconematidae	2	0	1	0	0	0	0	0	30	0
Dolichodoridae	25	24	14	16	18	19	10	20	22	31
Hoplolaimidae	0	20	34	0	3	12	20	15	29	2
Nordiidae	0	0	0	0	0	0	0	1	1	0
Paratylenchidae	0	0	0	1	1	0	5	0	6	0
Pratylenchidae	0	1	2	0	2	4	31	7	6	4
Trichodoridae	1	0	0	0	0	0	0	0	0	0
Tylenchidae	21	6	6	10	3	7	11	20	11	2
Tylenchulidae	0	7	0	1	0	0	0	0	1	0
Hyphal feeding	11	8	1	7	0	1	1	0	5	3
Aphelenchidae	2	4	0	0	0	0	0	0	0	0
Leptonchidae	9	4	1	7	0	1	1	0	5	3
Bacterial feeding	44	44	59	71	71	30	16	49	20	10
Cephalobidae	34	35	18	25	44	11	6	5	7	4
Chromadoridae	0	0	0	0	0	0	0	0	2	0
Desmocolecidae	0	0	0	1	0	0	0	0	0	0
Diplogasteroididae	0	1	0	0	0	0	0	0	0	0
Diplopeltidae	0	0	1	2	0	0	0	0	0	0
Diploscapteridae	0	0	0	0	1	0	0	0	0	0
Leptolaimidae	0	0	0	0	0	0	0	0	1	0
Panagrolaimidae	0	0	4	1	0	1	0	0	1	1

Plectidae	5	6	17	6	8	7	2	8	7	2
Rhabditidae	5	2	19	36	18	9	8	36	2	3
Teratocephalidae	0	0	0	0	0	2	0	0	0	0
Predator	8	2	3	5	7	3	4	4	2	35
Anatonchidae	0	0	1	0	3	0	0	4	1	3
Aporcelaimidae	0	0	0	0	0	0	0	0	1	0
Mononchidae	8	1	2	5	3	3	4	0	0	32
Nygolaimidae	0	0	0	0	1	0	0	0	0	0
Tripylidae	0	1	0	0	0	0	0	0	0	0
Omnivores	5	0	0	2	1	0	0	0	1	0
Achromadoridae	0	0	0	0	0	0	0	0	1	0
Campydoridae	0	0	0	1	1	0	0	0	0	0
Thornenematidae	5	0	0	1	0	0	0	0	1	0
Unclassified	3	13	2	22	10	12	9	9	8	0
Aphelenchoididae	0	0	0	1	0	0	1	0	0	0
Anguinidae	3	8	0	16	4	8	8	9	5	0
Monhysteridae	0	0	2	2	3	4	0	0	2	0
Diplogasteridae	0	2	0	2	0	0	0	0	0	0
Odontopharyngidae	0	0	0	0	3	0	0	0	0	0
Tobrilidae	0	3	0	0	0	0	0	0	0	0
Qudsianematidae	0	0	0	1	0	0	0	0	1	0

Appendix 3: List of Interesting Topics for the Social Research

General:

- Age
- Sex
- Part of the country
- education
- Production type (crops, dairy, vegetables, fruit,…)
- Organic/conventional
- Fulltime/part time
- Number of employees/workers on the farm
- Size of the farm? *(might be useful to see trends related to size)*

Knowledge of the farmers:

- About soil-borne pests (SBP)
- Pesticides
- Soil/Soil health
- Ecological interactions (Ecosystem services)
- About different SBP management strategies
- Where does the knowledge come from

Personal soil borne pest management methods:

- Do they have specific SBP management strategies
- Which specific SBP management methods do they have (preventive, curative, protective,…)
- Which other pest management methods do they use (very general: pesticides, crop rotation,…)
- Strategies for keeping costs and time use low? *(if not already too much)*
- On which strategy/method do they rely most
- Weed management strategies? *(would be interesting to know for no tillage systems)*

Personal perception and thoughts:

- About pesticide use (impact on environment, personal health,…)
- Resistances against pesticides in own fields
- About different SBP management methods
- What kinds of SBP management methods do they think are reliable or not (no tillage/tillage, no chemicals/pesticides, ecological)
- About the epidemic potential of agricultural pests?
- About the potential of ecological, nonchemical approaches
- If they get feedback/comments to their methods from neighbors, friends,…
- About economic damage from SBP (yield loss, costs, time)
- About future expectations
- About future developments of problems with SBP

Wishes and improvements:

- what would they like to improve
- How would they like to do this

Final part:

- Do they have other thoughts or whishes they want to share with scientists
- Ask for follow-up phone call/interview
- Ask if they want to see the results → mail address

Appendix 4: On-line Questionnaire

Preview | [default] [barrier-free]

SLU

Galley-proof

The galley-proof shows all pages of the questionnaire in one view using the chosen layout. Like in debug mode, the question IDs will be displayed.

