MICROBIALS

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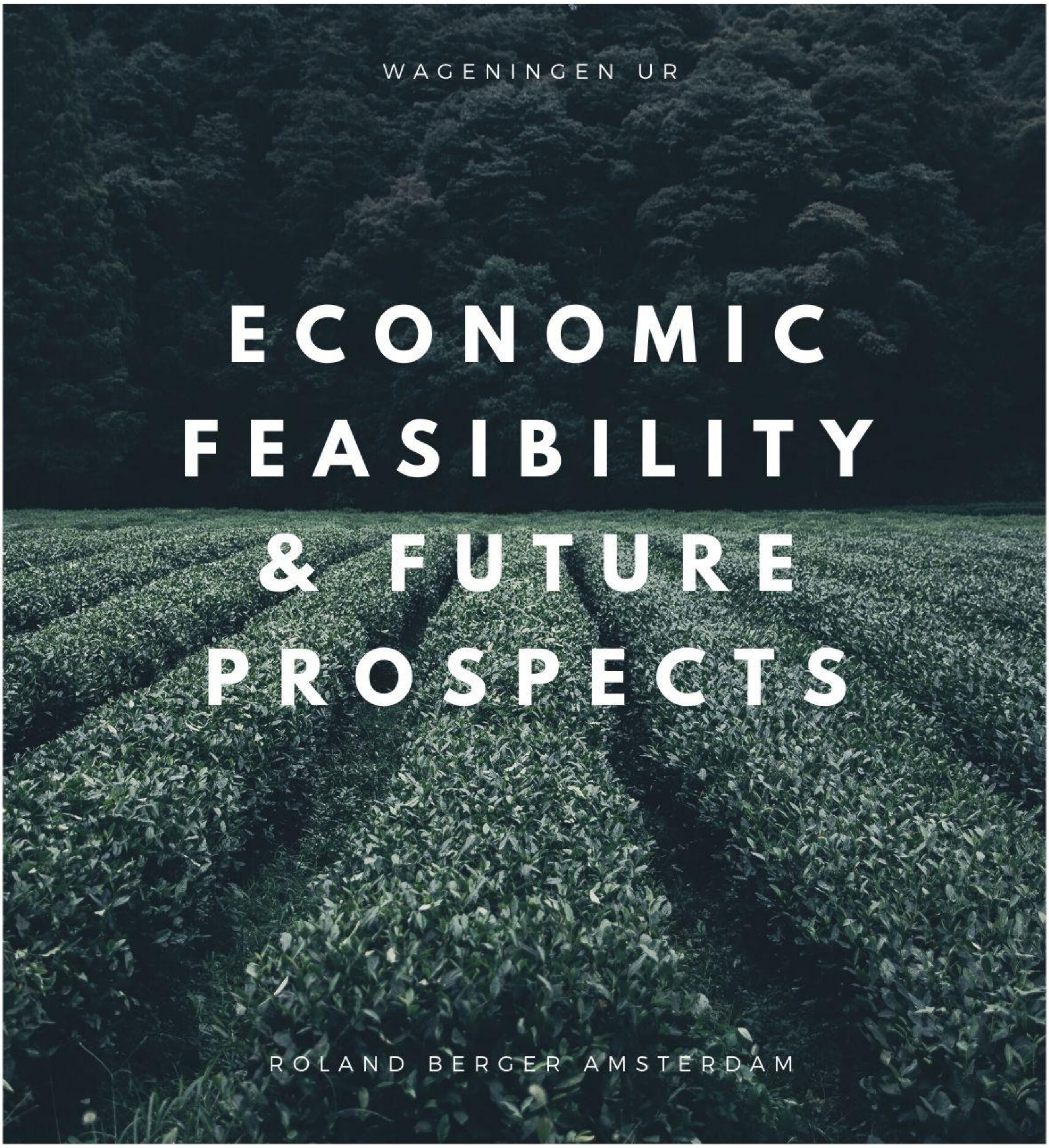

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Abstract

Excessive use of chemical crop protection products has been harming the environment for the past decades. Society and politics are pushing the agricultural sector to get rid of these harmful products and search for sustainable alternatives. Biologicals, and more specific microbials, are seen as the alternative product category with the most potential. Currently, few studies have been done on the economic feasibility of these products. The purpose of this report is to conduct an economic feasibility analysis on the different current applications of microbial biological control agents to replace chemical pesticides in agriculture and create a future prospect on its market potential. This has been done by a literature review and by interviewing 6 scientific experts and 8 business experts with the use of semi-structured questionnaires. Results from the research showed that the cost-benefit ratio of microbial products is on average less profitable than for chemicals. Even after upscaling of the industry the products will remain costlier. Results show however, that the costs do not play an essential role for further growth of the market share of these products. Political pressure, especially in the EU, is looking to ban chemical products from the market and therefore creating a gap in the market for microbials. The EU regulation process for biologicals will however have to change drastically to make it easier and cheaper for new innovative microbial products to be introduced on the market. Currently, microbial products can already be of added value to organic production, as they can increase organic yield levels on average by 50%. This report provides a contribution to the economic insights of microbial products in arable agriculture in Europe.

