Economic impact of ‘Candidatus Liberibacter Solanacearum’ in carrot farming in the EU

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Abstract
In this study the economic impact of ‘Candidatus Liberibacter Solanacearum’ (Calsol) in carrot farming in the European Union is investigated.

First the economic value of carrot farming in the EU is assessed. This value and hence the value at risk for Calsol is €1,727 million.

Information on the agronomic impact of Calsol on carrots is in this study obtained from a survey among experts set out within the EU Horizon2020 research project Pest Organisms Threatening Europe (POnTE). This survey indicated that at this moment (2018) only Finland is experiencing impact of Calsol within its carrot production.
To investigate the impact of Calsol three different scenarios are evaluated by means of stochastic partial budgeting to study the economic impact within the Finnish carrot production:
Scenario 1: situation without presence of Calsol (Baseline)
Scenario 2: situation with presence of Calsol and its vector(s)
Scenario 3: situation with presence of Calsol and control strategies

These scenarios are simulated with @Risk modelling to account for uncertainty in the data. The simulation found for the first scenario; the economic value of carrot farming in Finland (area x yield/ha x price) represents an average value of €46 million. The true value is likely to be between 38 and 56 million by a 90% confidence interval (CI).

Within the second scenario the average economic value of carrot farming in Finland with Calsol equaled a value of €27 million. Calsol is causing around €19 million damage in Finland, at this moment. This 40% of the economic value in carrot farming in Finland.

At this moment, spraying with insecticides is used in Finland by 75% of the Finnish farmers, while netting is only used by 5% of the Finnish farmers. When this situation is simulated, results did not alter much in comparison to scenario 2; current risk mitigation approach is not preventing the economic impact of Calsol.
The use of risk mitigation options is evaluated in scenario three by evaluating 100% use of insecticides or netting. Under the use of spraying with insecticides the average economic value of carrot production equaled €28 million (90% CI = [€19, €39 million]). The risk mitigation option netting resulted in an economic value of €44 million (90% CI= of [€34, €55 million]). These values show that the use of netting is economically more justified than spraying with insecticide.

Because the use of netting is economically justified, farmers are likely to adopt the use of netting. It is therefore unnecessary to impose European regulation to ensure the use of risk mitigation methods against Calsol.

Key words: Carrots, the EU, EU countries, Candidatus Liberibacter Solanacearum, Stochastic Simulation

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List of Abbreviations

Calsol= Candidatus Liberibacter Solanacearum
EU= the European Union
POnTE= Pest Organisms Threatening Europe
FAO= Food and Agriculture Organization of the United Nations
WTO-SPS= WTO agreement on Sanitary and Phytosanitary Measures
IPPC= International Plant Protection Convention
ISPMs=International Standards on Phytosanitary Measures

1. Introduction

1.1. General introduction

'Candidatus Liberibacter Solanacearum' (Calsol) is a bacterial plant pathogen that has an effect on the families Solanceae (potato, tomato, sweet pepper and tobacco) (Liefting et al., 2009) and Apiaceae (carrot, celery, parsley and parsnip) (Ben Othmen *et al.*, 2018). The bacterium is primarily spread by psyllid insect vectors.

Five haplotypes of Calsol are currently found in the world (A, B, C, D, and E) (Teresani *et al.*, 2014). Haplotypes A and B are associated with diseases of potatoes and other solanaceous crops, and are transmitted by the psyllid Bactericera cockerelli. These haplotypes cause big yield and quality losses in America and New Zealand. For example, in America Texas Calsol caused an annual potato yield loss of 33 million dollars, this is about 25 million euro (CNAS, 2009). In Europe these haplotypes and their vector have not been detected yet. Soliman (2012) estimated the direct impact on potato and tomato producers in case of an infection of Calsol would appear in Europe around 222 million euros per year.

In Europe, only the presence of the haplotypes C, D and E has been confirmed and is associated with carrot, celery and parsnip disorders (Teresani *et al.*, 2014). Haplotype C has been found in Finland and is transmitted by the psyllid Trioza apicalis (Munyaneza et al., 2010), whereas haplotypes D and E have been found in Spain, France and Morocco (Tahzima *et al.*, 2014; Teresani *et al.*, 2014), and the main vector seems to be B. trigonica, at least in Spain.
Recently haplotype U is found in stinging nettle in Finland. This one is completely distinct from the haplotypes found in Solanaceae or Apiaceae (Haapalainen *et al.*, 2018).

Calsol has an impact on quantity and quality of a crop (Soliman, 2012). Impacts in carrots are reduction in leaf weight, curled leaves and notably less root weight. Furthermore discoloration, reduced growth in the shoots, and secondary root proliferation are effects. Infections in carrots can cause up to 100% losses (Munyaneza et al., 2010), indicating a threating impact on the carrot industry in the European Union (the EU).

1.2. Problem description

The different haplotypes among the European countries have different vectors and might have different impacts. Knowledge about the economic impact of Calsol haplotypes C, D and E on the carrot production in Europe is currently lacking. This knowledge is, however, crucial for continuity of the carrot production. An economic risk assessment for Calsol in carrot production in the EU is therefore needed.

Various risk mitigation methods to prevent and control Calsol in carrots are already applied. The quantity used of risk mitigation methods for Calsol will become updated in this research. It is unknown if these risk mitigations methods are economically justified, this will also be assessed.

1.3. Research objective

The main objective of this research is to assess the economic impact of Calsol on carrot production in the EU.

1.4. Research questions

This objective will be answered by the following research questions:

1. What is the economic value of carrot farming in the EU?
2. What is currently the economic damage of Calsol in carrot production in the EU?
3. To what extent are risk mitigation methods for Calsol in carrots applied among the EU?
4. To what extent are the applied risk mitigation measures economically justified?

1.5. Outline report

The first chapter gives a general introduction of the plant disease Calsol. Furthermore it gives the problem description of this master thesis together with the research objective and research questions. The second chapter gives background information concerning carrot farming from seeding to harvesting of the carrots. Furthermore it gives information about the legislation of plant health and risk mitigation for Calsol. In the third chapter the material & methods as applied in this study are described with first the methodology design and then the method for each research question separately. Chapter four gives the results from the study per research question. Findings are subsequently discussed in chapter five and main conclusions are drawn in chapter 6.

2. Background information carrot farming in the EU

2.1. Cultivation of carrots

The Latin name of carrot is '*Daucus carotus*'. Nantes (Figure 1) is the most common carrot variety that is cultivated for 40% of the total carrot production in the world.

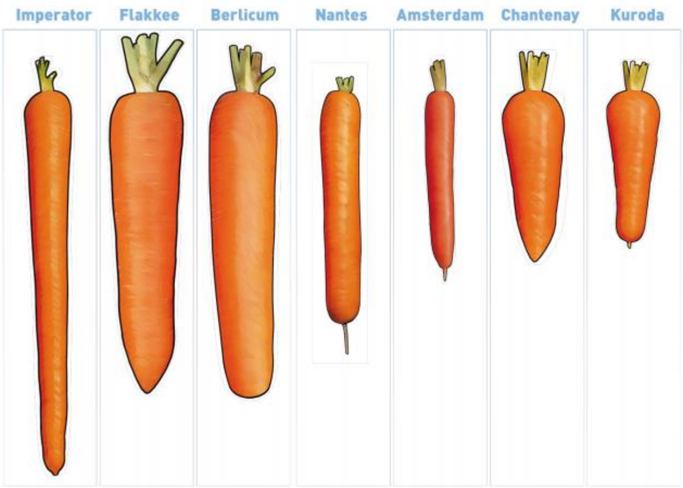

Figure 1 Carrot varieties (Bejo, 2017).

Carrot is a biennial crop, in the first year it will form the carrot root and in the second year after a respectable cold period, the carrot will start flowering and produce new seed. The carrot that will be produced for industry is mainly grown on sandy soils. Carrots for storage are cultivated on sabulous clay and light clay soils. Beneficial for the yield and quality is soil where the crop can grow its roots in depth and where there is enough water. Although too much water carrots will turn out pale, with short roots, will have less taste and contain less carotene. Carotene is a substance that will transform to vitamin A inside the human body. How stronger the orange color of the carrots, how higher the carotene level (*Verschil Bospeen Wortel*, no date).

2.1.1. Carrot seeding

One gram of seed can contain on average 1,000 seeds of 2-4mm long. The seed can already start the germination by 1.3 Celsius degrees. Therefore around 85-200 days with these degrees are needed for 90% of growth (Stichting TOG and Heijnen, 2018; Bejo, 2019).
A pneumatic seeder is a machine that can seed the carrots, as in the picture below. This machine makes use of a vacuum to put the seeds at a constant and precise spacing in the row.

Figure 2 Carrot seeding

Seeding is done between the beginning of March and the beginning of June. Grains can be sown among the carrots to prevent dusting, these can later be removed with herbicide. Lately paper pulp is also used for this. Carrots on sandy soil are seeded on beds. When the soil is sabulous –and clay the carrots are seeded on ridges.

2.1.2. Growing

The growth of the carrot has three critical periods between germination and growing when a moister upper layer is needed. The first period is when the seeds are just seeded and the seed needs to extract moisture to swell up. The second period is eight till ten days after seeding, when the germination of the seed takes place. The last is when the germinated plants will grow above the soil, therefore when soil has a hard clod formation growing through the soil is hard. So, in the beginning phase of the growth of carrots water is of great importance. Two weeks after emerging of the plant the water need is becoming smaller. Water is mainly important between the 50th and 120th day of growing when the largest grow will take place. Carrots needs around 400 mm per season.
Other important aspects for the soil is lacking of slum and clod formation in the soil, this will prevent carrots from growing. The roots growth of carrots will grow in depth between 30 and 100 cm. Root growth is parallel with the actual growth of the crop. Root depth is positively correlated with yield. So it is of great importance that there are no layers that cause too much resistance for growing the roots in depth. To prevent this occurrence tillage is done by the farmer before the seeding. Furthermore it is important that the ground is flat to prevent the heads of the carrots to be green and cutting of this piece by harvesting.

2.1.3. Harvesting

Most of the farmers manage the cultivation of carrots, harvest and sales on their own. However, there are also larger agricultural companies that use contractors (farmers) to cultivate crop, whereas the storage, processing and sales are done by themselves (Kars, 2019).
The harvest period is between the end of June and November. Carrots that are seeded in March can start harvesting by the end of June. In this way the processing companies have a long time to produce the carrots and less time to store them. The farmer will check the carrots during the growth period on quality. For the industry 'woody' carrots are a big issue (picture below). The farmers needs to remove these carrots before harvesting.

Figure 3 'Woody' carrots

In the case when harvest damage on the crops is not a real issue the harvest is, mainly done by 3 or 4 wheel harvesters and in one work progress. First the harvester cut the heads of the carrots to remove the leaves. Then the carrots are scooped from the ground and brought to the sieving mats to remove the sand etc. This harvester is comparable to traditional potato harvesters.
There is another type of carrot harvester, which is used to minimize the damage on the carrots. This harvester, called a top-belt lifter is shown in Figure 5. Depending on the purpose of the carrots it is chosen which harvester to use. The top-belt lifter uses a long clamping band where the leaves of the carrots are clamped in between and will sludge mud from the carrots. Later the leaves are optionally cut from the carrot itself (Stichting TOG and Heijnen, 2018).

Figure 4 Carrot harvesting (Landbouwmechanisatie, 2012).

Figure 5 Clamping band (*About the Dutch Carrot Group | Dutch Carrot Group*, no date)

2.2. Seeding industry

Carrot seeds are produced around the world in countries such as Australia, New Zealand, South Africa, France and USA. Seeds are shipped to cleaning, processing and packing locations before being re-exported and sold all over the world to farmers. There are many seed companies selling hybrid carrot seed, among which are Bejo Zaden, BASF, ENZA, Rijkzwaan, Syngenta, and Vilmorin. Hygiene, disease prevention are important to a seed company. Different measures are often implemented also to comply with phytosanitary requirements of importing countries (Kars, 2019).

2.3. Legislation plant health

Due to globalization of trade in plant material more and more plant pests are introduced in Europe. For this a plant health strategy is developed. Although most prevention methods are applied on farm level, legislation on a higher level is needed to prevent introduction and spreading of pests and other diseases.
Legislation has the purpose to prevent introduction of new pests and invasive plants into the EU, but also prevents the spreading of the diseases within the EU. The EU plant health policy is framed by measures of the WTO agreement on sanitary and Phytosanitary Measures (WTO-SPS) and the International Plant Protection Convention (IPPC).

On international level the IPPC developed the International Standards on Phytosanitary Measures (ISPMs). The Food and Agriculture Organization of the United Nations (FAO) have 170 governments' members that are responsible for the ISPMs. The IPPC standard setting procedure was conducted in 1993. First the horizontal standards were developed where vertical pest or commodity specific standards could be linked to. The most important standard is; principles of plant quarantine as related to international trade. Also included risks analysis, surveillance and eradication, the establishment of pest free areas, export certification and phytosanitary certificates, pest reporting and non-compliance notification.

The Council Directive 2000/29/EC established the plant health policy for EU level. This policy takes care of preventing the introduction of plant diseases in the EU from outside, but as well from inside the EU.
There are plants, plant products and specified soils that are completely prohibited for entering the EU. All plants that enter the border of the EU get a documentary check, an identity check and a plant health check. The standing Committee on Plant Health can take actions on a certain threats of risks.

Between EU borders plant and plant products that have a potential risk need a plant passport. This passport with a specific code and unique registration number give the health status and the origin especially when it comes from a third country.
When a listed plant disease is first found in a country it is compulsory to report this. But as well measures need to be taken to prevent or eradicate the disease. This also applies for plants that are new and not on the list yet. These need to be reported by the European Commission.
The global trend as well as in the EU is going on that more products are produced on the same or less land. This will benefit the atmosphere for spreading and developing new plant diseases. For this the EU plant health strategy is developed (Oskam et al. 2010).

For the prevention of Calsol Haplotype A and B and the vector B. cockerelli in the EU has import requirements according to EPPO (Munyaneza, 2013). The EU has currently no import requirements on carrot or carrots seed against the introduction of Calsol (Kars, 2019).

3. Material & Methods

3.1. Research question 1

What is the economic value of carrot farming in the EU?

This section provides an overview of the economic value of carrot farming in the EU. To answer the first research question the following data are needed: cultivated area, production volume and carrot prices.

First the area of arable land and the hectares of carrot farming per EU country in thousands of hectares are evaluated. As well as the total area of arable and carrot farming of the EU. This subsection will give an impression of the total area in the EU that is used to grow carrots. The data for the cultivated hectares are subtracted from the Eurostat database under agriculture and fishery.

Furthermore, information on the total carrot production of the EU and per EU country is obtained from the database of FAO (Food and Agriculture Organization of the United Nations) and the European Statistics Handbook of Fruit Logistica 2019. Fruit Logistica gives the data for the total EU and the following EU countries: Belgium, Denmark, Germany, France, Italy, Poland, Netherlands, Finland, United Kingdom, Spain, and Greece. The carrot production data of the other EU countries are obtained from the FAO database. The limitation of the FAO data is that the production figures reflect aggregated production figures on carrot and turnip production. The carrot production will be presented per EU country and for the total of the EU for the year 2017.

With the area of carrot farming and the production of carrots the efficiency is calculated for the specific EU countries and the total of the EU.

To obtain insight in the volatility of carrot prices in the EU, the fluctuations in carrot market prices were evaluated on a monthly base for the period between January 2014 and January 2019.

To calculate the total economic value per country, the specific annual prices of carrots in the different counties were obtained from Eurostat. Germany, Estonia, France, Greece, Italy, Luxembourg, Slovenia, Spain and the average of the EU did not have specific carrot prices in Eurostat. For these countries the year market carrot price are calculated from the monthly data of the market prices from the European Commission.

With the data on carrot production and prices the economic value of carrot farming in the EU is calculated. Besides the assessment of the total EU carrot value at risk, a sub-assessment is made based on the values of the EU countries where Calsol is already found.

3.2. Research question 2

What is currently the economic damage of Calsol in carrot production in the EU?

This thesis will argue from the theory of cost accounting. Drury (2012) stated that: ‘Cost accounting is concerned with cost accumulation for inventory valuation to meet the requirements of external reporting and internal profit measurement.’ The economic impact of Calsol can have direct and indirect effects (Soliman, 2012). Both direct and indirect form the total economic impact. Indirect effects will be the change in prices, producer and customer responses and internal trade further in the chain. Direct impact will be the yield losses and additional production costs. The main focus of this research will be on the direct impact assessment.

Cost accounting will be used by the method of partial budgeting in order to answer the research questions. Partial budgeting is a cost benefit analysis that demonstrates economic consequences. The method aims to illustrate the net increase or decrease in farm income. This basic method analyzes the direct impact when a pest occurs with the additional costs and lost revenues. The cost include the additional costs and reduced returns. The revenues include the additional returns and the reduced costs. This method can be used by both the situation with no pest, as well as the situation with the presence of the pest. In this way a comparison between the two situations can be made. The method can also be used to calculate if a risk mitigation method is feasible.