Please note some differences compared to the actual questionnaire:

- Filters do not work on principle,
- questions within PHP code will only be displayed if their ID is static,
- the way the question will be displayed may differ, due to the question IDs, and
- wildcards and dynamic elements can not be seen on principle.

Print View Variable View hide PHP code

Page 01

Hej!

Jag är en masters student som tillsammans med en grupp andra forskare, arbetar med att utveckla metoder för att bekämpa skadesvampar. Att få feedback från er som har praktisk erfarenhet är A och Ö för forskningens relevans. Därför vill vi gärna veta hur Svenska bönder tacklar det här problemet, hur det påverkar er ekonomi och vad ni tycker om olika metoder för bekämpning av skadesvampar. För mig personligen är frågorna i enkäten superviktiga för min mastersutbildning och jag skulle bli väldigt tacksam om du tog dig tid att svara, det tar ca 15 minuter.

Syftet med enkätundersökningen är att få ökad förståelse för hur bönder och odlare runt om i landet ser på problemen med skadesvamp. Frågorna är relativt generella och inte specifika för enskilda grödor. Trots att du kanske bara har problem med skadesvamp på vissa grödor och använder dig av olika kontrollmetoder, så hoppas jag att du kan ge en generell uppskattning av hur du ser på situationen som helhet.

Som tack för ditt deltagande finns möjlighet att få feedback om forskningen. Ange i så fall det i textfältet i slutet av enkäten så kommer jag att skicka en kopia av min masters avhandling när den är klar.

Informationen behandlas konfidentiellt och kommer inte att kopplas till dig som person. Om du väljer att uppge dina kontaktuppgifter så kommer de endast att användas för forskningsprojektet och inte vidarebefordras till någon utomstående.

Tack på förhand för att du tar dig tid att fylla i enkäten!

Med vänlig hälsning

Michael Löbmann

Page 02

Allmän information

Ålder? [PD01]

1. Kön? [PD02]

[välj]

2. Har du en familjebakgrund inom jordbruk? [PB01]

Ja Nej

3. **Vilket typ av jordbruk bedriver du? [FD04]**

[välj]

4. **I vilket län ligger din gård? [FD01]**

[välj]

Page 03

Informantion om gården

5. **Hur mycket mark brukar du? [FD02]**

All mark sammanlagt, inluderat skog, i hektar.

ha

6. **Ange arealen (i hektar) under det senaste året för de olika markanvändningsområderna i listan nedan. [FD03]**

Åkermarksgrödor	ha
Grönsaksodling	ha
Växthusodling	ha
Träda	ha
Betesvall	ha
Slåttervall	ha
Fruktodling	ha
Bärodling	ha
Skog	ha
Annat	ha

Page 04

Hur får du information?

7. **Var vänder du dig för att få information och rådgivning? [PB05]**

Det går bra att kryssa för mer än ett alternativ. Använder du andra rådgivningstjänster så skriv de i textfältet.

- Jordbruksverket
- Hushållningssällskapet
- Lantmännen
- Greppa näringen
- Säljare
- Privata konsulter
- Sociala nätverk
- Familj/vänner

☐ Fler

8. Hur ofta läser du om ny utveckling inom jordbruket? [PB04]
Välj det alternativ som passar bäst.

- ○ Flera gånger i veckan
- ○ En gång i veckan
- ○ En eller två gånger i månaden
- ○ Sällan
- ○ Aldrig

Page 05

Bekämpningsmetoder för skadesvampar

9. Vilka metoder använder du för att bekämpa skadesvampar i din produktion? [MK02]
Välj alla metoder som du använder och skriv i textfältet om du har fler som inte nämns nedan.

- ☐ Ingen bekämpning
- ☐ Fungicider
- ☐ Koppar
- ☐ Varierad växtföljd
- ☐ Hygien (fält och maskiner)
- ☐ Resistenta växtsorter
- ☐ Användning av friskt utsäde
- ☐ Andra metoder

Page 06

10. Vad tycker du om tillförlitligheten av de metoder för bekämpning av skadesvampar som anges nedan? [PT01]

	inte tillförlitligt				absolut tillförlitligt
Fungicider	○	○	○	○	○
Koppar	○	○	○	○	○
Varierad växtföljd	○	○	○	○	○
Resistenta växtsorter	○	○	○	○	○
Hygien (fält och maskiner)	○	○	○	○	○
Användning av friskt utsäde	○	○	○	○	○
Biologisk bekämpning	○	○	○	○	○

Page 07

11. Vilken metod tycker du borde tillämpas som bästa praxis för att bekämpa skadesvampar? [MK03]

Skriv metoden i textfältet om den inte finns i listan.