Key words: microbials, biopesticides, biostimulants, biofertilizers, arable agriculture, Europe, cost-benefit analysis, scenario analysis

Preface

This master thesis was written in the context of the master Management, Economics, and Consumer Studies at the Business Economics Group of Wageningen University. The subject of this thesis was commissioned by Roland Berger Amsterdam. The microbials industry caught the interest of Roland Berger Amsterdam because they heard about the high growth potential of the market. They wanted to know about this young market and assigned me and Boudewijn Beerkens on this topic. At the start it was a very tough subject for us, as we are business economists and not biologists, but after a couple of weeks of deep-dive into technical scientific papers, we learned a lot about the industry. From this moment, we divided the research in two theses: an industry analysis and an economic feasibility analysis. During the six months that I worked on this thesis, I spoke with a number of very inspiring people and I developed an expertise on this topic. The young and entrepreneurial character of this industry kept me motivated and interested in the work that went behind the writing of this thesis, as well as making the experience an enjoyable one.

Writing this thesis would not have been possible without the help of a few individuals. First of all, I would like to thank Alexander Belderok and Arnoud van der Slot for providing me the opportunity to work on my master thesis for the Amsterdam office of Roland Berger. Secondly, I would like to thank Emmy van Schijndel for revising my work on a regular basis and helping to find the right way to tackle the challenges I faced during this research. I appreciate that she took the time to help me during office hours besides her very busy job. Thirdly, I would like to thank Boudewijn Beerkens for his support and fruitful cooperation on the project. Without him and his extensive research, I would have not been able to complete the assignment for Roland Berger. He has proven to be a good research partner and I enjoyed our time spent together performing expert interviews. I would also like to thank Miranda Meuwissen for supervising my work and providing very helpful and constructive feedback. I really appreciate that she took the time to revise my work on a regular basis, in person or, when I could not travel to Wageningen, via Skype calls.

I would like to thank all the experts that cooperated with this research in the interviews and provided me with some very interesting insights. I would also like to thank the Roland Berger Amsterdam office for their great lunches, integrating activities with the rest of the personnel, but most of all for both producing a very productive work environment and facilitating our transportation around the Netherlands in order to conduct the expert interviews.

Finally, I would like to thank my friends and family for supporting me and showing interest in my research.

Luc Meerkerk

Amsterdam, February 2020

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List of abbreviations

Abbreviation	*Meaning*
CAGR	Compound annual growth rate
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
IBMA	International Biocontrol Manufacturing Association
INBIOSOIL	Innovative biological products for soil pest control
IPM	Integrated Pest Management
MBCA	Microbial biological control agent
Pers. comm.	Personal communication
R&D	Research and Development
ROI	Return on investment
SIIB	Social incremental irreversible benefits
SIRB	Social incremental reversible benefits
US	United States
WHO	World Health Organization

1. Introduction

1.1 General introduction

Integrated Pest Management (IPM) is an initiative on the field of crop protection stimulated by the Food and Agriculture Organization of the United Nations (FAO) with their IPM programme. It is used to carefully consider the use of a combination of pest control products to minimize risk for human health and the environment (FAO, 2019). The European Union's directive has obliged all the professional plant growers in the member states to comply with the principles of IPM since 2014 (Stenberg, 2017). Often named as the most well-researched element within- and cornerstone of IPM, are biologicals (Stenberg, 2017). Biologicals, also referred to as biological control agents, differ from chemical pesticides in the way that they exist of natural occurring materials, in most cases even living organisms. Farmers currently use them as a completion of their IPM program together with chemical pesticides, or as solitude pest control method (CropLife, 2018). It has been claimed that biologicals help to increase crop yields, crop quality and farm profitability over the long term (CropLife, 2018). Other advantages are that firstly, biologicals create a healthier work and living environment for farmers. Secondly, they do not have to wait for the harvest after releasing biological control agents. Thirdly, in addition to this, biological control agents significantly decrease pesticide residue levels in the harvest (Van Lenteren et al., 2017). Whereas tens of kilos of chemical pesticides had to be used to protect one hectare of land, biologicals reduce this quantity to mere tens of grams per hectare (CropLife International, 2018, June 20). Another big problem in modern agriculture is that pests rapidly evolve to be resistant against cultivars (Stenberg, 2017). A study by Gould et al. (1991) claimed that pests take longer to develop a resistance to biologicals rather than chemical pesticides.

The biologicals market has been facing four constraints during the development of the commercial process: size of the targeted market, cost of production, cost of registration and business profitably. Because of the relatively small size of the market these costs have been hard to reduce. In 2011 a microbial biological control agent was on average 2.5 times more expensive than its chemical alternative and the chemical pesticide market was making profits that were ten times greater than for biological pesticides (Blum et al., 2011). This implicates that an upscaling of the market could lower the product costs.