For the parameterization of the pest parameters expert knowledge is needed as in recent literature the impact of the disease has not been described yet.

This research is partly situated within the Horizon2020 project of POnTE (Pest Organisms Threatening Europe https://www.ponteproject.eu/). POnTE has the aim to 'minimize the risk of introduction/impact of emerging pests threatening EU agriculture and forestry'.

As part of POnTE and subsequently for this research an online survey has been distributed among plant disease experts of Calsol detected countries. This is done for assessing the impact of Calsol and costs and benefits of current risk mitigation methods. This survey contains various questions on yield reduction/losses. To account for the uncertainty in knowledge, experts are asked to answer these questions for their country by indicating a minimum, most likely and maximum value estimation. The survey tries to collect data about which risk mitigation methods are used in the various countries to answer the third research question.

To account for the indicated uncertainty in observed losses and costs the partial budgeting will be applied by means of stochastic simulation using @Risk. Probability distributions will be derived from the indicated minimum, most likely and maximum value estimations.

3.2.1. Survey layout

The survey consist of 39 questions divided among four sections (Appendix 1). It starts with some general information of the respondent. The first section contains questions about the impact with the presence of Calsol and its vector(s). The carrot growing area in the country and yield of carrots under normal conditions are asked. It contains questions which haplotypes and vectors are present in the country and the impact of them in percentages. At last, the proportion that is qualified to a lower quality by impact of Calsol is elicited. The impacts are asked per affected hectare.
The second section is about the control strategies to prevent Calsol and its vector(s). There are questions what the expected reduction yield (in quantity and quality) will be when Calsol and its vector(s) is introduced under the following control strategies: sprays with insecticide, sprays with Kaolin, mineral oils or botanical pesticides, nets, resistant or tolerant cultivars, and increased width of the crop rotation.
Additional costs is the subject of the third section. Here the additional annual costs of the control strategies per hectare are asked when these are applied.
The last section is about the future scenario of the present of Calsol in the EU. This has one question about what the expected impact will be of Calsol and its vector(s) within 5 years. When the current measures are maintained.

The survey was send to plant experts in ten EU countries were haplotypes of Calsol was already detected according POnTE (Bergey et al., 2017). In these EU countries the haplotypes C, D and E are found. The distribution of the haplotypes in the EU countries is presented in Figure 1.

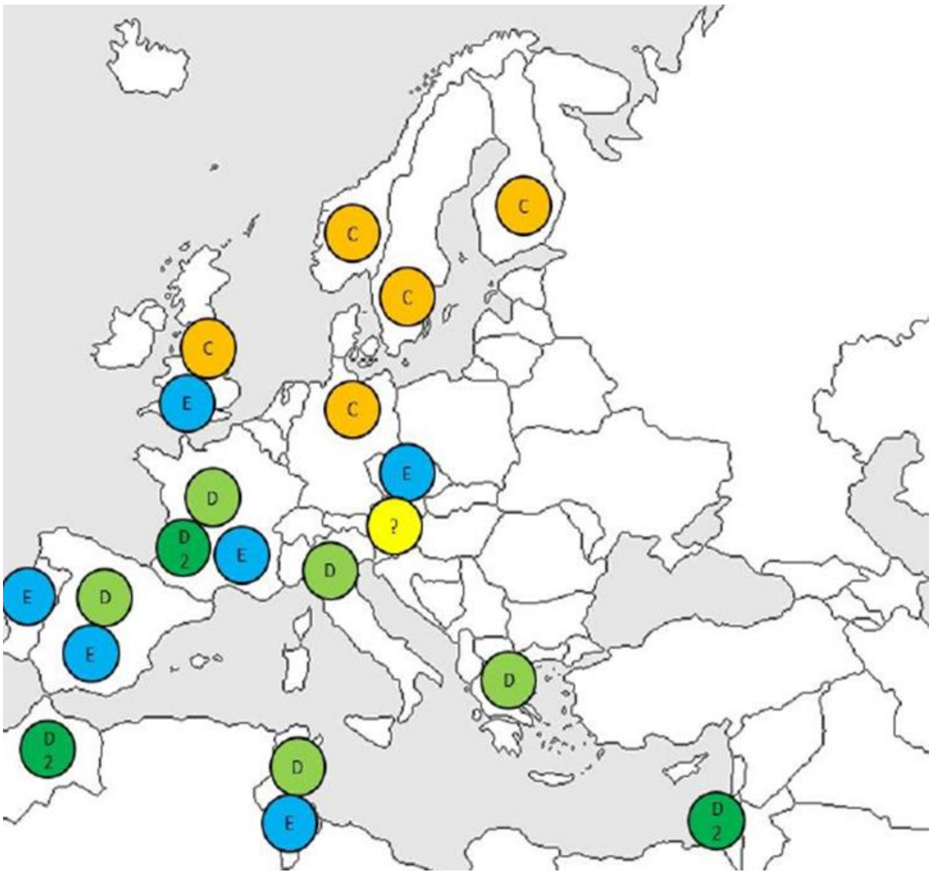

Figure 6 EU and Mediterranean region with presence of Calsol and found haplotypes (Bergey *et al.*, 2017)

Figure 6 also provides the different haplotypes of Calsol for the countries Norway, Morocco, Tunisia and Israel, although these countries do not belong to the EU. This study is an economic assessment of the EU therefore only EU counties will be taken into account.

3.2.2. Scenarios

The data that are needed to give an answer on research questions two and four contain uncertainty. The data are estimations from plant experts. Moreover, the contamination levels can have highly fluctuating impacts requiring a stochastic approach to investigate the economic impact distribution of Calsol in carrot farming. This stochastic assessment is done with the use of the Excel add-on @Risk7.5 (© Palisade).

Three scenarios are built for simulation with 10,000 iterations;

Scenario 1: The model representing the situation without presence of Calsol (Baseline)
First a scenario is made to predict the economic value of carrot farming in the carrot producing EU country. This is done by using information on the carrot growing area in the country (in ha), average carrot yield (tones/ha) and carrot price (€/ton) as registered during the last five years. Based on this information representative distributions have been fit by the use of the Best-fit option within @Risk. The carrot growing area and average carrot yield have a lower –and upper limit that is bounded, but unknown. The variables cannot turn out negative and have no infinity chance on extreme high values. Carrot price is most likely to turn out positive, although the upper limit will be again be bounded, but unknown.
There is a correlation assumed between the average carrot yield and the carrot price.

The baseline is used to compare a standard situation with a situation where Calsol and it(s) vectors are causing damage (scenario 2). With this comparison the impact of the plant disease can be estimated.

Scenario 2: Model with presence of Calsol and it(s) vector(s)
Scenario two reflects the situation with impact of Calsol by a normal farm strategy. With normal farm strategy is intended carrot farming in absence of any control strategies directed to Calsol. To simulate this scenario, estimations are used on the size of the affected area, yield decline and quality decline. These thee variables are all deducted from the survey of POnTE. The data are all given in minimum, most likely and maximum cases with percentages. Within the stochastic model the variation in these variables are modelled by means of a Pert distribution. Between the variable of yield reduction and quality reduction a positive correlation is assumed.
The baseline is used to compare a standard situation with a situation where Calsol and it(s) vectors are causing damage (scenario 2). With this comparison the impact of the plant disease can be estimated. The comparison of scenario one and scenario two will give an answer on research question two.

Scenario 3: Model with presence of Calsol and control strategies
In this model the risk mitigation methods are included when Calsol is present in carrot farming in the EU country. The survey of POnTE gives the data for the yield decline and the proportion to lower quality when a specific risk mitigation is applied on a hectare. The survey gives as well data for the costs of the control strategies. This situation can be compared with scenario two, when Calsol is present in carrot farming but when no risk mitigation measures are applied. The comparison will show if the use of a risk mitigation strategy is economically justified. This scenario will first be done for the risk mitigation methods applied in the country separately and compared to scenario two. The variables in this scenario will all have a Pert distribution.

3.3. Research question 3

To what extent are risk mitigation methods for Calsol in carrots applied among the EU?

In this research question the answers in the survey about risk mitigation are analyzed by means of basic descriptive statistics. The survey asked about the use and related mitigation effect with respect to the following risk mitigation options:

- Sprays with pesticides
- Sprays with Kaolin, mineral oils or botanical pesticides
- Nets
- Resistant or tolerant cultivars
- Increased width of the crop rotation in time

3.4. Research question 4

To what extent are the applied risk mitigation measures economically justified?

This research question is answered with the simulation of scenario three. The different risk mitigations will be simulated and compared with scenario two. This will show if the costs made for the control strategy are economically justified. It will also shows which risk mitigation measure is most efficient for the prevention of Calsol.
This scenario is applied for the situation in which the risk mitigation methods are used in current extent (partly implemented) and for the situation in which the methods are used by all farmers (100% implementation).

4. Results

This section gives the results for the four separate research questions.

4.1. Research question 1

In this section a literature review is done to estimate the economic value of carrot farming of the EU countries separately and as a whole. Currently the EU has 28 member states (*Landen - EUROPA | Europese Unie*, no date) (Appendix 2).

The economic value of carrot farming in the EU was investigated using data on the hectares of carrot farming, the total production of carrots and the market prices of carrots. First, the area of carrot farming in the EU in hectares, per EU country are represented. Then the production volume of carrot farming of the EU countries are discussed. At last, the carrot price in the EU was considered. With these three information elements a final answer of research question 1 is been calculated.

4.1.1. Area of carrot farming

The cultivated hectares and the area used for carrot farming of the 28 EU countries are given in the table below (Table 1). This is done for the total EU and for all the separate EU member countries. The last Colom gives the share in carrot farming compared to the total area of carrot farming in the EU. All the data are based on the year 2017.

Table 1 Arable and carrot farming area in thousand hectares in 2017

EU country	Arable land (x1000 hectares)	Carrot farming (x1000 hectares)	Share of national carrot farming in total EU carrot farming (%)
Belgium	842	5.7	4.7
Bulgaria	3,474	1.2	1.0
Cyprus	95	0.1	0
Denmark	2,369	2.2	1.8
Germany	11,772	12.6	10.5
Estonia	675	0.3	0.3
Finland	2,242	1.8	1.5
France	18,608	12.8	10.8
Greece	1,898	0.9	0.8
Hungary	4,325	2.0	1.7
Ireland	440	0.8	0.7
Italy	6,697	11.0	9.2
Croatia	815	0.6	0.5
Latvia	1,290	0.4	0.3
Lithuania	2,141	1.6	1.3
Luxembourg	62	0	0
Malta	9	0	0
Netherlands	1,037	9.4	7.9
Austria	1,329	1.8	1.5
Poland	10,915	22.4	18.8
Portugal	941	2.1	1.7

Romania	8,543	8.3	7.0
Slovenia	174	0.3	0.2
Slovakia	1,343	0.2	0.2
Spain	12,296	6.4	5.4
Czech Republic	2,502	0.8	0.7
Sweden	10,915	1.7	1.4
United Kingdom	6,089	11.9	10.0
The EU total	**113,838**	**119.0**	

('Eurostat_Table_arable land', 2017; Eurostat, 2017)

The total area of arable farming in the EU is 113,838 thousand hectares. The total carrot farming in the EU is 119 thousand hectares. The total share of carrot farming in the EU is thereby 0.1%, this is a small share compared to a main production crop like potato (Eurostat, 2018). Potatoes have a total area of 1,745 thousand hectares, this is a 1.5% share of the total arable farming ("Eurostat_Table_Potatoes," 2017).

4.1.2. Carrot production volume

In Figure 7, an overview of the total carrot production per EU country is given. The United Kingdom and Poland have a high carrot production, followed by Germany, the Netherlands, France and Italy. Figure 7, shows the most recent data. This is for the year 2017.

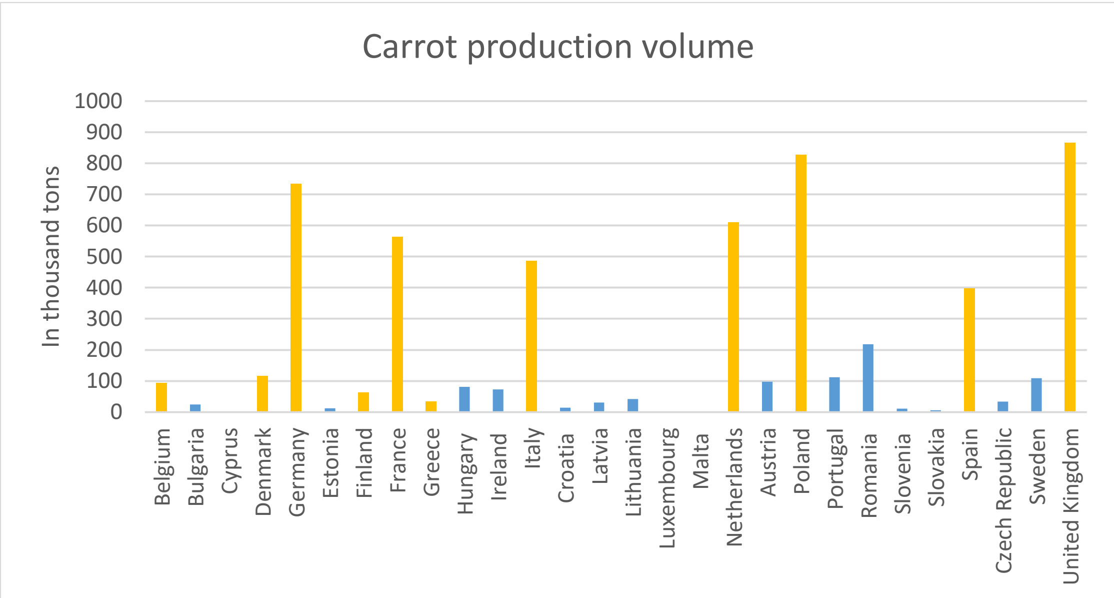

Figure 7 Carrot production volume per EU country in 2017 in '000 tons (FAO, 2017; Fruit Logistica, 2018, 2019)

The blue bars are the carrot production volume subtracted from FAO that have data on carrots including turnips. The orange balk are the values from Fruit Logistica that have specific data on carrot production.
The total carrot production in Europe in 2017 is 5,772 thousand tons. Among the years the carrot production volume numbers are rather stable. When a range of five years (2014-2018) is studied the minimum among these production figures equals to 5,083 thousand tons in 2015 and the maximum to 5,772 thousand tons in 2017 (Fruit Logistica, 2019). With an average of 5,428 thousand tons during these five years.

4.1.3. Efficiency of EU countries

In the above sections are the area and the production volume of carrot farming presented. With these numbers the efficiency per EU country can be derived. This is first done with data of Fruit Logistica and Eurostat that has data for specific carrot farming (Figure 8). However, Fruit Logistica has no data for carrot production volume of all the EU countries. So, for this reason there are also calculations made using the database of FAO (Figure 9). This database does not have specific data for the crops carrots but for carrots and turnips together.