- ○ Fungicider
- ○ Koppar
- ○ Varierad växtföljd
- ○ Resistenta växtsorter
- ○ Hygien (fält och maskiner)
- ○ Användning av friskt utsäde
- ○ Biologisk bekämpning
- ○ Kombinerad bekämpning
- ○ ______

12. Vad är anledningen till att du litar mest på den metoden? [MK04]

______

Page 08

13. Markera det alternativ som stämmer bäst på frågorna nedan. [PT02]

	inte alls rätt		neutral		helt rätt
Användning av fungicider kan skada människors hälsa.	○	○	○	○	○
Användning av fungicider kan skada bönders hälsa.	○	○	○	○	○
Användning av fungicider kan skada miljön.	○	○	○	○	○
Om fungicider används på ett riktigt sätt skadar de inte människors hälsa.	○	○	○	○	○
Om fungicider används på ett riktigt sätt skadar de inte miljön.	○	○	○	○	○

Page 09

14. Markera det alternativ som stämmer bäst på frågorna nedan. [PT09]

	inte alls rätt		neutral		helt rätt
Fungicider är en bra metod för bekämpning av skadesvampar.	○	○	○	○	○
Att spraya med koppar är en bra metod för bekämpning av skadesvampar.	○	○	○	○	○
Varierad växtföljd är en bra metod för bekämpning av skadesvampar.	○	○	○	○	○

Biologisk kontroll är en bra metod för bekämpning av skadesvampar.	○	○	○	○	○

Page 10

Skadesvampar och ekonomi

15. Uppskatta ugefär hur skadesvampar påverka din ekonomi. [MK06]

Hur stor förlust har du på grund av skadesvampar? [ ] %

Hur mycket tid spenderar du om året på att bekämpa skadesvampar? [ ] arbetstimmar/år

Hur mycket tid spenderar du om året på att lära dig om bekämpning av skadesvampar? [ ] timmar/år

16. Markera det alternativ som stämmer bäst på frågorna nedan. [MK05]

	Inte alls	nästan inte	lite	ganska mycket	mycket
Har du upptäckt resistens hos skadesvampar mot dina bekämpningsmetoder?	○	○	○	○	○
Har arbetstiden för skadesvampbekämpning ökat under de senaste 10 åren?	○	○	○	○	○
Har kostnaden för skadesvampbekämpning ökat under de senaste 10 åren?	○	○	○	○	○

Page 11

Utveckling

17. Vad tycker du kan förbättras eller förändras inom bekämpning av skadesvampar? [PT04]

18. Det finns många olika metoder för bekämpning av skadesvampar, men vissa metoder kan leda till ökade ogräsproblem. Därför är det viktig för forskare att veta hur bönder i Sverige hanterar ogräs. Var god beskriv kortfattat hur du hanterar ogräs i textfältet nedanför. [MK07]

Page 12

Avslutningsvis

19. Som avslutning undrar vi om du har några tankar och önskningar som du vill framföra till forskare. Du kanske har något speciellt område som du tycker att det borde forskas mer på. Du kanske har tankar om hur jordbruket kan förändras och förbättras. Vi vill gärna höra dina åsikter. [FQ01]

20. Ibland kan det vara värdefullt att kunna ta kontakt för att klargöra vissa frågor eller få fördjupad information. Om du är villig att eventuellt bli kontaktad kan du ange ditt telefonnummer nedan. Detta är absolut frivilligt. [FQ02]

21. Om du vill att jag skickar dig en kopia av min masters avhandling kan du fylla i din e-postadress nedan. E-postadressen kommer inte att sparas tillsammans med enkäten. Den kommer endast att användas för att skicka avhandlingen. [FQ03]

E-mail:

Last page

Tack så mycket!

Dina svar har sparats, du kan stänga webbläsarfönstret nu.

B.Sc. Michael Löbmann, Sveriges Lantbruktuniversitet (SLU) - 2015

Appendix 5: Interview Guide

General Questions:

Which crops do you grow?

How big is your farm?

Which soil do you have?

How much soil organic matter does your soil have?

Where do you get the knowledge about your methods from?

Do you work full time/half time on the farm?

How many people are working on the farm?

Management:

How do you treat the soil?

Do you have problems (crop loss) with soil borne fungal pests?

Do you have specific soil borne pest management strategies?

Which further pest management strategies do you have (for other pests)? (Short)

- Where do you apply pesticides?
- Do you have problems with resistances of pests against pesticides?

On which pest management strategy/method do you rely most? (Why?)

What do you think about ecological pest management approaches? (Are they reliable?)

Do you think, according to your experience, that the soil has got effects on pest appearance? (Why?/why not?)

How do you manage the weeds?

What do you think about no tillage systems?

What would you like to improve in your pest management?

How would you like to do this?

How do you get knowledge about new methods or developments?

Social/Private questions:

Do you have contact with neighbors or other farmers?

What do they think about your farm management? (Pesticide use, organic approach,…)

What are your future expectations of new pest management strategies?

How do you think will the problematic of fungal pests change in the future?

Do you have any thoughts or wishes for/to researchers about fungal pest management?