The biologicals market is steadily growing: between 1993 and 2016 its share on the total crop protection sales increased from 0.4% to 5.6% (Phillips McDougall, 2017). In 2008, the total sales of biologicals worldwide counted to 620 million euros, of which 122 million euros in Europe. This was however still a very small amount compared to worldwide chemical sales of 21 billion euros (Köhl, 2010). Starting in 2010, the industry shifted from niche markets to larger market operations when key players started acquiring small companies that were active in the biologicals field. From 2015 onwards, the trend shifted again when the big players in the market made huge deals between themselves, resulting in three mega deals: between Dow and DuPont, between ChemChina and Syngenta and between Bayer and Monsanto (Agrow, 2018). In the period between 2008 until 2018, the biologicals market grew by five hundred percent. This is ten times more than the synthetic pesticide market. The total investments in research and development at biologicals startups in 2019 have been forecasted at 270 million dollars (CropLife International, 2018, July 24). Growth of the biologicals market is due to high indirect costs of agrochemicals and their negative environmental impact. In 2017, the biologicals market was prospected to grow with 13,6% between 2016 and 2021 (Business Insider, 2017).

Biological crop protection can be divided into four categories: semiochemicals, natural products, macrobials and microbials (CropLife, 2018). The large category of microbials include: viruses, bacteria, fungi and protozoa (Dent, 2000). Microbials is the category of biologicals in which the most companies are active and in which the most research is done (Köhl, 2010). The advantages of microbials are that they are nontoxic to humans, wildlife and other organisms that are not very closely related to the pests. Their residue presents no hazard to health when the crops are consumed, as well as also being beneficial to the microflora in the soil, boosting crop yield (Usta, 2013).

1.2 Problem statement

Currently the biggest sales of microbials take place in North America (Van Lenteren et al., 2017). The use of microbials has been less adopted in the EU than in the United States. This is due to more complex regulation on legalization of pesticides, due to a central EU regulation and processes that vary from country to country. The registration of a new pest control product thereby takes, on average, 1.6 years longer to complete in the EU rather than in the US (Frederiks & Wesseler, 2018). Shorter registration periods for pest control methods could boost the future of biologicals and this could result in lower product costs. In the EU this was already being considered for low risk microbial substances in 2017 (Van Lenteren et al., 2017). This slow process is however not beneficial for the biologicals market. A google trends analysis in 2017 showed a declining number of search hits on biologicals (Brodeur et al., 2018).

According to Barratt et al. (2017), a large proportion of farmers are still unaware of the implementation costs of microbial biological control agents into their IPM program. The main reasons behind the non-adoption of the products are increasing bureaucratic barriers, fragmentation of the different biologicals sub-categories, which disturbs a clear overview of the options, and a lack of communication and engagement towards the public (Barratt et al., 2017). It also seems that biological control is financially attractive on the longer term for farmers because of the increased yield rates (Usta, 2013; CropLife, 2018), but authorities do not yet succeed to communicate this to the end users: relatively few assessments on its economic benefits have been conducted to proof its return on investment when it is implemented in the IPM program (Naranjo et al., 2015). Two issues can be distinguished: firstly, the biologicals programs have not yet succeeded in demonstrating the cost-effectiveness of the product to encourage governments to invest more and academics to carry out more research, which would accelerate the market development. Secondly, land managers and farmers only see slow progress or initially no impact on yields and do not immediately see the financial benefits of microbials, compared to their usual pesticides that they see as reliable and predictable (Barratt et al., 2017).

Valuation of biologicals will expand its utility in agriculture and especially crop protection (Naranjo et al., 2015). In the literature there is not much information to be found about details on production economics (Ravensberg, 2011) and Barratt et al. (2017) recommended to conduct research on the financial benefits of the products to communicate the profitability and the future prospect on the profitability of the product. Some research has been published, but there is no record yet of an economic analysis on the benefits of the microbial category in particular.

1.3 Research objectives

The objective of this study is to conduct an economic feasibility analysis on the different current applications of microbial biological control agents to replace chemical pesticides in agriculture and create a future prospect on its market potential.

More specifically, the sub-objectives are:

1. To map all the current legalized microbial substances in the European Union and the corresponding legalized products in the Netherlands.
2. To map current knowledge in literature on the difference in cost-benefit ratio between microbial biological control agents and their chemical alternative on the European market.
3. To create a future prospect on growth of the market share of microbial biological control agents and their ability to replace the chemical alternatives on the short and long term.

As little numbers on costs and benefits of these products are available because of the early growth stage the market, the research focuses on acquiring qualitative results. The analysis of this research focuses on the application of microbial biological control agents on the European market for arable agriculture.

1.4 Thesis outline

In the first chapter of this research an introduction on the subject is provided. In the second chapter background information on the topic of microbials is presented. In Chapter 3, the materials and methods for the generation of results for the three sub-objectives are described. In the first part of the fourth Chapter of this thesis, an overview is given of current legalized active substances in the EU and current legalized microbial products in the Netherlands. The complete lists of active substances and products can be found in appendix A.1. In the second part of this Chapter, an overview has been made on all the present information on costs and benefits of current practices of microbials. This overview is supported by a table which presents all the present information on the topic in literature. In the third part of Chapter 4, the results from the expert interviews are used to perform a scenario analysis. In the last part of Chapter 4 the results from the literature review and the expert interviews are compared. Chapter 5 consists of the discussion, conclusion and recommendations for further research. The last part of this thesis consists of references and the appendices, which consist of two tables of current practices and the complete questionnaire from the expert interviews.