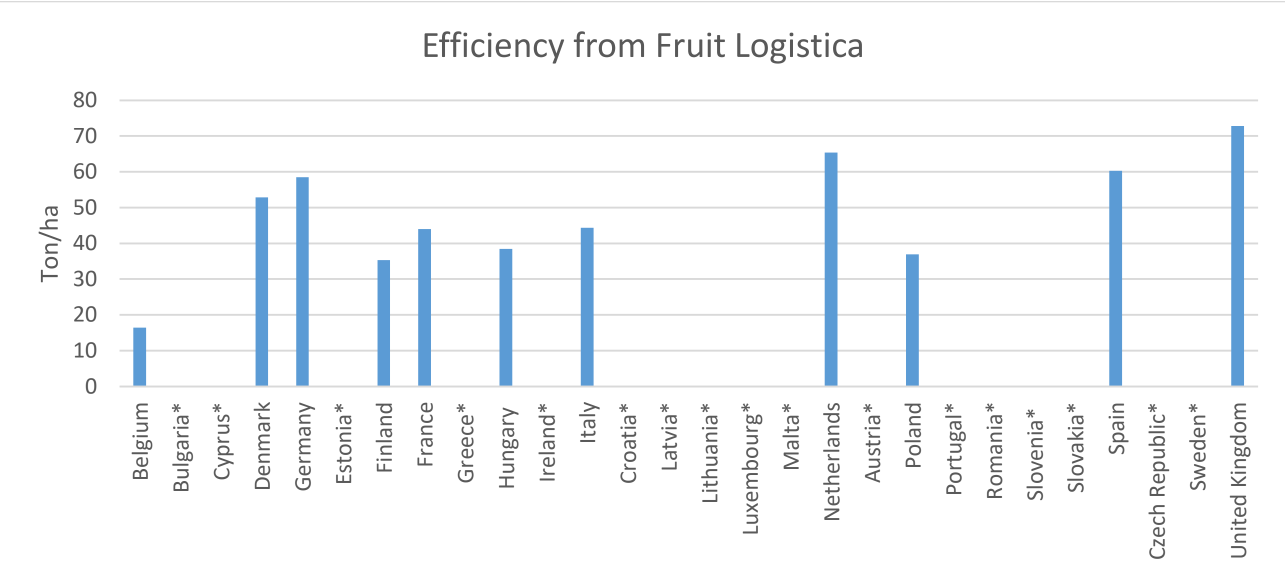

Figure 8 Efficiency from Fruit Logistica in 2017 ton/ha (Eurostat, 2017; Fruit Logistica, 2018, 2019)

*no carrot production data available in Fruit Logistica database

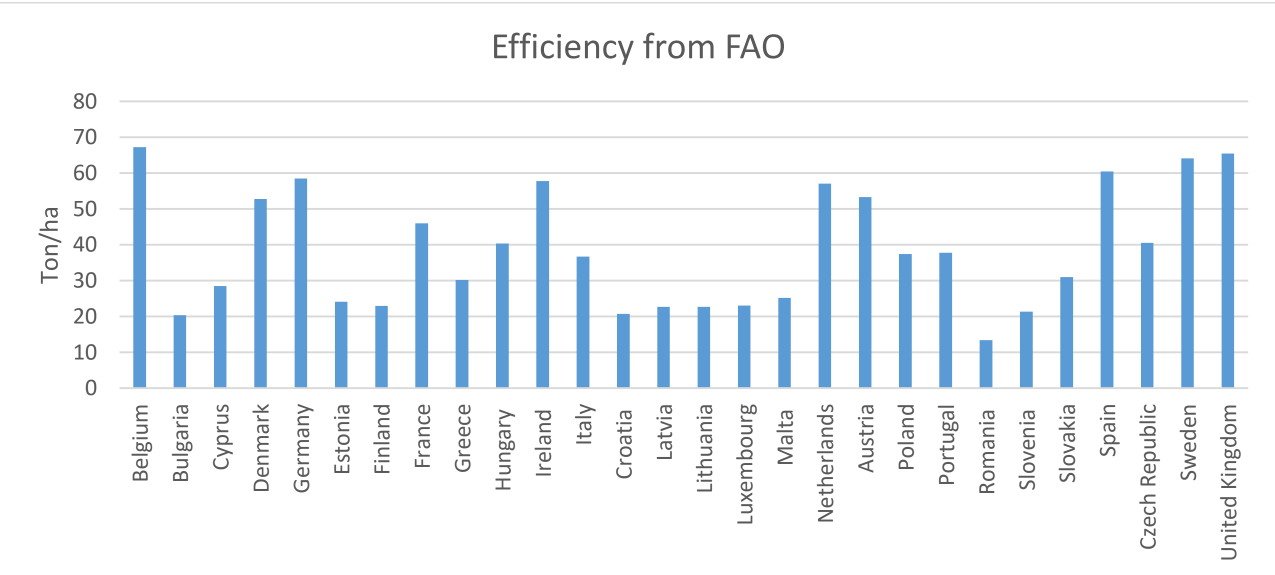

Figure 9 Efficiency from FAO in 2017 ton/ha (Eurostat, 2017; FAO, 2017)

A comparison between Figures 8 and 9 indicates that there are large differences in the estimated production efficiency for some of the EU countries, given the two different databases.
The largest difference is found for Belgium indicating a difference of more than 50 ton by the FAO data compared to the Fruit Logistica data. This means that the production data of FAO on carrots and turnips includes a large share of turnips.

The average efficiency in the EU can be explained with the total area of carrot farming and total of carrot production volume. Total hectares of carrot farming are 119 thousand hectares and the carrot production is 5,772 thousand tons. This makes the average efficiency of carrot farming in the EU equal to 48.5 ton carrots per hectare.

4.1.4. Carrot prices

In the figure below the market prices of carrot are given for the EU as a whole. The market prices are found as an average per month. In this figure the seasonal fluctuation is represented, as well as the difference between years.

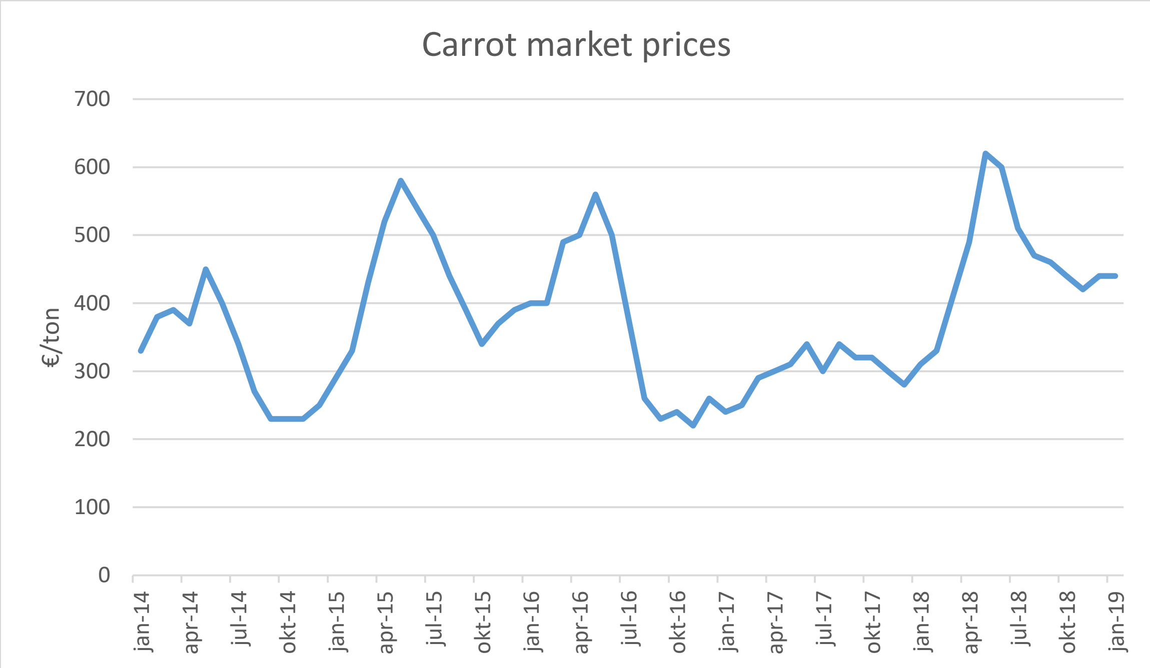

Figure 10 Carrot market price fluctuation EU (European Commission, 2019)

The average market price of these five years is €376/ton. In the figure above (Figure 10) the variation of market prices for carrot in and between years is represented. It is shown that there are fluctuations between years but as well within the years. This is just due to the approach of supply and demand (*SEASONAL VARIATION IN PRICES*, no date). Figure 10, shows a drop in 2017 this is due to good growing conditions for carrots what resulted in an oversupply (Rush Group, 2017). Within years you see that in summer the prices are decreasing and around November the prices start increasing again.

4.1.5. Economic value of carrot farming in the EU

In Figure 11 the economic value of carrot farming per EU country is given. The values in the blue bars are calculated using the average EU price in 2017 of €0.30,-/kg, due to the lack of country specific prices. The economic value represented by the orange bars indicates the economic value derived from country specific carrot prices of 2017.

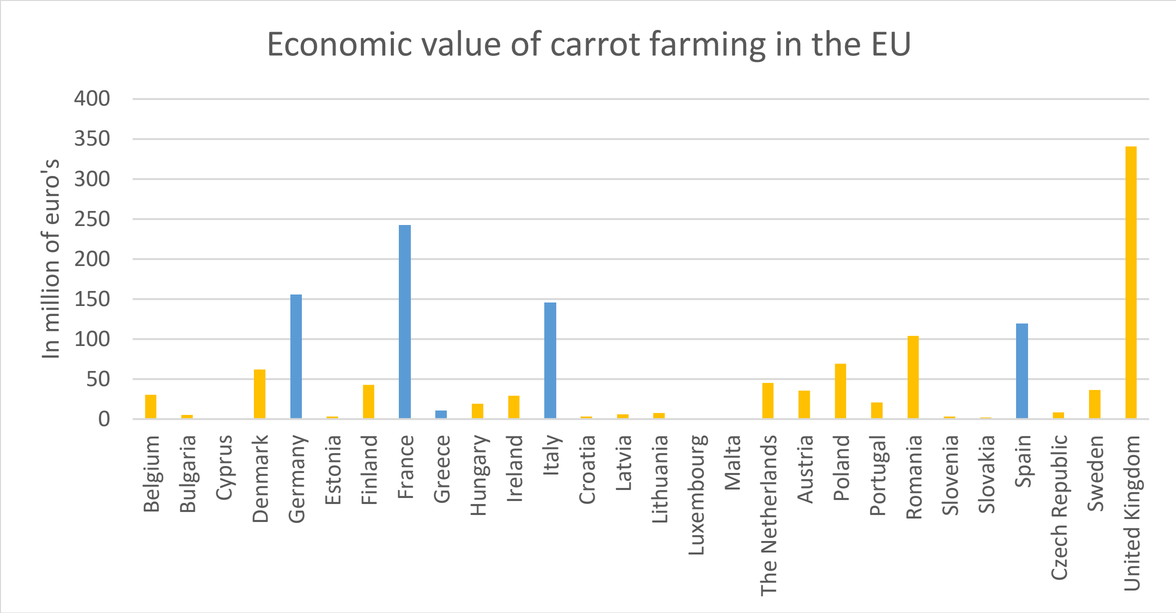

Figure 11 Total economic value of carrot farming per EU country in millions of euro's (European Commission, 2019; Eurostat, 2018b; FAO, 2017; Fruit Logistica, 2018, 2019)

Summation over the EU countries results in the total economic value at risk of carrot farming in the EU based on the situation of 2017, which is equal to €1,727 million.

Calsol is currently present in ten EU countries. The economic value of only these EU counties is given in Table 2.

Table 2 Economic value of carrot farming in the Calsol detected EU countries

	Economic value of carrot farming in million euro's in 2017
Germany	156
Finland	43
France	243
Greece	10
Italy	146
Portugal	21
Spain	119
Czech Republic	9
Sweden	36
United Kingdom	341
Total Calsol detected EU countries	**1,123**

The total economic value of the Calsol detected EU countries equals 1,123 million euro which represents more than half of the total economic value of carrot farming in the EU.

4.2 Research question 2

In this section the effect of Calsol on the economic value of carrot farming is estimated. Due to the lack of information on the impact of the disease, the POnTE survey was used to obtain expert elicitations in this respect. The survey got seven responses from EU countries obtained from experts in Denmark, Scotland UK, Finland, Germany, Spain and France (2x). Denmark is an EU country without the presence of Calsol.

From these respondents only Finland indicated to experience real damage due to the presence of Calsol and it(s) vector. Spain gave an estimation of what Calsol could do to carrot farming in this EU country. Although, at the moment Spain is not experiencing any damage of Calsol and it(s) vectors. Due to lack of any perceived impact in the remainder countries only Finland will be taken further into account for this study.

The respondent from Finland is Anne Nissinen a Senior Scientist of LUKE (Natural Resources Institute Finland), a research and expert organization in Helsinki for renewable natural resources and sustainable food production (Luke - Luonnonvarakeskus n.d.).

Calsol was first detected in Finland in 2008 and it was the first time Calsol was found other than by the Solanceaous family and outside Central America and New Zealand. It was a new haplotype (C) by a different plant family, the Apiaceae family (J. E. Munyaneza *et al.*, 2010; Haapalainen *et al.*, 2017).

Finland counted 312 enterprises in 2017 that take care for the carrot production on 1,762 hectares in the country. A slight trend has seen over the last 10 years showing a decrease in the number of carrot producing farms (-75) and an increase in the average production area per farm (+2 hectares) (Luke, 2018a, 2018b). The average area of carrot farming equaled in 2017 5.6 hectare/carrot producing farm. The average utilized agricultural area in Finland was 47 ha/farm in 2017 (Luke, no date).

Anna Nissinen replied on the survey that when the current management methods are maintained she expects in five years from now (2018), an increase in the Calsol affected growing area of 5 -15%. Currently the Calsol effected growing area is about 70%.

Damage of Calsol based on the expert elicitation

In Finland, Calsol in carrots is only caused by haplotype C. Moreover, there is only one vector that transmit Calsol; Trioza Apicalis. Impact due to a Calsol infection is a combined effect resulting from the bacteria as well as the vector. According to the expert, the vector causes the majority of the impact in crops as reflected by the indicated minimum, most likely and maximum percentages of the total damage caused by the vector (Table 3). Table 4, gives the data of the survey for the variables for the simulation of scenario 1.

Table 3 Damage of Calsol and it(s) vector(s)

	Minimum	Most likely	Maximum
By Calsol in %	12.3	16.7	23.1
By the vector(s) in %	85.7	83.3	76.9

Table 4 given data in survey

Input	Minimum	Most likely	Maximum
Carrot growing area (ha)	1,600	1,650	1,700
Average carrot yield (kg/ha)	40,000	70,000	90,000
Carrot price (€/kg)	0.44	0.5	0.66

Table 4 present the given data in the survey for the variables for the simulation of scenario 2.

Table 5 Effect of Calsol in Finland in percentage

Input	Minimum	Most likely	Maximum
Affected area (%)	60	70	80
Yield decline (%)	10	25	100
Proportion qualified to lower quality (%)	15	30	100

The qualification to a lower quality class is seen as a total loss (opportunity costs = €0), because there are no clear findings that these carrots can be used for other purposes than food consumption. This loss is calculated from the production volume after the yield decline. To investigate the assumption on the lack of alternative opportunities for the degraded carrots a sensitivity analysis is been made (Sensitivity analysis opportunity costs of carrots under quality loss).

4.2.1. Scenario 1: The model without presence of Calsol (Baseline)

Input scenario 1

Within the survey the experts were asked to indicate their estimations on the carrot growing area in hectares and the average carrot yield in absence of Calsol (Table 4). Estimations for Finland are indicated in Table 4. Moreover additional information was obtained from Statistical databases on agricultural production in Finland (Kasvistieto Oy, 2018; Luke, 2018b) (Table 6).

Table 6 Input data for scenario 1

Year	Carrot growing area (ha)	Average carrot yield (kg/ha)	Carrot price (€/kg)
2009	1,626	41,375	NA
2010	1,606	41,878	NA
2011	1,663	43,649	NA
2012	1,480	37,564	0.638
2013	1,582	44,751	0.718
2014	1,652	44,939	0.619
2015	1,644	38,786	0.608
2016	1,697	42,956	0.651
2017	1,762	35,370	0.686
2018	1,833	36,342	0.883
Average	1,655	40,761	0.686
Standard deviation	97	3,510	0.095

(Kasvistieto Oy, 2018; Luke, 2018b)

Based on the statistical data distributions were fit to reflect the uncertainty in the input variables (Table 7).

Table 7 Input sources for scenario 1

Input	Source	Data for	Distribution
Carrot growing area (ha)	(Luke, 2018b)	10 years (2009-2018)	=RiskTriang(1437,94:1644:1880,9)
Average carrot yield (kg/ha)	(Luke, 2018b)	10 years (2009-2018)	=RiskUniform(34306;46002)
Carrot price (€/kg)	(Kasvistieto Oy, 2018)	7 years (2012-2018)	=RiskPert(0,608;0,608;1,1264)

Simulation results
The simulations on the economic value of carrot farming in Finland is given in Figure 12. It represents the outcomes based on the settings of the three stochastic variables as indicated in Table 7, accounting for a certain amount of correlation between yield and price.

Between the variables yield and price a negative correlation might occur. In general, prices start rising when yields are decreasing (*SEASONAL VARIATION IN PRICES*, no date). The exact correlation cannot be estimated because of the scarcity of data. For this, three scenarios were considered, by accounting for a correlation coefficient between yield and price of 0, -0.4 and -0.8, respectively (Table 8 and Figure 12).