2. Literature study on the background of the microbials market within the biologicals industry

As the world population is rapidly increasing, food production is increasing very rapid as well. Over the past fifty years, the worldwide agricultural production has increased by nearly three hundred percent, while the cultivated area in the world has only increased by twelve percent (FAO, 2011). As the world population keeps on growing, the productivity of the cultivated area will have to keep growing with it. Farmers cannot afford to have failed harvests, and this means that pests and infertile soil are a farmer’s worst nightmare. To protect their crops against pests and not let the soil degrade over time, farmers have been increasingly making use of chemical pesticides. A survey conducted in 2007, which covered data of fifty-five percent of the total usable agricultural land in the Netherlands between the years 1993 and 2003, found out that this proportion of the Dutch farmers together already used an amount of 5.030.000 kg of active substances of chemical plant protection products in the year 2003 (Muthmann, 2007). Also, in the period between 2008 until 2012, the worldwide use of pesticides increased from 2,30 million tons to 2,64 million tons (Atwood & Paisley-Jones, 2017).

From a study that was published in 2014, it turned out that a lot of chemical pesticides that are used worldwide, are a lot more toxic for the human health and the environment than has been claimed. Normally the toxic level of pesticides is measured by their active substance. This study found, for instance, that Roundup, a pesticide that is known for its apparent safety, is actually up to one thousand times more toxic than its active substance level. It turned out to be actually one of the most toxic herbicides and insecticides known (Mesnage et al., 2014). As it is stated in Article 5 of the ‘International Code of Conduct on Pesticide Management’, which was developed in 1985 and is regularly reviewed, governments should continuously review the pesticides that are marketed in their countries and the health risks that come with these pesticides (WHO & FAO, 2014). There is need for crop protection that is less harmful to the environment and human health.

So, what could be a possible solution to the problem of environmental- and health risks that come with most pesticides? Due to aversion against genetically modified crops, legislation by the European Union and increasing consumer awareness, the search for sustainable agricultural practices has been boosted (Velivelli et al., 2014). Another category of crop protection exists, and its market is developing at high pace: biologicals. These products differ from chemical pesticides in the way that they are made up of natural occurring materials, in some cases even living organisms. Farmers currently use them as a completion of their Integrated Pest Management (IPM) program together with chemical pesticides, or as sole pesticide (CropLife, 2018). Within the biologicals category, besides the crop protection products, also referred to as biological control, another category can be distinguished: biostimulants. Biostimulant is the name given to the process of using biological materials for modification of physiological and biochemical plant processes in order to boost growth, nutrition efficiency, resistance to stress factors and overall health of the plant (Yakhin et al., 2016). The third category that can be distinguished is biofertilizers (Trimmer, 2016).

2.1 Development of the biologicals industry

The first record of biologicals being used as pest management tool dates back from 300 AD when the Chinese used ants to protect citrus trees against other insects (Van Lenteren, 2005). They used small bamboo bridges between the trees to enable inter-tree movement for the ants and this is seen as the first form of conservation biological control practice. These ants were still for sale until at least 1970 (DeBach, 1974). Europe was a lot slower with the development of biological control. For nearly two thousand years the science of entomology in Europe was dominated by the work of Aristotle, who lived between 384 and 322 BC (Van Lenteren, 2005). Whilst China began using complex biological control methods in the 11th century, the first evidence of Europeans developing their own biological control methods stems from the 17th century (Cai et al., 2005; Orr, 2009; Van Lenteren & Godfray, 2005). The general accepted first successful application of controlling an insect by a different insect was in the late 1800s with the control of the cottony cushion scale (Fleschner, 1960, Doutt, 1964). This success gave a boost to the development of biological control. The real large-scale use started in the 1920s, with the production of beetles reaching over 40 million over time. These beetles are still for sale in Europe and the United States (Van Lenteren, 2003).

In the 19th century humans also started to produce manmade pesticides, consisting of Sulphur and copper components (Brodeur et al., 2017; CropLife, 2017). This led to the development of the first fungicides and chemical crop protection products in 1930, which increased the crop yields drastically (Brodeur et al., 2017; CropLife, 2017). This success of chemical crop production resulted in development of a lot of cheap chemical crop protection products from the 1940s until the mid-1960s, which were eventually named 'the dark ages of pest control' because of the harm done by the chemical pesticides to humans and the environment (Kogan, 1998; Newson, 1980). People came to realize the harmful effects of chemical pesticides during the 1960s and this opened up the market for biological crop protection (Barratt et al., 2018; Nicot et al., 2011). In the following decades, scientific interest started to grow. Up until 2000 the cumulative number of publications on this topic was however still just 878. Starting in 2000, the number of publications regarding biological control methods began to increase. In Figure 2.1 the number of publications on biological control of plant diseases between 2000 and 2019 is shown. The number of publications reached an all-time high in 2019 with 584 publications in one year.