Table 8 Economic value of carrot farming in Finland with different correlations between yield and price

Correlation	0.0	-0.4	-0.8
Mean	46,125,331	45,977,232	45,824,250
5th value	36,470,318	37,824,839	39,722,482
95th value	58,429,198	55,907,492	52,743,513
Standard deviation	6,715,648	5,509,887	3,943,991

Red: Economic value of carrot farming with correlation 0.0
Blue: Economic value of carrot farming with correlation -0.4
Green: Economic value of carrot farming with correlation -0.8

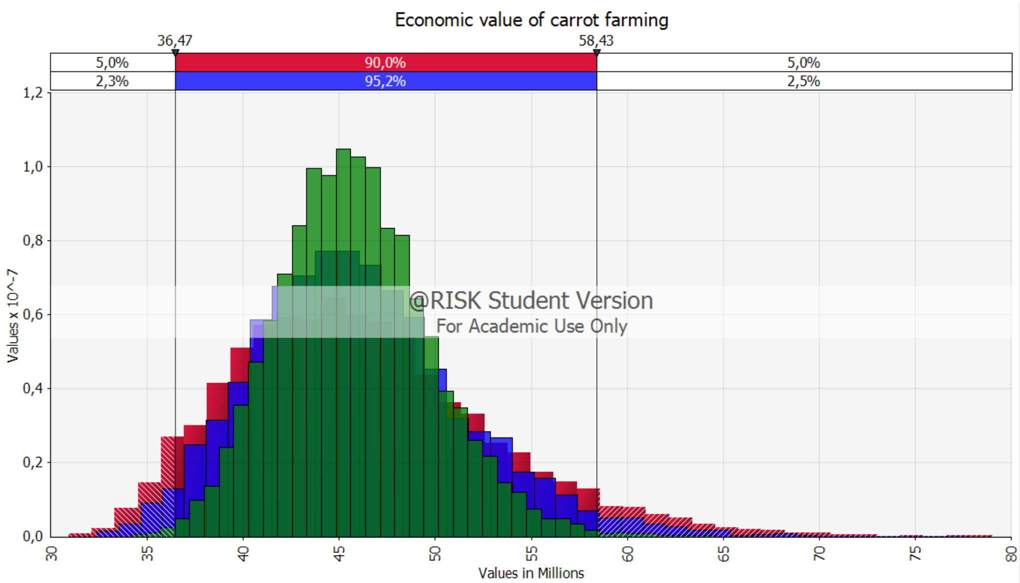

Figure 12 Distribution graph of correlation price and yield

The difference in the mean by the different correlations is not extreme. By the zero correlation the mean is the highest (46 million). This means that when there is no correlation between price and yield this will have the highest economic value. The 5% value and 95% value shows in which range the 90% confidence interval is by the different correlations. The confidence interval is becoming smaller by a stronger correlation. This is also in line with the standard deviation that gets smaller the more negative the correlation gets. As well, the confidence interval shows the wide range where the economic value can be. By a correlation of -0.4 the confidence interval has a range of around 18 million.
The skewness in all the correlations are positive what means that the distributions are right skewed (Prybutok and Ott, 2006). This means that more values are on the right side of the tail, more chance on higher values.

In the forthcoming comparisons with the default situation, comparisons are made on the scenario considering a correlation-coefficient of -0.4.

4.2.2. Scenario 2: Model with presence of Calsol and its vector(s)

Input for scenario 2

The input data of scenario 2 are coming from the survey. All the variables have from now on Pert distributions.

Table 9 distributions for scenario 2

Input	Distribution
Affected area (%)	=RiskPert(0.6;0.7;0.8))
Yield decline of affected area (%)	=RiskPert(0.1;0.25;1))
Yield decline due to lower quality (%)	=RiskPert(0.15;0.3;1))

Simulation results & correlation analysis between quantity –and quality loss

For the simulation of the three variables of scenario 2 a Pert distribution is used in @Risk as described in Table 9.
After the simulation and calculation to the absolute production number they had the following values:

Table 10 simulation output of scenario 2

Variable	Mean	90% confidence interval	
		5th percentile	**95th percentile**
Affected area (ha):	1,158	1,059	1,257
Yield decline of affected area (kg)	16,274,360	6,509,744	29,758,830
Yield decline due to lower quality (kg)	11,837,660	5,742,524	19,947,716

In Table 10 the confidence interval show the variation around the mean. The confidence interval show a wide range. The affected area has already a range of around 200 hectares. The total yield decline due to Calsol has a range more than 20 million kilograms and total decline due to quality around 14 million kilograms. This conclude that the effect of Calsol by introduction of the disease can be very uncertain.

The presence of a correlation is assumed between a decline in yield and a decline in quality due to Calsol. Expected is that when yield declines due to the effect of Calsol there is also a decline in the quality. This means that there is a positive correlation between quantity loss and quality loss.

The exact correlation between quantity loss and quality loss is not known. This due to the scarcity of data. For this reason three correlation are investigated to account for the effect of any correlation between these variables.

Table 11 Economic value of Carrot farming in Finland with Calsol with different correlation between quantity and quality loss

Correlations	**0.4**	**0.6**	**0.8**
Mean	26,791,178	26,947,176	27,084,980
5th percentile	17,537,472	17,208,770	17,022,573
95th percentile	37,015,596	37,474,551	37,937,311
Standard deviation	5,965,858	6,179,876	6,416,507

Red: Economic value of carrot farming with Calsol with correlation 0.4
Blue: Economic value of carrot farming with Calsol with correlation 0.6
Green: Economic value of carrot farming with Calsol with correlation 0.8

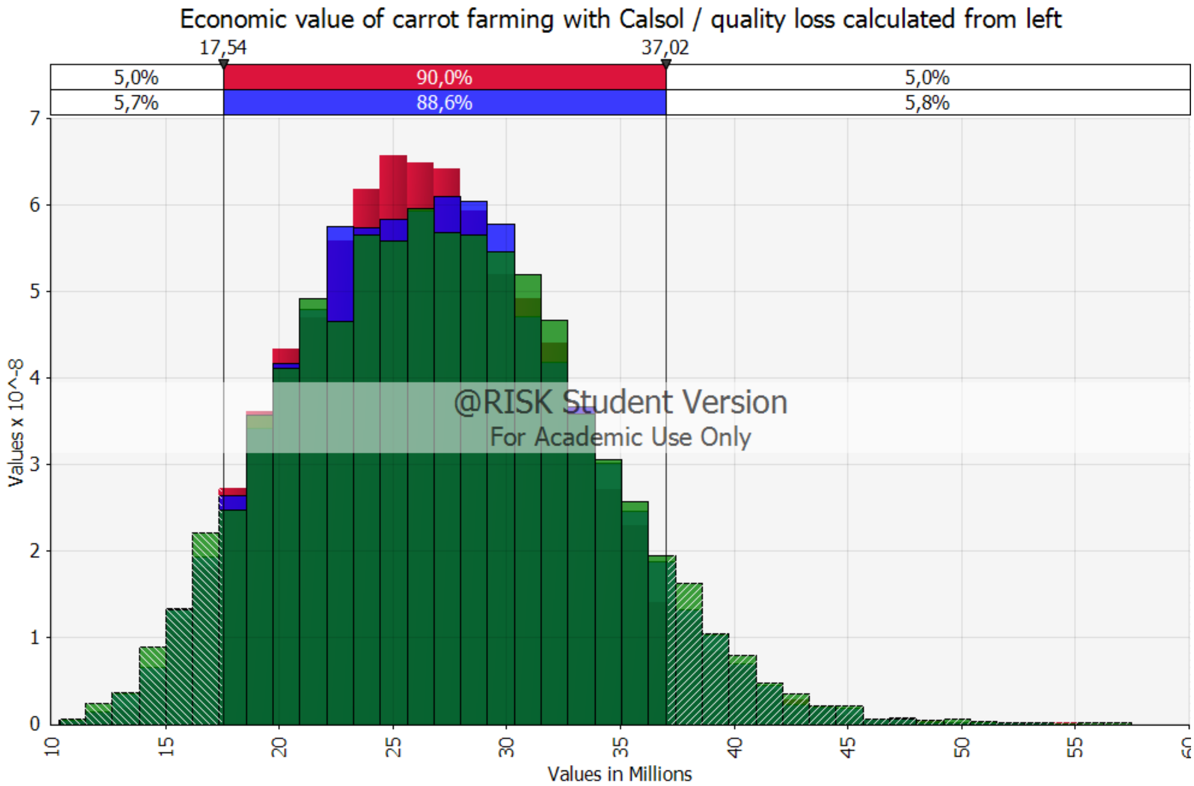

Figure 13 Distribution graph of correlation between quantity -and quality loss

In Table 11 and Figure 13 the different correlations between quality loss and quantity loss were analyzed. The mean (the economic value of carrot farming with Calsol), confidence interval and standard deviation are slightly increasing when the correlation gets stronger; the coefficient of variation increases only from 0.22 to 0.24 when comparing the results from the scenario based on the correlation of 0.4 to the scenario based on the correlation of 0.8. The confidence interval is approximately in the same range.

The simulation results below in Figure 14 and 15 give the baseline (red) together with scenario two (blue). It represent the difference in economic value of carrot farming under the absence and presence of Calsol. It is done with 10,000 iterations and the correlation between yield and quality loss set at 0.6. The correlation between price and yield is defined at -0.4.

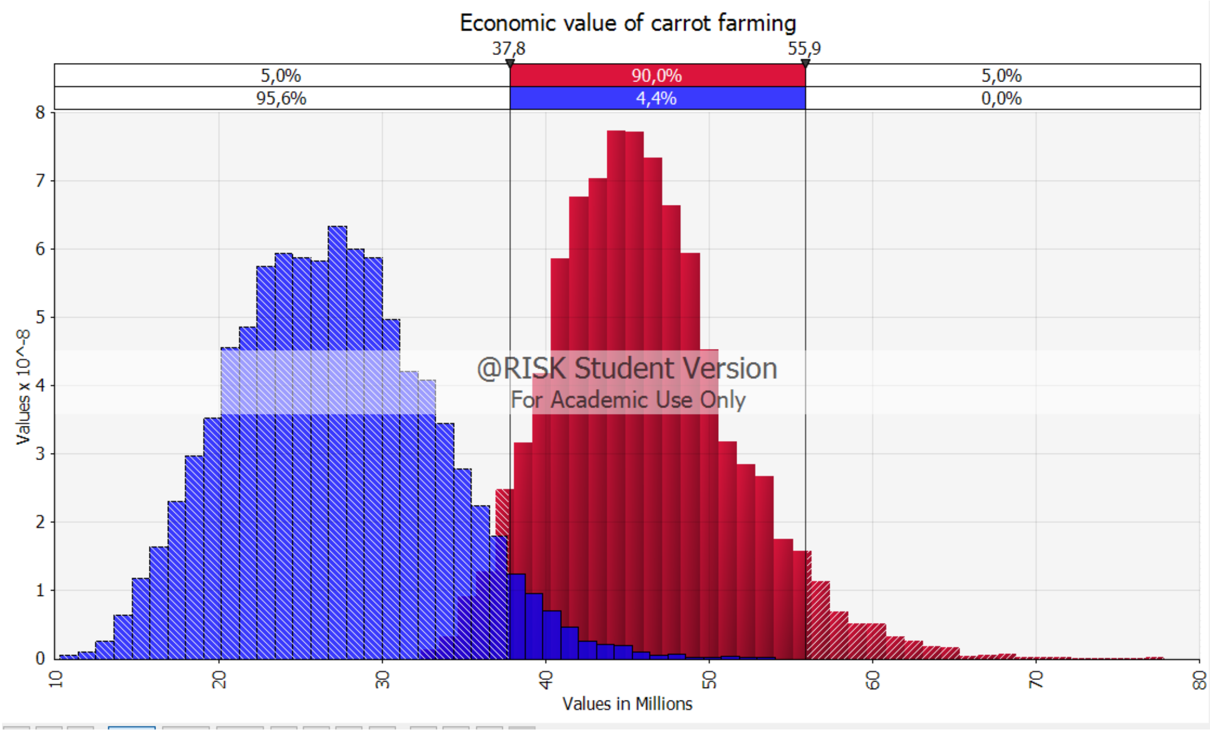

Figure 14 Distribution graph of scenario 2

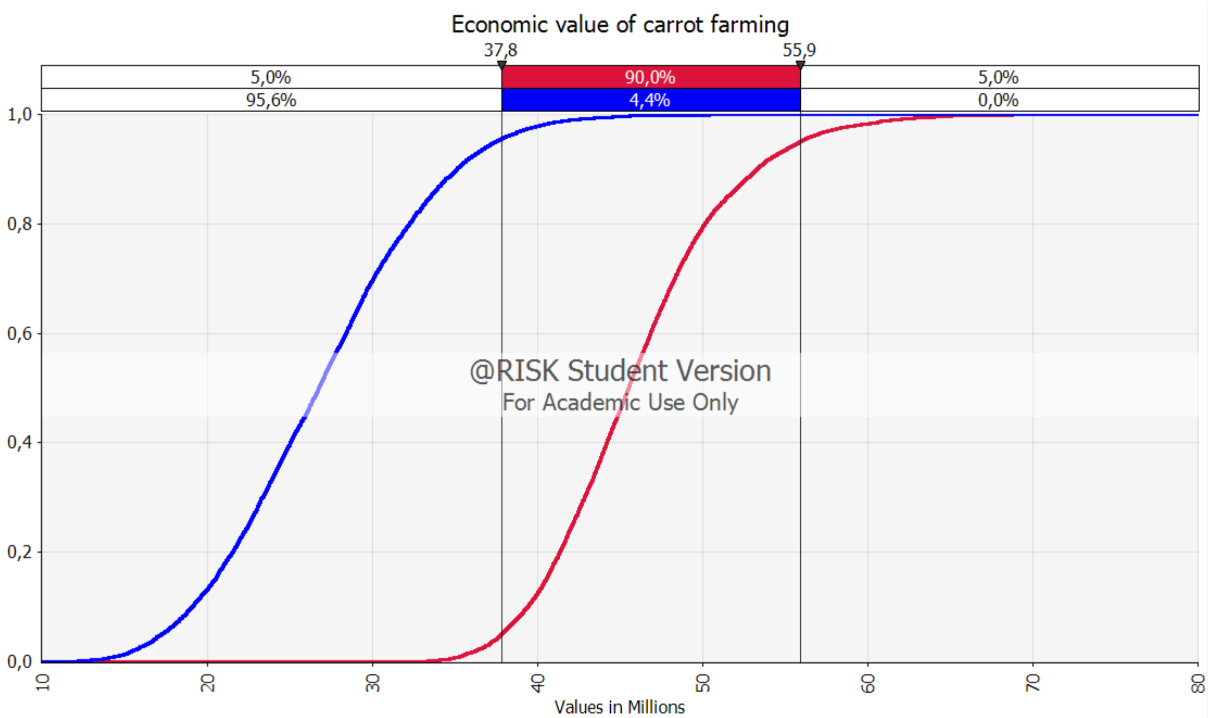

Figure 15 Cumulative graph of scenario 2

Table 12 Output scenario 1 and 2 in €

	Scenario 1	Scenario 2
Mean	45,977,232	26,947,176
5th percentile	37,824,839	17,208,770
95th percentile	55,907,492	37,474,551
Standard deviation	5,509,887	6,179,876

The above represented model gives the risk output of economic value of carrot farming with (blue) and without Calsol (red). This distribution for scenario two is created with 10,000 iterations. A standard deviation of €6 million is found in both situations. The variation is due to the level of impact of infestation level and thereby the yield loss and quantification to lower quality.

The mean of the situation with Calsol is 27 million euro. This is 17 million euro lower than the situation without Calsol. This means without risk mitigation Calsol can cost Finland around 18 million euros on average.

Sensitivity analysis opportunity costs of carrots under quality loss

Results of scenario 2 as depicted in Figure 14 are based on the assumption that the carrots with lower quality has no alternative value, hence resulting in a value of €0 ed. In this section a sensitivity analysis is performed under the assumption that these carrots still have an opportunity value although reduced, considering values equal to 25% and 50% of the market value. This can be the case if the carrots still can be used for example as cattle feed.

Results of this sensitivity analysis are presented in Figures 20 and 21; on average a 50% value for quality degraded carrots reduce the loss in economic value due to Calsol and its vector with 4 million Euros.

Red: Quality loss, 'zero' value
Blue: Quality loss, 25% value
Green: Quality loss, 50% value

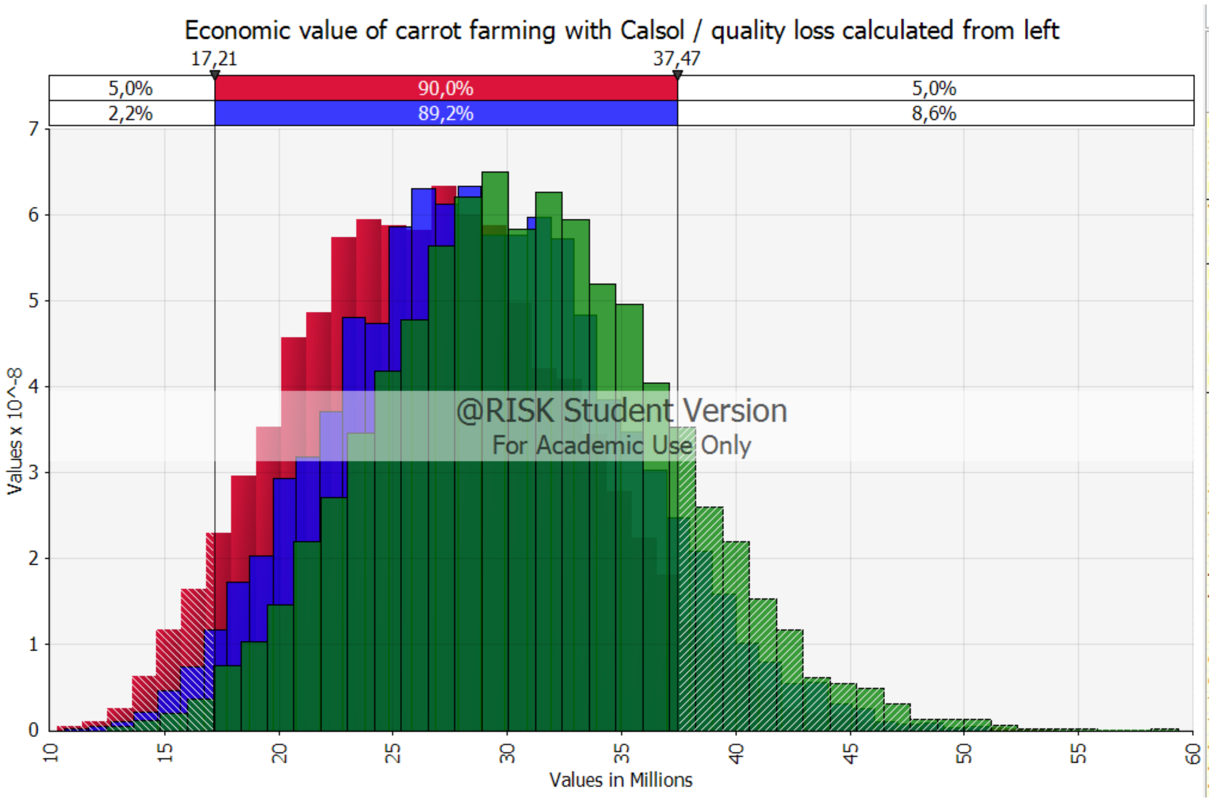

Figure 16 Distribution graph of sensitivity analysis of quality loss

Table 13 Output of sensitivity analysis of quality loss

	Scenario 2; quality loss 'zero' value	Scenario 2; quality loss 25% value	Scenario 2; quality loss 50% value
Mean	26,947,176	28,885,962	30,826,747
5th percentile	17,208,770	19,031,720	20,890,802
95th percentile	37,474,551	39,260,706	41,190,764
Standard deviation	6,179,876	6,151,487	6,214,313

The different degrees of quality losses all result in a confidence interval range between lower and upper value of around €20 million.

4.3 Research question 3

When Calsol is causing significant damage in the country, risk mitigation methods can be applied as a solution. Finland and Spain are the only EU countries that answered on the survey to use risk mitigation for Calsol in Carrot farming.

In Table 14, is showed in what extent the risk mitigation measures are used in Finland. The percentages represent the share of farmers that make use of that risk mitigation method.

Table 14 Risk mitigation applied in Finland

Risk mitigation method	Finland
Sprays with insecticide	75%
Sprays with kaolin, minerals oils or botanical pesticides	NA
Nets	5%
Resistant or tolerant cultivars	NA
Increased width of the crop rotation	NA

Farmers in Finland are applying a spraying program to beat the psyllid. Most of them are using Pyrethroids (Meadow, 2010). Pyrethroids are a synthetics pesticide (Vijverberg, 1987). This is the only liquid that is used, but is experienced as ineffective. This can be due to the resistance of the psyllid or sheltered position of the psyllids in the curled leaves in which way it cannot be reached. Pyrethroids are already used for a long time in Finland what makes it probably ineffective.
The number of insecticides sprayed in the years was asked in the survey. Finland filled in data for the minimum, most likely and maximum values with consecutively; 0, 6 and 13 sprays a year.

Another risk mitigation method is to cover the crop with net covers. This method is experienced as effective in countries where it is already widely used. Although there are also disadvantages related to the use of netting. The method requires more labor and results in less exposure for sunlight. It also needs enough spaces above the plants so it will not harm upcoming plants. Change in microclimate and higher humidity and temperature are other threats.
The nets can also be applied between fences. These are only effective by low flying insects (Meadow, 2010). This is not widely used in Finland yet. Although, how to work with this method is studied further by Luke. Nets are applied the whole year around.

The cost and effectiveness of the two risk mitigation methods are given in the next section.

4.4 Research question 4

The last section of the results will give the outcome if the risk mitigations used in Finland are economically justified for prevention of Calsol. This is done by comparing the situation where a risk mitigation strategy is applied with the situation where no risk mitigation is applied (scenario 2). Farmers from Finland make use of two risk mitigation methods; spraying with insecticide and nets. The questions in the survey asked for the reduction in yield and a quantification to lower quality by an affected hectare when only one specific risk mitigation method is applied. As well the cost of the risk mitigation method is asked. This is done for the additional annual cost per hectare.
First the simulation is run to evaluate the impact of the risk mitigation methods are currently applied in Finland. Secondly, simulations are run to evaluate the situation in which all farmers in Finland will make use of spraying with insecticides or insect netting. In this way it gives a representation of what the economic value will be when one of these risk mitigation measures is completely applied (Figure 21 and 22).

Damage reduction due to risk mitigation based on the expert elicitation
The expected yield decline and quality decline under the application of one of the risk mitigation measures (Table 15) as well as the annual cost per risk mitigation method per hectare (Table 16) are obtained from the survey response.

Table 15 Effect of Calsol with risk mitigation in Finland in percentage

Risk mitigation		Minimum	Most likely	Maximum
Sprays with insecticide	Yield decline of affected hectare (%)	10	25	60
	Proportion qualified to lower quality (%)	10	25	100
Nets	Yield decline of affected hectare (%)	0	0	5
	Proportion qualified to lower quality (%)	0	3	5

Table 16 Annual cost of risk mitigation in Finland in hectare in €

Risk mitigation method	Minimum	Most likely	Maximum
Sprays with insecticide	0	250	500
Nets	250	350	500

Table 17 Distributions for scenario 3

Input	Spray with insecticide	Nets
Yield decline (%)	=RiskPert(0.1;0.25;0.6)	=RiskPert(0;0;0.05)
Yield decline of affected area (%)	=RiskPert(0.1;0.25;1)	=RiskPert(0;0.03;0.05)
Yield decline due to lower quality (%)	=RiskPert(0;250;500)	=RiskPert(250;350;500)

4.4.1. Scenario 3: Model with presence of Calsol and its control strategies

Simulation result in current situation
Finnish farmers are using risk mitigation methods against the effects of Calsol. Currently, 75% of farmers spray with insecticides and only 5% of farmers make use of netting (Table 14). This means

that 20% is not using risk mitigation at all. This current usage of risk mitigation methods is simulated in scenario 3.

Table 18 simulation output of scenario 3 in current situation

Variable	Mean	90% confidence interval	
		5th percentile	95th percentile
Total yield decline of affected area (kg)	13,353,203	7,705,619	20,207,742
Total yield decline due to lower quality (kg)	12,251,722	2,069,316	5,071,114
Total annual cost of method (€)	339,941	145,466	539,692

Table 18, gives as well the range of the effect of Calsol on the different variables for the 90% confidence interval by spraying with pesticides by 75% of the Finnish farmers. The total yield decline will be for a 90% chance be between 8 million and 20 million kg. The total quality decline will be for a 90% chance be between 2 million and 5 million kg. This makes the total decline in kg be between 9 million and 32 million kg. The total annual cost will be between €145 thousand and €540 thousand. This means that when 75% of the Finnish farmers spray with pesticides this will results still in a wide range of the effect of Calsol.

The correlation between price and yield, and quantity and quality are already been studied in research question 2. So, for the correlation between price and yield again a correlation of -0.4 is been taken. And, for the correlation between quantity and quality decline again 0.6 is been taken.

In Figure 17 and 18 different situations are shown. The different colors represent different situations.
Red: Economic value of carrot farming in Finland (Baseline, scenario 1)
Blue: Economic value of carrot farming in Finland with Calsol and no risk mitigation methods (scenario 2)
Green: Economic value of carrot farming in Finland with Calsol with the current situation of risk mitigation methods (scenario 3)

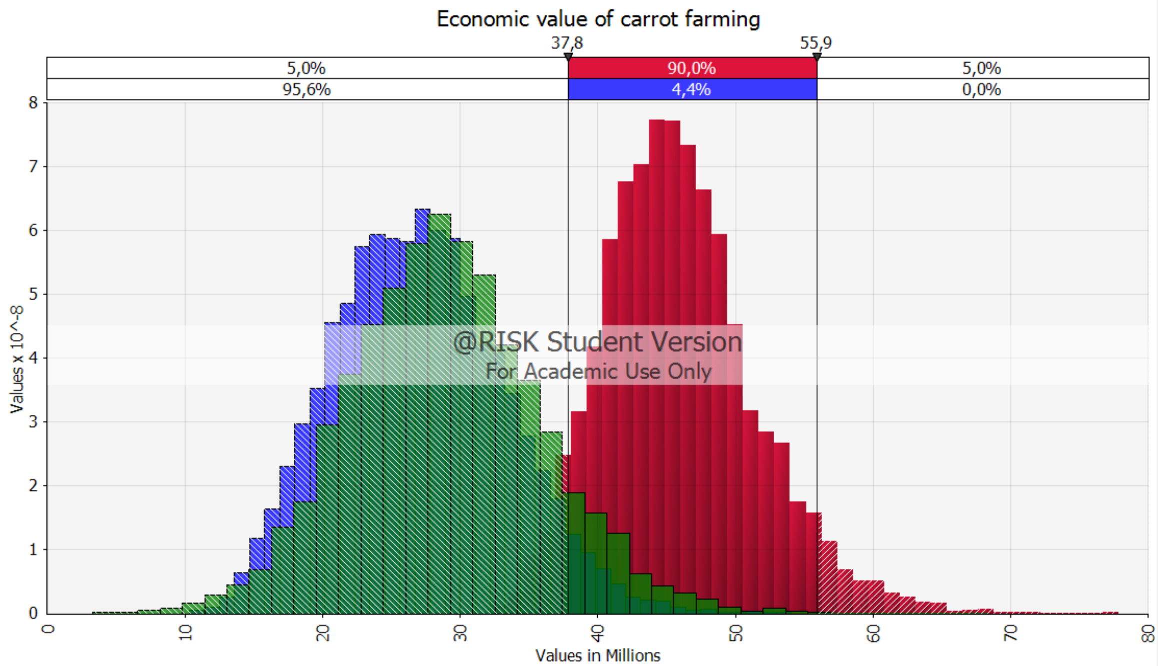

Figure 17 Distribution graph of scenario 3 in current situation

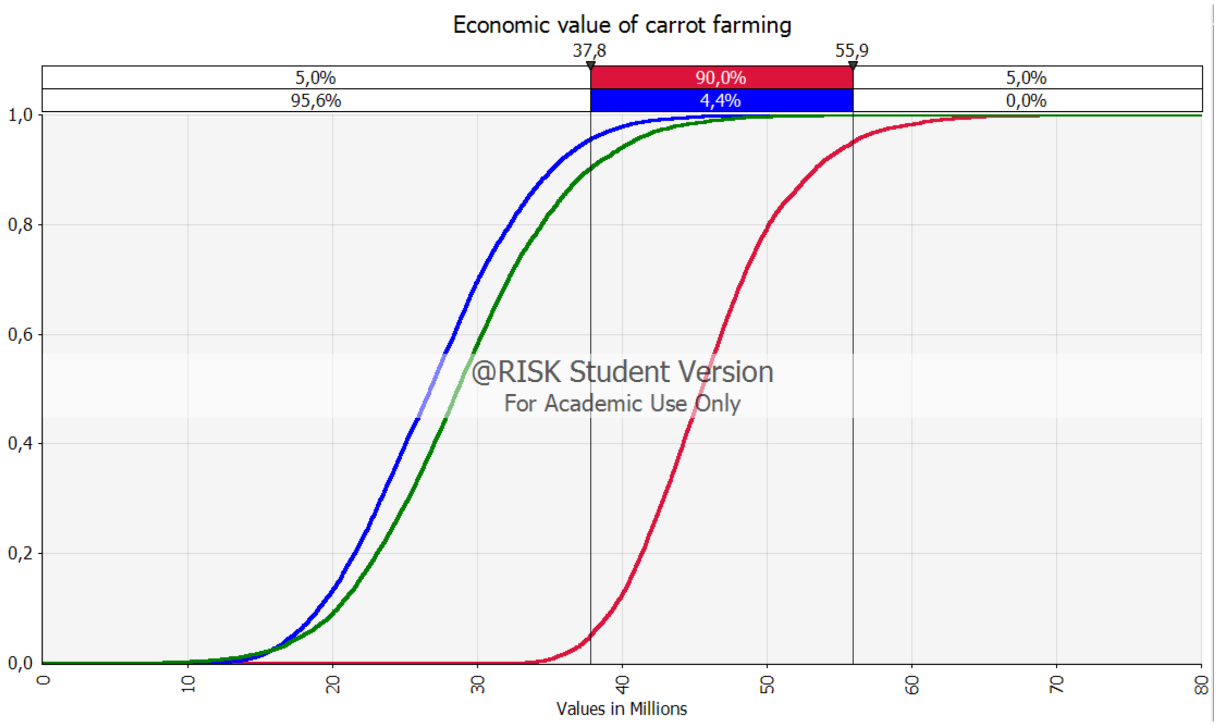

Figure 18 Cumulative graph of scenario 3 in current situation

Table 19 Output of scenario 3 in current situation

	Scenario 1	Scenario 2	Scenario 3 in current situation
Mean	45,977,232	26,947,176	28,842,650
5th percentile	37,824,839	17,208,770	17,906,326
95th percentile	55,907,492	37,474,551	40,636,682

Table 19, gives the output for the economic values of the three scenarios. The mean of the economic value with Calsol and the use of the risk mitigation methods in current situation is €29 million (90% CI = [€18, €41 million]). So when risk mitigation methods are applied there is as well a wide variation in the total economic value.

In the next simulation it is investigated what the effect will be when spraying with insecticides and netting are used on all the carrot growing hectares in Finland.

Simulation results by 100% application

In this section are the variables simulated when the risk mitigation methods are used on the whole area. After defining the distribution of the data for the two risk mitigation method the obtained value are represented in Table 20 and 21.

Table 20 Simulation output scenario 3 by 100% application, spraying insecticides

Variable	Mean	90% confidence interval	
		5th percentile	95th percentile
Total yield decline of affected area (kg)	13,375,422	7,081,105	21,243,316
Total yield decline due to lower quality (kg)	11,841,182	4,736,473	21,652,447
Total annual cost of method (€)	413,625	156,565	670,685

In Table 20, the mean are given but as well the 90% confidence interval by 100% use of spraying with pesticides by Finnish farmers. The range of total yield decline is between 1 million kg and 21 million kg. The total quality decline lays between 5 million kg and 22 million kg. The total decline will thereby be between 6 million kg and 53 million kg. The total annual cost will be between €157 thousand and €670 thousand.

Table 21 Simulation output of scenario 3 by 100% application, netting

Variable	**Mean**	**90% confidence interval**	
		5th percentile	**95th percentile**
Total yield decline of affected area (kg)	393,395	24,076	1,063,865
Total yield decline due to lower quality (kg)	1,326,396	574,735	2,014,686
Total annual cost of method (€)	592,863	471,235	725,680

The total yield decline when netting is used by 100% of the Finnish farmers will be for 90% confident be between 24 thousand and 1 million kg. And for the quality decline between 575 thousand and 2 million kg. This makes the total decline be between 599 thousand and 3 million. The total annual cost will be between €471 thousand and €726 thousand.
The variance by netting is smaller than by spraying with pesticides, this is because Calsol will have less chance on causing effect by netting.