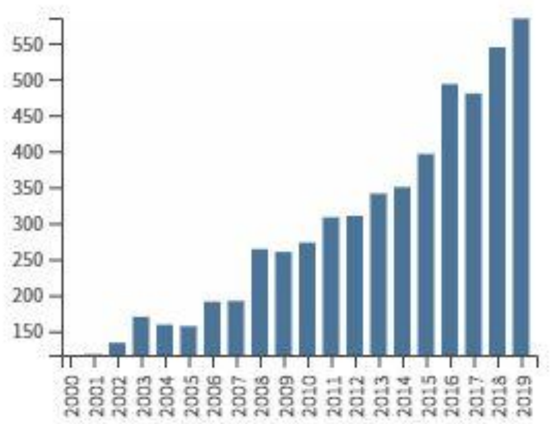

Figure 2.1: Evolution of yearly number of publications dedicated to biological control of plant diseases between 2000 and 2019 based on the Web of Science Core Collection.

An increasing amount of investments are being made in the research and development of biological crop protection products by larger R&D-based companies, as well as by smaller enterprises and start-ups (Phillips McDougall, 2018). The biopesticide sales have grown from a hundred million in 1993 to three billion in 2016 and its share of the total crop protection sales have grown from 0.4% to 5.6% (Phillips McDougall, 2018). Sales and market share are developing at steady pace.

2.2 Methods of biological control

Within the use of biological control, five methods can be distinguished. These are listed in table 2.1. The most emphasis in the history of biological control has been on classical biological control, but since the end of the twentieth century inundative and augmentative control gained popularity (Dent, 2000). For a long time mainly the introduction method has been used in biological control: a natural enemy of a certain pest that lives somewhere else is imported into the own agricultural system to permanently establish itself and control the pest over the long term (Greathead & Waage, 1983). In some cases, the buildup of the population does not go as easily as planned. This is where augmentative biological control can serve as an effective solution (Dent, 2000). Over time other methods were developed to control pests with the use of biological control as efficient as possible (Dent, 2000).

Table 2.1: Five different methods of biological control (derived from Dent, 2000)

Method of biological control	**Definition**
Classical biological control/Introduction	• The introduction of an exotic beneficial organism in a new area to become permanently established and control a certain pest • Historically most emphasis on this category [1]
Inundation	• Introduction of very large numbers of natural enemies at once to suppress a pest for a short time • Very similar use as for chemical pesticides
Augmentation	• Addition of laboratory-bred individuals to boost buildup of the introduced control agents • Often used as addition to classical biological control
Inoculation/Seed treatment	• Addition of organisms to the soil at a similar time as planting the crops to well position the control agent around the crop roots • For seed treatment: coating the seeds with the active ingredient to perfectly position the organisms • Ideal mechanism for delivery of high densities of beneficial microbials to the soil [2]
Natural enemy conservation	• Taking measures for conservation of already present natural enemies • Increasing populations of already present natural enemies

[1] Greathead & Waage (1983); [2] O'Callaghan et al. (2012)

2.3 Categories of biologicals

In 1983 Greathead and Waage distinguished six different categories of biologicals: predators, parasitoids, insects for weed control, parasites, pathogens and antagonists. Although seemingly outdated, these categories' main focus is on distinguishing different 'macrobials', while the current market is strongly developing on the field of especially 'microbials' (Köhl, 2010). CropLife distinguished four new categories in 2018, which are more relevant to the current market. These categories can be found in table 2.2 The four categories all have different properties, application methods and objectives.

Table 2.2: four categories of active ingredients used as biologicals (derived from CropLife, 2018)

Category of biologicals	Definition	Main examples
Semio-chemicals	• Communication tools from organisms found in nature • No killing effect • Used to disrupt paring of pests	• Pheromones • Plant volatiles
Natural products	• Botanicals and other natural occurring substances • Used to repel pests	• Products derived from nature
Macrobials	• Natural predators that can protect the crop against natural enemies	• Predators • Parasites • Nematodes
Microbials	• Micro-organisms with similar qualities as pesticides • Used as preventive- and direct pest control	• Viruses • Bacteria • Fungal pathogens • Yeast • Protozoa

Currently the largest part of the biologicals market consists of microbials. They are expected to make up close to sixty percent of the biological control market by 2025 (Agrow Agribusiness Intelligence, 2018). The most applied microbials are bacteria, because of their low costs and ease of use compared to fungal biological control agents (Agrow Agribusiness Intelligence, 2018). Fungal pathogens are the second biggest group, followed by viruses. Protozoa and yeasts are the least used microbials (Köhl, 2010).

These four categories of biologicals are being used to produce biological products. The biological products can be divided into three product categories: biofertilizers, biostimulants and biological control. A more specific subdivision of the product categories can be found in figure 2.2. Biopesticides represented 51.8% of the market in 2018.

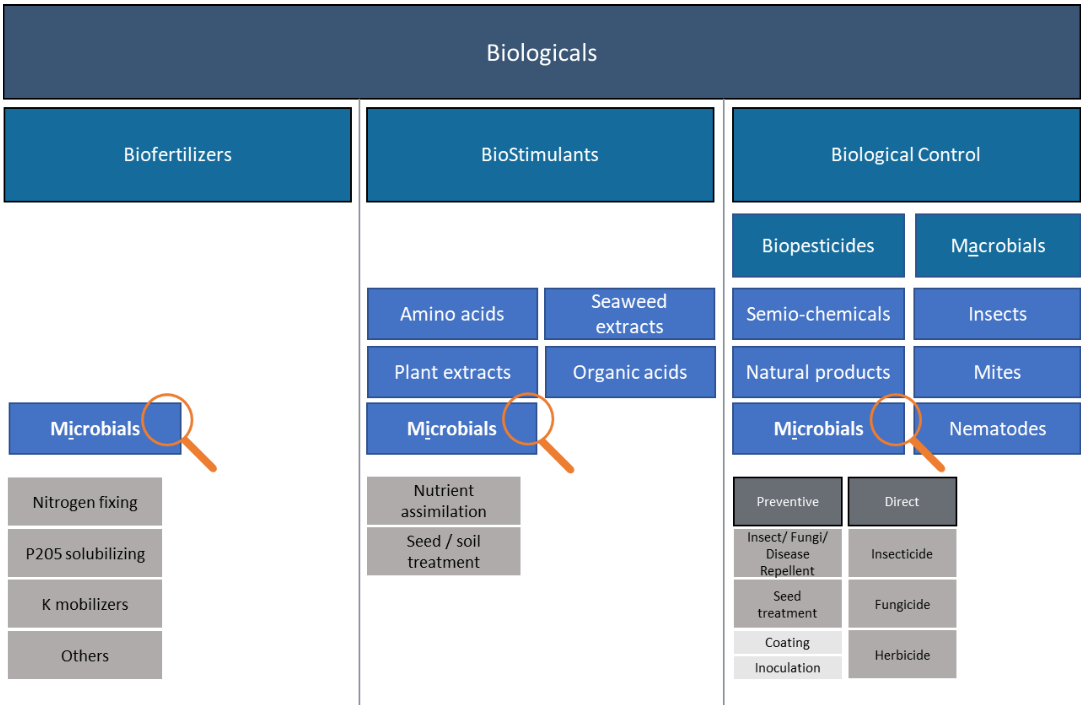

Figure 2.2: The three product segments of biologicals (derived from Trimmer, 2016)

2.4 Rise of microbials

The notion of using micro-organisms for control of insects and pests first emerged 150 years ago (Steinhaus, 1956). Hagen already suggested in his paper from 1879 the spread of a disease-causing organism on crops to reduce pests (Ravensberg, 2011; Steinhaus, 1956). He mentioned the cheapness of the remedy, the ease of preparation, that it is not toxic to men and domestic animals and that, if successful, could prove to be beneficial to mankind (Steinhaus, 1956). All these considerations are still relevant in today's crop protection product selection (Ravensberg, 2011). The use of fungus was envisaged around the same time in Russia by Metchnikoff. He succeeded in artificially controlling the growth of the fungus *Metharhizium anisopliae* with which field applications were conducted in the 1880s for the control of different insects (Steinhaus, 1956).

The first pathogens that were discovered as insect pathogens were two bacteria in the first decades of the twentieth century (Lord, 2005). These bacteria were put in production and eventually became available as the first biopesticide in 1938 in France under the name Sporeine (Ravensberg, 2011). After this success, the United States launched a project to use entomopathogenic nematodes as pest control, but this project was halted because of the second World War (Ravensberg, 2011). The first fungal product came from the Soviet Union in 1965 and was used to control potato beetles and codling moths (De Faria & Wright, 2007). The first product from viruses was not developed until the 1970s (Lord, 2005).

During the 1960s and 1970s serious investments were made and agrochemical companies also started adopting strategies to enter the biopesticide market, resulting in the launch of the first large-scale commercially available biopesticides in Europe and the United States in the first years of the 1960s (Ravensberg, 2011). Since then the market has constantly been increasing but the total use remains at a few percent of the total pesticide use worldwide. Between 1950 and 2006 over four hundred companies joined the industry, but most of them did not last and left the industry again (CPL, 2006). Between 1950 and 2005 the implementation barriers for microbials have been addressed by many authors, which are outlined by Gelernter (2005) and Ravensberg (2011). The main reasons that were reported are: variable efficacy and quality of the products, their cost-performance level, price and long process of registration, tough competition of the chemical pesticide industry, underestimation of the required investment and time to the market, overestimation of market size and market adoption rate, and the non-optimal collaboration between product developers and academic researchers in the biopesticide industry (Gelernter, 2005; Ravensberg 2011).

In the 2010's the microbials sector started to attract attention. Companies began to recognize the necessity to get rid of chemicals in crop protection over time. This resulted in biological control becoming the fastest growing segment in the global plant protection market over the past few years, in which microbials are currently the fastest growing segment (Dunham, 2017). The market is getting a huge impulse because of multiple billion-dollar acquisitions and research and development and commercial agreements between pesticide producers and research centers. Megacompanies like Bayer, ChemChina and BASF are completing major acquisitions which unlocks a lot of capital for research on microbials (Dunham. 2017). With the three mega deals between Bayer and Monsanto, Dow and Dupont and ChemChina and Syngenta over the past few years, microbials have finally become a sector to watch in the worldwide pesticide market (Agrow Agribusiness Intelligence, 2018). With a total sales reaching three billion in 2016 and a compound annual growth level of 16% (Agrow Agribusiness Intelligence, 2018; Phillips McDougall, 2018), sales are forecasted to grow to 13.9 billion dollars by 2025, whilst also achieving a pesticide global market share of 29.9%.