In Figure 21 and 22 the economic values under the different situations are presented.
Red: Economic value of carrot farming in Finland (Baseline, scenario 1)
Blue: Economic value of carrot farming in Finland with Calsol and no risk mitigation methods (scenario 2)
Green: Economic value of carrot farming in Finland with Calsol by 100% application of spraying pesticides (scenario 3)
Purple: Economic value of carrot farming in Finland with Calsol by 100% application of nets (scenario 3)

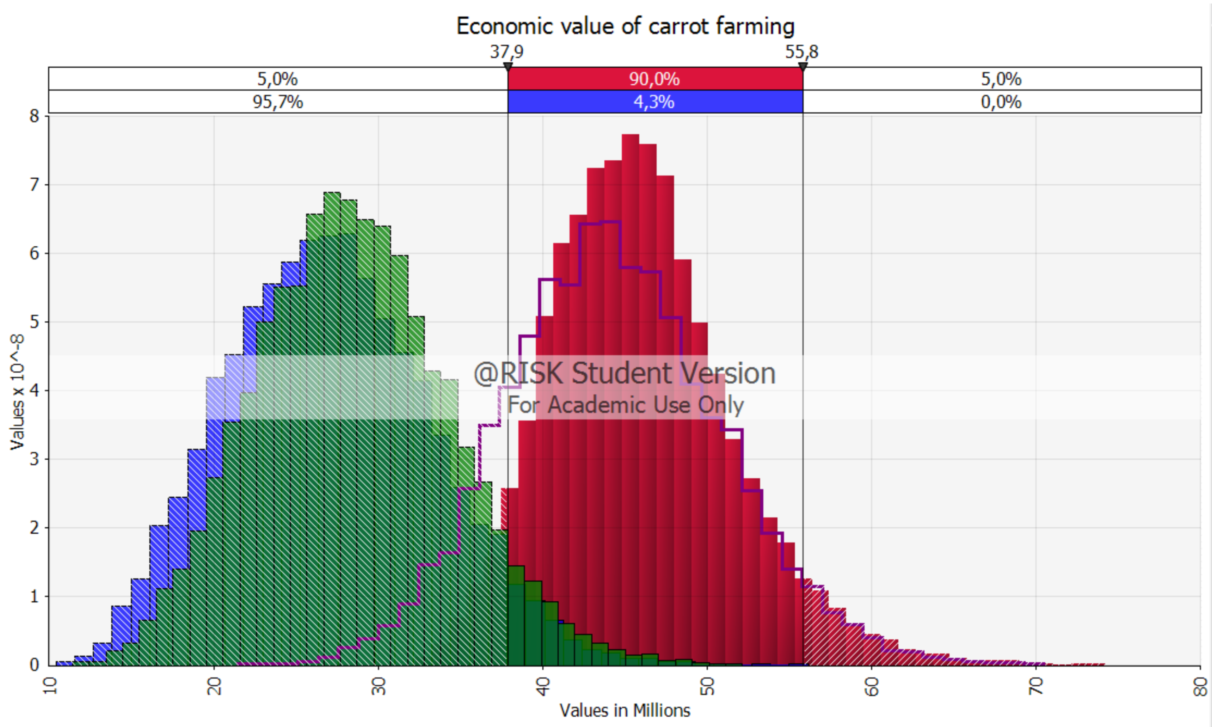

Figure 19 Distribution graph of scenario 3 when applied on 100% of carrot growing area in Finland

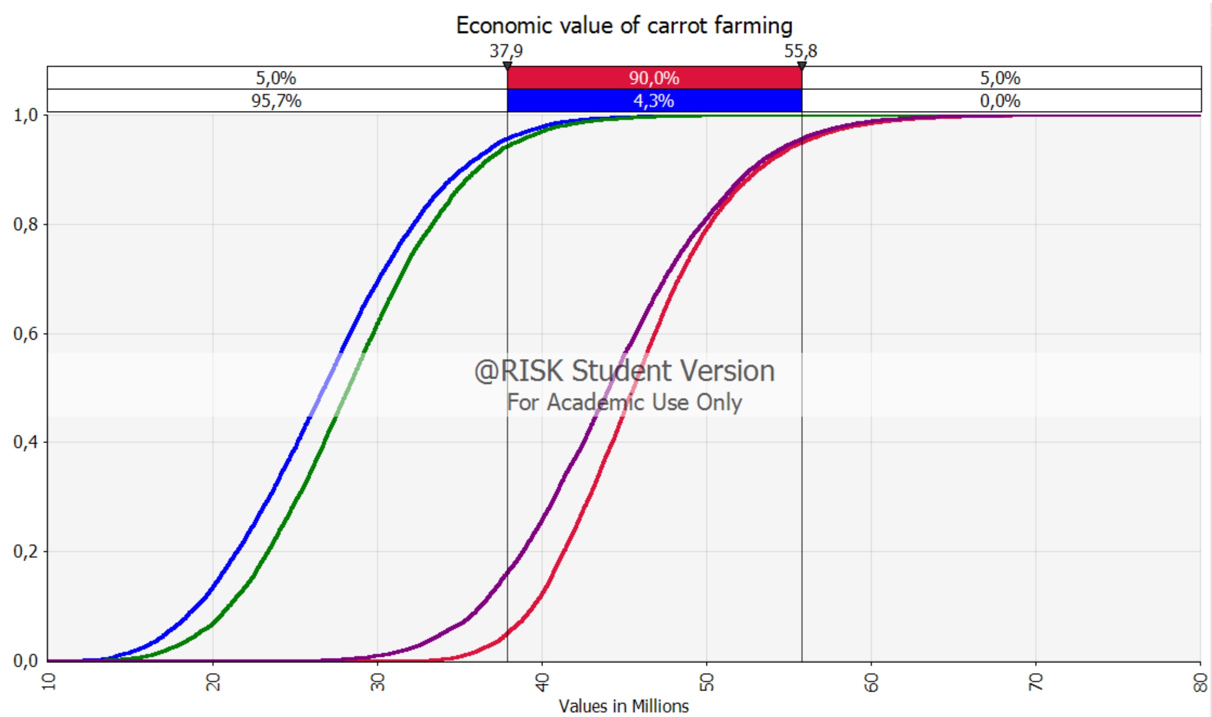

Figure 20 Cumulative graph of scenario 3 when applied on 100% of carrot growing area in Finland

From Figure 22 the stochastic dominance is analyzed. Based on first stochastic dominance the red line dominates per definition because it represents the unaffected state. The purple line dominates the green and blue line. This means that the use of netting is favorable when it will be used by a 100% application. Green dominates blue (Hardaker, no date). Which indicates that it is always better – from an economic point of view - to spray insecticides than using no risk mitigation methods at all.

Table 22 Output of scenario 3 by 100% application

	Scenario 1	Scenario 2	Scenario 3 by 100% application (spraying pesticides)	Scenario 3 by 100% application (nets)
Mean	45,977,232	26,947,176	28,416,980	44,279,411
5th percentile	37,824,839	17,208,770	19,140,312	34,018,278
95th percentile	55,907,492	37,474,551	38,696,225	55,084,830

Table 22, gives the exact means for the economic value of carrot farming in Finland by the use of spraying pesticides (€28 million) and the use of netting (€44 million). The 90% confidence interval for spraying with insecticides is between €19 million and €39 million, while for netting between €34 million and €55 million.

5. Discussion

5.1. Research question 1

The total economic value of carrot farming in the EU was for 2017 equal to €1,727 million. A large value that shows that there is an economic risk if Calsol causes damage in carrot farming in the EU.

The United Kingdom and Poland are the highest carrot producing EU countries. Carrots in the UK are almost harvested whole year around due to different climates and techniques (Great Britisch Carrots, 2019). The database of Tridge (Global Trade Platform) as well confirms that Poland is a high carrot production country in the EU (Tridge, 2016). A reason for the high share in carrot farming area and production can be that carrot are the second most grown vegetable in Poland (Szwejkowska, Winnicki and Duchovskis, 2009). The Netherlands is as well a high producer and also have carrots as second most important grown vegetable for the country after unions (DCA Mulitmedia, 2017).
When analyzing the economic value of carrot farming in the EU not all the data of the production volume were present. For this, the FAO database is used. The limitation of this database is that it has no specific data for carrot production. The production volume of carrots are given together with the production volume of turnips for the separate EU countries. So, for a few EU countries the economic value of carrot farming could not be derived that accurate. When this data is needed for a specific EU country this accurate information needs to be obtained from a specific database of the country itself. This was done for Finland in this study.

5.2. Research question 2

What is currently the economic damage of Calsol in carrot production in the EU?

The average expected economic damage of Calsol in carrot production in Finland is €19 million. This is found by comparing the situation with and without Calsol. The average economic value of carrot farming without Calsol in Finland is estimated at an average of €46 million. This value has a 90% confidence interval between €38 million (5th percentile) and €56 million (95th percentile).
The economic value of carrot farming with Calsol in Finland was equal to an average of €27 million. This value has a 90% confidence interval between €17 million and €37 million. The means show that there is a reduction of 40%, indicating that Calsol is causing real damage in Finland.

In research question two the responses on the survey of POnTE were used for the first time. The project team within POnTE was dissatisfied with the rate of responses. Why the experts weren't triggered to fill in the survey can be due to several factors. It could be too long, too difficult or the expert did not see Calsol as a potential threat in their country (which in some cases (Germany, Sweden) was confirmed).
This survey is filled in by plant experts from EU countries. The research made in this study has an economic focus. Plant experts have pathological knowledge and do not have that much knowledge about the economic influence of a plant disease. Interdisciplinary research is needed to investigate the impact of Calsol. Because both economic numbers and the reduction numbers of yield and quality on a plant are needed.
An advice for improvement in the response rate is to perform the survey face-to-face by the experts. In this way there is a lower chance on misunderstanding about the questions. As well, the respondents will have the feeling that their knowledge is important. Of course the experts are all diffused over Europe. For this, it would be better to find a convention/meeting where experts will gather together.

The economic value of carrot farming in Finland in research question one and two were determined in different ways. This value derived by research question one was only based on the year 2017. The

data in research question two were coming from Finland research centers themselves and provided an estimation over multiple years. The prices for carrots derived in research question one (Eurostat, 2018b) are approximately the same as the carrot prices derived for the model building in research question two for Finland (Kasvistieto Oy, 2018).
The economic value of carrot farming in Finland resulting from research question one equaled 42.8 million. The mean results in the model of scenario one equaled 46 million. The €46 million is considered a realistic estimation for the economic value of carrot farming in Finland.

There was not a clear answer in which proportion the quality is qualified when it is classified as low quality instead of high quality. For this it is assumed that when it is qualified to a lower quality this is seen as a yield loss. In this research only 'zero', 25% and 50% rest value of quality is investigated. Zero value has the same average value as scenario 2; €27 million (90% CI = [€17, €37 million]). Where 25% rest value as an average of €29 million (90% CI = [€19, €39 million]) and 50% average rest value of €31 million (90% CI = [€21, €41 million]. So, when the rest value will go from 'zero' to 50% rest value for quality this will have an average increase in economic value of €4 million (15%).
Between the average total economic values is a difference of around four million euros. To make the calculations more exact for the share of quality loss per volume of carrots this assumption needs further research.

The appearance of Calsol in other regions in Europe will have different epidemiology of the Calsol and it(s) vectors (Luke, 2018c). So when the economic impact of Calsol will be studied for other EU countries this need to be taken into account. The exact same assumptions cannot be made. The economic impact assessment need to be done in the different EU countries separately.

5.3. Research question 3

Spraying with insecticide is used by 75% of the farmers in Finland. Although this risk mitigation is experienced as ineffective by the farmers.
The use of insect netting is expected to be more effective but is currently only used by 5% of the famers in Finland.

In research question two it is proven that Calsol is causing a significant damage in Finland. When the data for research question three is analyzed farmers in Finland do not use enough risk mitigation yet. When you compare the current situation of risk mitigation against Calsol and the actual damage of Calsol Finland needs to consider a change in their management strategy.

Finland is currently investigating the use of insect netting. In summer 2018 a group of Finnish farmers went to Norway to study the method where it is already applied on a larger scale. The use of netting is as well experienced to have prevention against other plant diseases. In Sweden this method was first used against another psyllid. Later it was experienced that netting was also preventing against the psyllids that transmits Calsol. These benefits can as well apply for Finland (Luke, 2018c).

5.4. Research question 4

In the last research question it is investigated if the risk mitigation methods applied in Finland are economically justified. Insect netting will be more profitable when it is used more in Finland than it is used in the current extent (5% of the Finnish farmers use netting). As well, spraying with insecticides is economically justified. Although this is not that effective as netting.

In this study only two risk mitigation methods are investigated in Finland. This is because these two are only used in Finland at the moment. So, only for these two risk mitigation measures data is available about the yield and quality losses when a risk mitigation method is applied. Data on the effect of other methods are not available for Finland. To make this a full research these could also be studied. The other risk mitigation could be spraying with kaolin, mineral oils or botanical pesticides, resistant or tolerant cultivars and increased width of the crop rotation in time. To investigate these risk mitigation methods knowledge about the effect of them and the cost in Finland are needed. Effect of risk mitigation differ among the EU due to different climates.

The zero cost by the minimum use of spraying with insecticides are farmers that don't make cost for spraying with insecticides but normally do. A possible explanation might be that when a farmer would normally spray against psyllids curatively, but some years no psyllids show up, so he does not have to spray.

The first simulation of scenario 3 shows the economic value of carrot farming in Finland with Calsol and the use of risk mitigation in the current situation. This 75% use of spraying with insecticides and 5% of netting. So, in this situation there are as well carrot growing area with no risk mitigation (20%). For these hectares there is assumed that there is damage as stated in scenario 2. This gives an average value of €29 million (90% = [€18, €41 million]).
This scenario is as well simulated for the use of the risk mitigations for 100% application. This gives an average value for spraying of €28 million (90% = [€19, €39 million]) and for netting an average value of €44 million (90% = [€34, €55 million]). This proves that netting is more effective then spraying.

The cost of netting in Finland are given per year. It is now not taken into account that the material of netting can be used over more than one year. It is not clear now of this fact is taken into account in the given data. For this it is needed to have the knowledge about the depreciation period. Furthermore, when netting is applied in Finland this can as well be beneficial for other vectors of plant diseases. If this is the case the cost of netting can as well be assigned to the prevention for other plant diseases. This makes insect netting for Calsol even more profitable.

In an earlier research it is found that netting has as well negative impacts on the growth of apples. Netting can also has a negative impact on the growth of carrots. This is due to less exposure to sunlight, change in microclimate and a higher humidity and temperature (Bosančić *et al.*, 2018). Other disadvantages than found in data for the results can be that there is more land space needed for applying the nets over the crops. When these negative impacts induce more than or come close to the prevented damage of Calsol this method will not be profitable anymore. So probably in this research the economic value with use of netting is slightly overestimated. To truly factor these negative effects out, further research is needed.

Evaluated risk mitigation options indicated that the use of insect netting against Calsol and it(s) vector is more effective option for Finland than the use of insecticides.

The negative impacts cannot exceed on average €15 million (€44 million – €29 million, Table 22) or netting will not be profitable for carrots anymore. This would mean that the netting should cause a decrease in yield of 34% on average. This is not likely.
These values are again exposed to variation. So, when the 5th percentiles are assumed it cannot exceed €15 million (€34 million - €19 million, Table 22). And, when the 95th percentiles are assumed it cannot exceed again €16 million (€55 million - €39 million, Table 22).

Above, is discussed that insect netting is the most profitable method out of the two used in Finland. It would be the best solution if this method would be used more in Finland instead of spraying with insecticides. At the moment, Finnish farmers look at this strategy if this method would work out better for them (Luke, 2018c).

Currently there is no European regulation to prevent further spreading of Calsol haplotypes C, D and E and it(s) vectors. As stated above, netting is an economically justified risk mitigation method against Calsol. This means that when Finnish farmers are confronted with Calsol, it is profitable for them to adopt netting. Regulation on a European scale is therefore not necessary, as farmers would adopt this risk mitigation method on their own.

6. Conclusion

The total economic value of carrot farming in the EU was for 2017 €1,727 million.
This study focused further on Finland due to the fact that this is the only EU country that really experiences impact of the plant disease Calsol. The economic value of carrot farming in Finland equals on average €46 million (90%CI = [€38, €56 million]). The economic value of carrot farming in Finland with Calsol equals on average €27 million (90%CI = [€17, €37 million]). The estimated impact of Calsol in a situation without any control is estimated at an average of €19 million/year. This is a reduction of 40% compared with the situation without any risk of Calsol.

At the moment, 75% of the Finnish farmers makes use of spraying with pesticide. Although this risk mitigation method is experienced as ineffective by Finnish carrot farming (Luke, 2018c). Only, 5% of the farmers apply insect netting to their fields to protect against the psyllid *Trioza Apicalis*.

From the two risk mitigation methods applied it is investigated if these are economically justified. The two risk mitigation methods are economically justified when they are used in current extent with an economic value of €29 million (90% CI = [€18, €41 million]).

This is different when the two risk mitigation methods would be separately applied by all carrot growers in Finland. When only spraying with insecticides is used this mitigation option is barely economically justified. The economic value of carrot farming in Finland with Calsol and spraying with insecticides is €28 million (90% CI = [€19 million, €39 million]). This risk mitigation will only be profitable when the economic value of carrot farming with Calsol and the use of spraying with insecticides is at the higher side of the confidence interval (Economic value without risk mitigation is €27 million).
Insect netting is not widely used in Finland just yet. However based on a 100% application this risk mitigation method would by far be the most effective method. The economic value of carrot farming in Finland with Calsol and insect netting is €44 million (90% CI= [€34 million - €55 million]). The situation with the economic value of carrot farming in Finland with Calsol and insect netting applied is less than €2 million lower of the economic value of carrot farming in Finland if there would be no effect of Calsol.

To conclude, Calsol is not having a big impact on the economics of carrot farming in the EU at this moment. Although in Finland Calsol is causing a large economic impact in carrot farming.