2.5 Integration into Integrated Pest Management systems

IPM is an initiative by the FAO to carefully consider the use of a combination of pest control products to minimize risk for human and environmental health (FAO, 2019). It is based on a 'better safe than sorry' principle. IPM distinguishes three categories of crop protection management, which are, in order of importance: preventive (indirect) crop protection, risk assessment and responsive (direct) crop protection (Meissle et al., 2011). IPM has become a very important principle for farmers, because the European Union's directive has obliged all professional plant growers to comply with the principle of IPM since 2014 (Stenberg, 2017). How do microbials fit in this program? Biological control can be used in IPM together with synthetic crop protection or as solitude method (CropLife, 2018). This means that they will have to operate together in an optimal way, so interactions between different methods should be considered. In table 2.3 it can be found how biological control interacts with the IPM principles.

Table 2.3: interaction of biological control with IPM principles (derived from Orr, 2009)

Principle of IPM	Sub-categories of principle	Way in which biological control interacts
Population monitoring		Sampling of pest populations for considering of need or timing for pesticide application
Cultural controls	Habitat stability, crop rotation, intercropping, trap cropping, cover cropping, manipulation of non-crop vegetation	Variety of practices that can be used to manipulate the enhancement of natural enemies of insect pests. Aimed at increasing density of populations to increase effectiveness
Mechanical or physical controls	Tillage, traps and barriers	Tillage methods, traps and barriers can have side effects on beneficial organisms that have to be considered when used
Plant breeding and transgenic crops	Conventional plant breeding, transgenic plants	Consideration of interactions between biological control and host

		plant resistance, as they do not always work independently
Pesticide use	Side effects on natural enemies, modification of pesticide use practices, reduced risk pesticides, selectivity, resistant natural enemies	Use of biological control as a classic pesticide (herbicide, insecticide or fungicide).

2.6 Issues for development

In 2009, Nicot et al. distinguished the main issues for development of the biological control market. These key issues are shown below in table 2.4.

Table 2.4: key issues for development of the biological control market (derived from Nicot et al., 2011).

Category	Issue
Research issues	Better strategies of screening of the agents need to be devised
	Knowledge need to be improved on efficacy-related issues
	To better integrate biocontrol with IPM multidisciplinary approaches need to be promoted
	Delivery technologies need to be adapted to the needs of microbial biocontrol agents
	Durability of biological control need to be safeguarded to prevent resistance of pests
Developmental issues (to improve acceptability by farmers and the efficacy of biological control)	Farmers and advisers need to be trained because of technical complexity
	Decision Support Systems of growers need to be developed and disseminated
	Better dissemination of information by developing farmers' networks and establishing demonstration schemes is needed
Industrial issues	Quality of the products need to be guaranteed by continuous quality control
	To safeguard the quality of the product, distribution systems need to be improved

In 1997, Dent stated that the known information on microbial biological control was built up in a haphazard way. Individual scientists all focused on their own research and interests, while the chemical pesticide industry worked on development of their crop protection products in a constructive way with big R&D departments. In 2011, Ravensberg regretted to find out that not much had changed in this situation and suggested that academic scientists and biopesticide developers would start to collaborate earlier in the process of development and commercialization of the product. The big rise in investment by mergers and acquisitions described by Phillips McDougall (2018) should be the start of this process. However, the main hurdle remains the registration process, which is a long and cumbersome procedure (Ravensberg, 2011). Currently the EU registration process for new active substances is the same for biopesticides as for chemical pesticides. In the United States biopesticides have a separate registration system, which makes commercialization of new applications a lot easier (Frederiks & Wesseler, 2018). The length of the registration period is however decreasing faster in the EU compared to the US (Frederiks & Wesseler, 2018).

3. Materials and methods

This chapter consists of three sub-chapters on the materials and methods of the mapping of current products, the cost-benefit analysis and the scenario analysis conducted in this research. The method used in the mapping of current products and the cost-benefit analysis is a literature review. As a method for data collection for the scenario analysis, semi-structured interviews were done with scientific and business experts on the topic. In-depth questions were asked to the experts focusing on their personal expertise. The initial idea of the data that should be generated in this research was in some cases different than the data that was eventually generated. This was due to a lack of presence of quantitative data on costs and benefits of microbial products. Instead of quantitative data, qualitative data was used to assess the economic feasibility and future prospects of the microbials product group. Table 3.1 shows the differences between the initial demanded data and the data that was eventually generated in the end. This change in research focus is relevant to be named, as the lack of quantitative data is also one of the research outcomes and should be considered for further research.