As such European regulation is not necessary for prevention of Calsol haplotype C. This can be concluded from the fact that netting is an economically justified risk mitigation method that can be applied by the Finnish farmers.

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8. Appendix

7.1. Appendix 1

Survey of POnTE set out by plant experts

Questionnaire on the presence, impact and control of CaLsol and its vector(s) across Europe

Start of Block: General Information

Q1 **Name**

____

Q2 **Country**

____

Q3 **Organization**

____

Q4 **Position Title**

____

This survey intends to assess the current impact of CaLsol and its vector(s) in the European Union, as well as the effects of different control strategies. The expected time to completion is around 30 minutes.

Please answer the questions for your country as a whole. Use information that you have on specific regions only to inform your estimates for the whole country.

For some questions, we will ask you to provide a quantitative estimate, e.g. the proportion of the carrot growing area affected by CaLsol. For such quantitative estimates, we ask that you express

your knowledge taking into account uncertainties. We therefore ask you to specify what you consider the most likely value, as well as the minimum and maximum value that you consider possible.

If you have any questions, please do not hesitate to contact us under:

kevin.schneider@wur.nl

End of Block: General Information

Start of Block: Current extent

Section 1: Current Extent

In this section, we ask questions about the current impact of CaLsol and its vector(s) in your country. When answering questions about the impact of CaLsol and its vector(s) on carrot yield and quality, please compare the current situation to a hypothetical scenario without CaLsol and its vector(s). Most questions pertain to CaLsol and its vector(s) without distinguishing the two, because there is very little information on which damage is caused by the bacterium and which damage by the vectors. The two kinds of damages are therefore considered in aggregate.

QP **Which part of the carrot production you are considering?** *Please tick the industry you are most familiar with and answer all succeeding question for the chosen product. If you not expect different impacts on yield, feel free to tick both options.*

- ☐ Fresh market
- ☐ Industry

Q5 **How large is the carrot growing area in your country?**

If you are uncertain, please indicate a minimum, most likely and maximum value in hectare. If you are certain about the area of production feel free to just indicate the most likely value.

- ◯ Minimum area (in hectare) ____

- ◯ Most likely area (in hectare) ____

- ◯ Maximum area (in hectare) ____

Q6 **Which haplotypes of CaLsol are currently the most important in terms of the expected economic impact in your country?**

Please select one or multiple haplotypes by rating their importance in terms of the economic impact. Please assign the value 0 in case a haplotype is not present or has no economic impact in your country. Use 100 if the haplotype is causing sizable economic impact.

0 10 20 30 40 50 60 70 80 90 100

A	
B	
C	
D	
E	

Q7 **Which haplotypes of CaLsol are currently the most important in terms of their distribution in your country?**

Please select one or multiple haplotypes by rating their importance in terms of their distribution. Please assign the value 0 in case a haplotype is not present in your country. Use 100 if the haplotype is widely spread.

0 10 20 30 40 50 60 70 80 90 100

A	
B	
C	
D	
E	

Q8 **Which vectors of CaLsol are present in your country?**
Please write down one or multiple vector species.

- ○ 1) ____
- ○ 2) ____
- ○ 3) ____
- ○ 4) ____

Q9 **Which vectors are the most important in terms of the dispersal of CaLsol in your country?**
Please rate the importance of the vectors in terms of the dispersal of CaLsol. Please assign the value 0 if the vector is not involved in the dispersal. Use 100 if the vector is very important for the dispersal of CaLsol.

0 10 20 30 40 50 60 70 80 90 100

1	
2	
3	
4	

Q10 **Which vectors are the most important in terms of the expected economic impact caused by the vector in your country?**
Please rate the importance in terms of the economic impact caused by the vector. Please assign the value 0 if the vector does not have any economic impact. Use 100 if the vector is causing sizable economic impact.

	0 10 20 30 40 50 60 70 80 90 100
1	
2	
3	
4	

Q11 **Do the vector species in your country cause direct damage to the crop?**

◯ Yes

◯ No

◯ I do not know

Display This Question:

If Q11 = Yes

Q12 **What percentage of the total damage (i.e. loss in yield and quality) to the crop is expected to be caused by CaLsol and what percentage by the vectors?**
Please indicate a minimum, most likely and maximum values for CaLsol and the vector(s).

- ◯ Minimum percentage of the total damage caused by CaLsol
____
- ◯ Most likely percentage of the total damage caused by CaLsol
____
- ◯ Maximum percentage of the total damage caused by CaLsol
____
- ◯ Minimum percentage of the total damage caused by the vector(s)
____
- ◯ Most likely percentage of the total damage caused by the vector(s)
____
- ◯ Maximum percentage of the total damage caused by the vector(s)
____

Q13 **Which part of the carrot growing area in your country is expected to be affected by CaLsol and its vector(s)? Here, a**ffected means that the disease or its vector(s) are present.
Please indicate a minimum, most likely and maximum value.

- ◯ Minimum area affected (in %) ____
- ◯ Most likely area affected (in %) ____
- ◯ Maximum area affected (in %) ____

Q14 **In absence of CaLsol and its vector(s), what is the average carrot yield in tonnes per hectare in your country? Please indicate representative averages for your country across different years.**

○ Minimum yield (t/ha) ____

○ Most likely yield (t/ha) ____

○ Maximum yield (t/ha) ____

Q15 **Given that a hectare is affected by CaLsol and its vector(s), what is the expected average yield reduction (in % of harvested carrots) under current farming practices? Please indicate representative averages for your country across different years.** *Please indicate a minimum, most likely and maximum value.*

○ Minimum yield reduction (in %) ____

○ Most likely yield reduction (in %) ____

○ Maximum yield reduction (in %) ____

Q16 **Given that a hectare is affected by CaLsol and its vector(s), what is the expected average increase in proportion of carrots (in % of harvested carrots) that is classified as low quality instead of high quality under current farming practices?** Please indicate representative averages for your country across different years.

Please indicate a minimum, most likely and maximum value.

○ Minimum increase in yield classified into the lower quality category (in %)

____

○ Most likely increase in yield classified into the lower quality category (in %)

____

○ Maximum increase in yield classified into the lower quality category (in %)

____

Q17 **What is the average difference in price per ton of high quality carrots versus low quality carrots in your country?**
Please indicate a minimum, most likely and maximum value.

○ Minimum difference (Euro per ton)
____

○ Most likely difference (Euro per ton)
____

○ Maximum difference (Euro per ton)
____

End of Block: Current extent

Start of Block: Control Strategies

Section 2: Control Strategies (disease management)

In this section, we will ask you questions about the potential control strategies (disease management) against CaLsol and its vector(s) in your country. When answering questions about the impact of CaLsol and its vector(s) on carrot yield and quality in presence of a given strategy, please compare each scenario to the hypothetical situation without CaLsol and its vector(s).

Q18 **Which control strategies are used for CaLsol in carrots in your country?**
Please indicate only those measures that are applied *__specifically__* *against CaLsol and its vector(s). More than one option may be applied.*

- ☐ Sprays with insecticide
- ☐ Sprays with kaolin, mineral oils or botanical pesticides
- ☐ Nets
- ☐ Resistant or tolerant cultivars
- ☐ Increased width of the crop rotation in time
- ☐ No measures available
- ☐ No measures used

Q19 **What percentage of farmers in your country applies control strategies against CaLsol?**
Please indicate the most likely value.

- ○ Sprays with insecticide ____
- ○ Sprays with kaolin, mineral oils or botanical pesticides ____
- ○ Nets ____
- ○ Resistant or tolerant cultivars ____
- ○ Increased width of the crop rotation ____
- ○ No measures used ____

Q20 **Given that a hectare is affected with CaLsol and its vector(s), what is the expected average yield reduction (in % of harvested carrots) <u>if nothing is done</u> to control CaLsol and its vector(s)? Please indicate representative averages for your country across different years.** *Please indicate a minimum, most likely and maximum value.*

- ◯ Minimum yield reduction (in %) ____
- ◯ Most likely yield reduction (in %) ____
- ◯ Maximum yield reduction (in %) ____

Display This Question:

If Q18 = Sprays with insecticide

Q21 **Given that a hectare is affected with CaLsol and its vector(s), what is the expected average yield reduction (in % of harvested carrots) <u>if the farmer would only spray insecticides</u>? Please indicate representative averages for your country across different years.**

Please indicate a minimum, most likely and maximum value.

- ◯ Minimum yield reduction (in %) ____
- ◯ Most likely yield reduction (in %) ____
- ◯ Maximum yield reduction (in %) ____

Display This Question:

If Q18 = Sprays with kaolin, mineral oils or botanical pesticides

Q22 **Given that a hectare is affected with CaLsol and its vector(s), what is the expected average yield reduction (in % of harvested carrots) <u>if the farmer would only spray kaolin, mineral oils or botanical pesticides</u>? Please indicate representative averages for your country across different**

years.
Please indicate a minimum, most likely and maximum value.

○ Minimum yield reduction (in %) ____

○ Most likely yield reduction (in %) ____

○ Maximum yield reduction (in %) ____

Display This Question:

If Q18 = Nets

Q23 **Given that a hectare is affected with CaLsol and its vector(s), what is the expected average yield reduction (in % of harvested carrots) <u>if the farmer would only apply nets</u>? Please indicate representative averages for your country across different years.**
Please indicate a minimum, most likely and maximum value.

○ Minimum yield reduction (in %) ____

○ Most likely yield reduction (in %) ____

○ Maximum yield reduction (in %) ____

Display This Question:

If Q18 = Resistant or tolerant cultivars

Q24 **Given that a hectare is affected with CaLsol and its vector(s), what is the expected average yield reduction (in % of harvested carrots) <u>if the farmer would only cultivate resistant or tolerant cultivars</u>? Please indicate representative averages for your country across different years.**
Please indicate a minimum, most likely and maximum value.

○ Minimum yield reduction (in %) ____

○ Most likely yield reduction (in %) ____

○ Maximum yield reduction (in %) ____

Display This Question:

If Q18 = Increased width of the crop rotation in time

Q25 **Given that a hectare is affected with CaLsol and its vector(s), what is the expected average yield reduction (in % of harvested carrots) <u>if the farmer would only widen the crop rotation in time</u>? Please indicate representative averages for your country across different years.**
Please indicate a minimum, most likely and maximum value.

◯ Minimum yield reduction (in %) ____

◯ Most likely yield reduction (in %) ____

◯ Maximum yield reduction (in %) ____

Q26 **Given that a hectare is affected by CaLsol and its vector(s), what is the expected average increase in proportion of carrots (in % of harvested carrots) that is classified into a lower quality class <u>if nothing is done</u> to control CaLsol and its vector(s)? Please indicate representative averages for your country across different years.**
Please indicate a minimum, most likely and maximum value

◯ Minimum increase of yield classified into the lower quality category (in %)
____

◯ Most likely increase of yield classified into the lower quality category (in %)
____

◯ Maximum increase of yield classified into the lower quality category (in %)
____

Display This Question:

If Q18 = Sprays with insecticide

Q27 **Given that a hectare is affected by CaLsol and its vector(s), what is the expected average increase in proportion of carrots (in % of harvested carrots) that is classified into a lower quality class <u>if the farmer would only spray insecticides</u>? Please indicate representative averages for your**

country across different years.
Please indicate a minimum, most likely and maximum value

○ Minimum increase of yield classified into the lower quality category (in %)
____

○ Most likely increase of yield classified into the lower quality category (in %)
____

○ Maximum increase of yield classified into the lower quality category (in %)
____

Display This Question:

If Q18 = Sprays with kaolin, mineral oils or botanical pesticides

Q28 **Given that a hectare is affected by CaLsol and its vector(s), what is the expected average increase in proportion of carrots (in % of harvested carrots) that is classified into a lower quality class <u>if the farmer would only spray kaolin, mineral oils or botanical pesticides</u>? Please indicate representative averages for your country across different years.**
Please indicate a minimum, most likely and maximum value

○ Minimum increase of yield classified into the lower quality category (in %)
____

○ Most likely increase of yield classified into the lower quality category (in %)
____

○ Maximum increase of yield classified into the lower quality category (in %)
____

Display This Question:

If Q18 = Nets

Q29 **Given that a hectare is affected by CaLsol and its vector(s), what is the expected average increase in proportion of carrots (in % of harvested carrots) that is classified into a lower quality class <u>if the farmer would only apply nets</u>? Please indicate representative averages for your country**

across different years.
Please indicate a minimum, most likely and maximum value

○ Minimum increase of yield classified into the lower quality category (in %)
____

○ Most likely increase of yield classified into the lower quality category (in %)
____

○ Maximum increase of yield classified into the lower quality category (in %)
____

Display This Question:

If Q18 = Resistant or tolerant cultivars

Q30 **Given that a hectare is affected by CaLsol and its vector(s), what is the expected average increase in proportion of carrots (in % of harvested carrots) that is classified into a lower quality class <u>if the farmer would only cultivate resistant or tolerant varieties</u>? Please indicate representative averages for your country across different years.**
Please indicate a minimum, most likely and maximum value

○ Minimum increase of yield classified into the lower quality category (in %)
____

○ Most likely increase of yield classified into the lower quality category (in %)
____

○ Maximum increase of yield classified into the lower quality category (in %)
____

Display This Question:

If Q18 = Increased width of the crop rotation in time

Q31 **Given that a hectare is affected by CaLsol and its vector(s), what is the expected average increase in proportion of carrots (in % of harvested carrots) that is classified into a lower quality class <u>if the farmer would only widen the crop rotation</u>? Please indicate representative averages for**

your country across different years.
Please indicate a minimum, most likely and maximum value

◯ Minimum increase of yield classified into the lower quality category (in %)
____

◯ Most likely increase of yield classified into the lower quality category (in %)
____

◯ Maximum increase of yield classified into the lower quality category (in %)
____

End of Block: Control Strategies

Start of Block: Additional Costs

Section 3: Additional Costs

In this section, we will ask you questions about the costs of control strategies (disease management) against CaLsol and its vector(s) in your country. When answering questions about the additional costs of control strategies, please compare each scenario to a hypothetical situation without CaLsol and its vector(s). For example, the additional costs of spraying insecticides include the spraying efforts that are undertaken on top of the commonly practiced number of sprays.

Display This Question:
If Q18 = Sprays with insecticide

Q32 **How many additional sprays of insecticides are applied per year to control CaLsol and its vector(s)?**
Please indicate a minimum, most likely and maximum value.

◯ Minimum number of additional sprays
____

◯ Most likely number of additional sprays
____

◯ Maximum number of additional sprays
____

Display This Question:

If Q18 = Sprays with insecticide

Q33 **What are the additional annual costs of spraying insecticides? (including cost of insecticide, higher usage of spraying machine, additional labor costs, etc.)**
Please indicate a minimum, most likely and maximum value.

- ◯ Minimum (Euro per hectare) ____
- ◯ Most likely (Euro per hectare) ____
- ◯ Maximum (Euro per hectare) ____

Display This Question:

If Q18 = Sprays with kaolin, mineral oils or botanical pesticides

Q34 **What are the additional annual costs of spraying kaolin, mineral oils or botanical pesticides? (including cost of kaolin, higher usage of spraying machine, additional labor costs, etc.)**
Please indicate a minimum, most likely and maximum value.

- ◯ Minimum (Euro per hectare) ____
- ◯ Most likely (Euro per hectare) ____
- ◯ Maximum (Euro per hectare) ____

Display This Question:

If Q18 = Nets

Q35 **What are the additional annual costs of nets? (including costs of netting, cost of labor, reduced yield, etc.). Please also account for depreciation which is calculated by dividing the**

purchasing price of the netting by the number of years used.
Please indicate a minimum, most likely and maximum value.

- ◯ Minimum (Euro per hectare) ____
- ◯ Most likely (Euro per hectare) ____
- ◯ Maximum (Euro per hectare) ____

Display This Question:
If Q18 = Resistant or tolerant cultivars

Q36 **What are the additional annual costs of resistant or tolerant cultivars? (including cost of labor, reduced yield, etc.)**
Please indicate a minimum, most likely and maximum value.

- ◯ Minimum (Euro per hectare) ____
- ◯ Most likely (Euro per hectare) ____
- ◯ Maximum (Euro per hectare) ____

Q37 **In your opinion, is it possible to control CaLsol and its vector(s) with crop rotation alone?**

- ◯ Yes
- ◯ No
- ◯ I do not know

Display This Question:
If Q37 = Yes

Q38 **If you want to control CaLsol and its vectors by crop rotation alone, how much wider is such a rotation compared to the current rotation?**
Please indicate a minimum, most likely and maximum value.

○ Minimum number of years wider than the normal rotation
____

○ Most likely number of years wider than the normal rotation
____

○ Maximum number of years wider than the normal rotation
____

End of Block: Additional Costs

Start of Block: Future Scenario

Q39 **Assuming that the current measures against CaLsol and its vector(s) are maintained, which part of the carrot growing area in your country do you expect to be affected by CaLsol and its vector(s) in 5 years from now?** *Please indicate a minimum, most likely and maximum value. If you expect a reduction (increase) of the area affected indicate this with negative (positive) values.*

○ Minimum change in area affected (in %)
____

○ Most likely change in area affected (in %)
____

○ Maximum change in area affected (in %)
____

End of Block: Future Scenario

Start of Block: Contact Information

Thank you very much for participating in this survey!

If you are interested in receiving the results of this assessment, or would like to allow us to contact you in case further clarification is required, please give us your Email address below.

○ Email : ____

○ Would you like to receive the results via Email?
____

End of Block: Contact Information

7.2. Appendix 2

The EU countries

(*Landen - EUROPA | Europese Unie*, no date)

7.3. Appendix 3

Data output from survey

1									
2	name	Hellen Mathiaser	C Jeffries	Anne Nissine	Ofir Bahar	Loiseau	Foissac	Susana SanJuan	Eva Forne
3	country	Denmark	UK (Scotland)	Finland	Isreal	France	France	Spain	Germany
4	organization	HortiAdvice	SASA	Luke	ARO-Volcani Cente	ANSES-LSV	INRA	Agricola Villena	JKI
5	position	crop advisor	International Plant Health Cons	Senior Scient	Principal Investiga	Deputy head of team "virology-Phytoplasmolo	Senior scientist	Technical Manager	
6	product	Fresh market	Fresh market, Industry	Fresh market	Fresh market	NA	Fresh market, Industi	Fresh market, Ind	Fresh mar
7	prod_area_min	NA	NA	1600	NA	NA	10500	NA	NA
8	prod_area_most	2290	3500	1650	3800	NA	13500	6444	12545
9	prod_area_max	NA	NA	1700	NA	NA	14000	NA	NA
10	imp_hapl_a_impact	0	0	0	0	0	0	0	0
11	imp_hapl_b_impact	0	0	0	0	0	0	0	0
12	imp_hapl_c_impact	0	0	100	0	0	0	0	1
13	imp_hapl_d_impact	0	0	0	100	100	0	0	0
14	imp_hapl_e_impact	0	0	0	0	100	0	0	0
15	imp_hapl_a_dist	0	0	0	0	0	0	0	0
16	imp_hapl_b_dist	0	0	0	0	0	0	0	0
17	imp_hapl_c_dist	0	5	100	0	0	0	0	1
18	imp_hapl_d_dist	0	0	0	100	100	75	0	0
19	imp_hapl_e_dist	0	0	0	0	100	25	0	0
20	name_vector	NA	Trioza apicalis, Trioza anthrisci	Trioza apicali	Bactericera trigoni	Bactericera trigonica	Bactericera trigonica	Bactrocera trigoni	T.apicalis
21	imp_vector_disp	NA	0, 0	100	100	100	100	NA	1
22	imp_vector_impact	NA	0, 0	100	100	100	0	NA	1
23	vector_direct_dmg	2	2	1	2	0	2	2	1
24	dmg_share_calsol_min	NA	NA	10	NA	NA	NA	NA	NA
25	dmg_share_calsol_most	NA	NA	15	NA	NA	NA	NA	NA
26	dmg_share_calsol_max	NA	NA	30	NA	NA	NA	NA	NA
27	dmg_share_vector_min	NA	NA	60	NA	NA	NA	NA	NA
28	dmg_share_vector_most	NA	NA	75	NA	NA	NA	NA	NA
29	dmg_share_vector_max	NA	NA	100	NA	NA	NA	NA	NA
30	area_affected_min	NA	NA	60	NA	5	5	50	NA
31	area_affected_most	0	0	70	100	10	20	60	10
32	area_affected_max	NA	NA	80	NA	15	40	NA	NA
33	normal_yield_min	50	NA	40	82	NA	36	20	NA
34	normal_yield_most	55	75	70	83,5	NA	55	55	58,5
35	normal_yield_max	60	NA	90	85	NA	68	70	NA

36	current_yield_decline_min	NA	NA	10	3	0	0	3	NA
37	current_yield_decline_most	NA	0	25	4	1	2	20	1
38	current_yield_decline_max	NA	NA	100	20	2	10	100	NA
39	current_quality_decline_min	NA	NA	15	<1	0	NA	3	NA
40	current_quality_decline_most	NA	0	30	1	1	NA	20	NA
41	current_quality_decline_max	NA	NA	100	4	2	NA	100	NA
42	price_difference_min	NA	NA	440	25%	NA	NA	10	NA
43	price_difference_most	NA	300	500	50%	NA	NA	50	NA
44	price_difference_max	NA	NA	660	100%	NA	NA	69	NA
45	insecticides_used	0	0	1	1	0	0	0	0
46	kaolin_used	0	0	0	0	0	0	1	0
47	nets_used	0	0	1	0	0	0	0	0
48	resistant_used	0	0	0	0	0	0	0	0
49	rotation_used	0	0	0	0	0	0	1	0
50	unavailable_used	0	0	0	0	0	0	1	0
51	no_measures_used	1	1	1	0	1	1	0	1
52	share_farms_insecticides	NA	0	75	100	0	0	0	NA
53	share_farms_kaolin	NA	0	0	0	0	0	30	NA
54	share_farms_nets	NA	0	5	0	0	0	0,5	NA
55	share_farms_resistant	NA	0	0	0	0	0	0	NA
56	share_farms_rotation	NA	0	0	0	0	0	30	NA
57	share_farms_no	NA	0	20	0	100	100	70	100
58	nothing_yield_decline_min	NA	NA	0	3	0	1	NA	NA
59	nothing_yield_decline_most	NA	0	35	15	1	2	NA	NA
60	nothing_yield_decline_max	NA	NA	100	50	2	5	NA	NA
61	insecticides_yield_decline_m	NA	NA	10	3	NA	NA	NA	NA
62	insecticides_yield_decline_m	NA	NA	25	5	NA	NA	NA	NA
63	insecticides_yield_decline_m	NA	NA	60	10	NA	NA	NA	NA
64	kaolin_yield_decline_min	NA	NA	NA	NA	NA	NA	NA	NA
65	kaolin_yield_decline_most	NA	NA	NA	NA	NA	NA	NA	NA
66	kaolin_yield_decline_max	NA	NA	NA	NA	NA	NA	NA	NA
67	nets_yield_decline_min	NA	NA	0	NA	NA	NA	NA	NA
68	nets_yield_decline_most	NA	NA	0	NA	NA	NA	NA	NA
69	nets_yield_decline_max	NA	NA	5	NA	NA	NA	NA	NA
70	resistant_yield_decline_min	NA	NA	NA	NA	NA	NA	NA	NA
71	resistant_yield_decline_most	NA	NA	NA	NA	NA	NA	NA	NA
72	resistant_yield_decline_max	NA	NA	NA	NA	NA	NA	NA	NA
73	rotation_yield_decline_min	NA	NA	NA	NA	NA	NA	NA	NA
74	rotation_yield_decline_most	NA	NA	NA	NA	NA	NA	NA	NA
75	rotation_yield_decline_max	NA	NA	NA	NA	NA	NA	NA	NA
76	nothing_quality_decline_min	NA	NA	30	2	0	NA	NA	NA
77	nothing_quality_decline_mos	NA	0	50	10	1	NA	NA	NA
78	nothing_quality_decline_max	NA	NA	100	50	2	NA	NA	NA
79	insecticides_quality_decline_	NA	NA	10	1	NA	NA	NA	NA
80	insecticides_quality_decline_	NA	NA	25	5	NA	NA	NA	NA
81	insecticides_quality_decline_	NA	NA	100	10	NA	NA	NA	NA
82	kaolin_quality_decline_min	NA	NA	NA	NA	NA	NA	NA	NA
83	kaolin_quality_decline_most	NA	NA	NA	NA	NA	NA	NA	NA
84	kaolin_quality_decline_max	NA	NA	NA	NA	NA	NA	NA	NA
85	nets_quality_decline_min	NA	NA	0	NA	NA	NA	NA	NA
86	nets_quality_decline_most	NA	NA	3	NA	NA	NA	NA	NA
87	nets_quality_decline_max	NA	NA	5	NA	NA	NA	NA	NA
88	resistant_quality_decline_mi	NA	NA	NA	NA	NA	NA	NA	NA
89	resistant_quality_decline_mo	NA	NA	NA	NA	NA	NA	NA	NA
90	resistant_quality_decline_ma	NA	NA	NA	NA	NA	NA	NA	NA
91	rotation_quality_decline_min	NA	NA	NA	NA	NA	NA	NA	NA
92	rotation_quality_decline_mo	NA	NA	NA	NA	NA	NA	NA	NA
93	rotation_quality_decline_ma	NA	NA	NA	NA	NA	NA	NA	NA
94	number_sprays_min	NA	NA	0	6	NA	NA	NA	NA
95	number_sprays_most	NA	NA	6	8	NA	NA	NA	NA
96	number_sprays_max	NA	NA	13	14	NA	NA	NA	NA
97	cost_insecticides_min	NA	NA	0	280	NA	NA	NA	NA
98	cost_insecticides_most	NA	NA	250	375	NA	NA	NA	NA
99	cost_insecticides_max	NA	NA	500	660	NA	NA	NA	NA
100	cost_kaolin_min	NA	NA	NA	NA	NA	NA	NA	NA
101	cost_kaolin_most	NA	NA	NA	NA	NA	NA	NA	NA
102	cost_kaolin_max	NA	NA	NA	NA	NA	NA	NA	NA
103	cost_nets_min	NA	NA	250	NA	NA	NA	NA	NA
104	cost_nets_most	NA	NA	350	NA	NA	NA	NA	NA
105	cost_nets_max	NA	NA	500	NA	NA	NA	NA	NA
106	cost_resistant_min	NA	NA	NA	NA	NA	NA	NA	NA
107	cost_resistant_most	NA	NA	NA	NA	NA	NA	NA	NA
108	cost_resistant_max	NA	NA	NA	NA	NA	NA	NA	NA
109	rotation_alone	0	2	2	2	0	1	1	2
110	rotation_width_min	NA	NA	NA	NA	NA	NA	NA	NA
111	rotation_width_most	NA	NA	NA	NA	NA	NA	NA	NA
112	rotation_width_max	NA	NA	NA	NA	NA	NA	NA	NA
113	future_area_min	NA	NA	5	100	0	1	NA	NA
114	future_area_most	NA	0	10	100	1	2	NA	1
115	future_area_max	NA	NA	15	100	2	10	NA	10

7.4. Appendix 4

Stochastic simulation and scenarios excel file.

Scenario 1

Scenario 1: The model without presence of Calsol (Baseline)			
Finland			
Carrot growing area in hectares	1654		
Minimum	1480		
Maximum	1833		
		Total production	
Average carrot yield (kg/hectare)	40154		66425959
Minimum	35370		
Maximum	44939		
Carrot market price (€/kg)	0,69		
Minimum	0,61		
Maximum	0,88		
Economic value of carrot farming	46126186,01		

@RISK Correlations	Average carrot yield (kg/hectare) / Finlan	Carrot market price (€/kg) / Finland in B12
Average carrot yield (kg/hectare) / Finland in B8	1	
Carrot market price (€/kg) / Finland in B12	-0,4	1

Scenario 2

				CI 5%	CI 95%	SD	
				0,64	0,76	3,78%	
Affectted area	70%	Affected area	1157,996	1058,7392	1257,253	62,53178	
Minimum	60%						
Most likely	70%						
Maximum	80%						
			Yield loss kg	left			
Yield decline of affected area	0,35	Yield decline of affected area	16274360	30223811,4			
Minimum	10%			CI 5%	CI 95%	SD	
Most likely	25%			0,14	0,64	0,15	
Maximum	100%			6509743,99	29758830	6974726	
			quality loss c	left			
Yield decline due to lower quality	0,391666667	Yield decline due to lower quality	11837659,5	18386151,9			left
Minimum	15%			0,60458333	28112019	18386152	12767344
Most likely	30%						
Maximum	100%					28112019	
Decline in economic value of carrot farming	19520986,31	Economic value of carrot farming with Calsol	26605199,71				

@RISK Correlatio	Yield decline of affected area in F9	Yield decline due to lower quality in F14
Yield decline of a	1	
Yield decline due	0,6	1

Scenario 3 in the current extent

	combin yield decline	0,282916667					
Spray insecticide				**Nets**			
	%		Total		%		Total
Yield decline by spraying	28%	# quantity decline * 75%	10031566,12	Yield decline when applying ne	0,8%	# quantity decline * 5%	19669,73748
Minimum	10%	€	6883087,436	Minimum	0%	€	13496,24988
Most likely	25%			Most likely	0%		
Maximum	60%			Maximum	5%		
		over #:	33831948,47			over #:	46813975,21
Quality decline by spraying	35%	# quality decline * 75%	8880886,473	Quality decline when applying	2,8%	# quality decline * 5%	66319,79821
Minimum	10%			Minimum	0%		
Most likely	25%	€	6093556,819	Most likeley	3%	€	45504,85583
Maximum	100%			Maximum	5%		
Annual cost of spraying (ha)	€ 250,00	Total cost 75%	€ 310.218,75	Annual cost of nets (ha)	€ 358,33	Total cost 5%	€ 29.643,13
Minimum	0			Minimum	€ 250,00		
Most likely	250			Most likely	€ 350,00		
Maximum	500			Maximum	€ 500,00		
Decline in economic value of carrot farming and by spraying with insecticide			€ 13.286.863,00	Decline in economic value of carrot farming when applying nets			€ 88.644,23
Economic value of carrot farming with Calsol and by spraying with insecticide			€ 27.943.558,37	Economic value of carrot farming with Calsol when applying nets			€ 27.433.636,14

Total for the risk mitigation methods				
13355751,75				
€ 10.201.099,58				
		CI 5%	CI 95%	
83.950.439,57		0,1689	0,4144	
12251722,17		2069316	5077114	
€ 9.443.577,57				
	x			
€ 339.861,88				
yield decline 20% no risk mitigation				
3916611,714				
Total economic value of carrot farming with Calsol and the risk m				
€ 28.834.067,06				

CI yield decline		
CI 5%	15%	5310829,12
CI 95%	45%	15932487,36
SD	9%	3186497,472
CI quality decline		
CI 5%	14%	3552354,589
CI 95%	64%	16239335,27
SD	15%	3806094,203
CI annual cost		
CI 5%	€ 94,63	€ 117.424,00
CI 95%	€ 405,37	€ 503.013,50
SD	€ 94,50	€ 117.262,69

CI yield decline		
CI 5%	0,05%	1203,787934
CI 95%	2,25%	53193,26447
SD	0,70%	16.522,58
CI quality decline		
CI 5%	1,23%	28736,75868
CI 95%	4,30%	100734,3119
SD	0,94%	22002,56835
CI annual cost		
CI 5%	€ 284,82	23561,7345
CI 95%	€ 438,61	36284,01225
SD	€ 46,82	3873,1845

Scenario 3 with 100% application

Yield decline by spraying	28%	# quantity decline * 100%	13375421,49	Yield decline when applying ne	0,8%	# quantity decline * 100%	393394,7496
Minimum	10%	€	9177449,915	Minimum	0%	€	269924,9975
Most likely	25%			Most likely	0%		
Maximum	60%			Maximum	5%		
		over #:	33831948,47			over #:	46813975,21
Quality decline by spraying	35%	# quality decline * 100%	11841181,96	Quality decline when applying	2,8%	# quantity decline * 100%	1326395,964
Minimum	10%			Minimum	0%		
Most likely	25%	€	8124742,425	Most likeley	3%	€	910097,1166
Maximum	100%			Maximum	5%		
Annual cost of spraying (ha)	€ 250,00	Total cost 100%	€ 413.625,00	Annual cost of nets (ha)	€ 358,33	Total 100%	€ 592.862,50
Minimum	0			Minimum	€ 250,00		
Most likely	250			Most likely	€ 350,00		
Maximum	500			Maximum	€ 500,00		
Decline in economic value of carrot farming and by spraying with insecticid			€ 17.715.817,34	Decline in economic value of carrot farming when applying nets			€ 1.772.884,61
Economic value of carrot farming with Calsol and by spraying with insecticic			€ 28.557.039,37	Economic value of carrot farming with Calsol when applying nets			€ 44.499.972,10

CI yield decline				CI yield decline		
CI 5%	15%	7081105		CI 5%	0,05%	24076
CI 95%	45%	21243316		CI 95%	2,25%	1063865
	9%	4295871			0,70%	330452
CI quality decline				CI quality decline		
CI 5%	14%	4736473		CI 5%	1,23%	574735
CI 95%	64%	21652447		CI 95%	4,30%	2014686
	15%	5155989			0,94%	12468
CI annual cost				CI annual cost		
CI 5%	94,63	156565		CI 5%	284,82	471235
CI 95%	405,37	670685		CI 95%	438,61	725680
SD	94,5	156350,25		SD	46,82	69294