Table 3.1: initial required results as formulated in research proposal and results that eventually were generated per sub-objective

Sub-objective	Method of data analysis	Originally preferred results	Obtained results
1	Literature review	List of current uses of microbial products in the EU with corresponding product prices	List of current uses of microbial products in the Netherlands
2	Cost-benefit analysis	Quantitative difference between cost-benefit ratios of microbial products and their chemical alternatives in the European Union	Current known qualitative knowledge in literature on comparison between costs and benefits of microbial products and their alternatives
3	Scenario analysis	Quantitative prospects on decrease of cost price of microbial products after upscaling of the production	Qualitative facts, trends and developments negatively influencing and positively contributing to the growth of the market share of microbial products

3.1 Mapping of current microbial uses in Europe

It turned out that the legalization of active substances is regulated on European level and the legalization of the specific products is regulated on national level. To create an overview of the current uses in the European Union, two tables were put together: table 7.1 with legalized active microbial substances in the EU and table 7.2 with legalized microbial products. To maintain a reasonable scope for this research, only the legalized microbial products in the Netherlands were analyzed. The table with active substances has been derived from the EU's

Pesticide database (2019). The table with microbial products that have been legalized in the Netherlands has been derived from the Ctgb toelatingenbank (2019).

After an extensive search in existing literature and databases and personal contact with arable agriculture farm (pers. comm. 15), the conclusion was made that there is no reliable information on product prices available. Purchasing prices of the products differ per wholesaler and per buyer and depend on different factors like the ordering size. For this reason, sellers are not willing to release their product prices in the open. Due to this issue, prices of the current products are not included in table 7.1 and 7.2.

3.2 Literature research for cost-benefit analysis

As no specific costs and benefits were available for current uses of microbial products, a literature research was conducted to create an overview of all the known information in existing literature on costs and benefits of these products compared to their chemical alternatives.

The literature search strategy that was used consisted of the general search terms 'microbial* OR MBCA* OR virus* OR bacterial* OR fungus' and 'crop protection OR pesticide* OR biopesticide* OR biostimulant* OR biofertilizer*' and 'chemical*' and 'cost* OR benefit*' and 'efficacy OR cost-effectiveness OR effectiveness'. Articles published between 2010 and December 2019 that both assess microbial products and chemical alternatives were selected, as the industry and its products have changed so much the last decennium that articles from before 2010 on costs and benefits can be considered as not representative anymore.

The search strategy delivered 26 initial results in the Web of Science database and 9 initial results in the Scopus database. Most of these articles however turned out to focus on non-monetary costs and benefits. After filtering out these articles, 4 articles remained relevant from the Web of Science database and 5 articles remained relevant from the Scopus database. To enlarge this small number of articles, the snowballing method was used: the reference lists of the selected articles were filtered for additional relevant articles. In the snowball sampling method subjects are gathered through an initial subject that provides the names of other authors (Atkinson, 2004). In the end, a total of 19 relevant articles were selected and analyzed. All the statements that were found in these articles on costs and benefits of microbial products compared to their chemical alternative, quantitative and qualitative, were put together in an overview in table 4.2. This table was later used for developing the questionnaire for the scenario analysis, for which the method is further described in section 3.2.1.

3.3 Scenario analysis

The method used for data collection for the scenario analysis is semi-structured interviews with scientific and business experts based on a questionnaire. The output of the interviews has been used to create an image of ongoing developments in the market that directly or indirectly influence the cost development of microbial products. The results from the analysis were categorized in tables 4.3 until 4.9. In these tables, the results were categorized into three columns: negative impacts on the industry, neutral facts and trends, and contributing facts and trends. The statements in the negative impacts category are facts, trends and expectations which will lead the market to a worst-case scenario. The statements in the neutral category are facts, trends and expectations that will lead the market to a most-likely scenario and the statements in the contributing category are facts, trends and expectations that will lead the market to an optimistic scenario.

3.3.1 Design of questionnaire used in interviews

The questions of the questionnaire were mainly based on found literature. This research was an exploratory research, for which the interviews were used to provide data. An exploratory research is initial research to in the end form a hypothetical or theoretical idea (De Vaus, 2001). In some of the questions explicit references to statements found in literature were made, to test the statements on the reference group of scientific- and business experts. As the questionnaire was used for exploratory research, the interviews were semi-structured and the researcher told the experts before the interview that the questionnaire was meant to initiate an open discussion, in which the expert could also talk about subjects that he or she thought to be interesting for the research as well. The found information on costs and benefits of microbials in literature were limited, so the researcher was open for topics initiated by the experts besides the interview questions as well. A complete overview of the discussed topics in the questionnaire with corresponding sub-questions can be found in table 3.2. If the question referred to literature, the references are stated with the corresponding sub-question in the table as well. The questionnaire was the same for the scientific experts as for the business experts.

Topics

The questionnaire contained open- and closed-ended questions. The open-ended questions were used to get in-depth information on the topic from the expert and to initiate an open discussion on the topic. The substantive part of the interview contained five main topics for this research. Within the interview format there were a couple of questions that were relevant for a different research done by another thesis student working on this topic. These questions are not addressed on in this research, but can be found in the complete questionnaire in appendix B. In the first main topic the current market composition was discussed. It was discussed in which sector the microbial products are currently being used the most and which product category is currently being used the most. Also, the expert's expectation on in which sector the biggest growth potential is present and the expectation on growth of the total microbial sector were discussed. In the second main topic the current situation of the market was addressed. In this main topic especially the current cost competitiveness of the products was discussed, as well as current adoption by farmers in the EU. In the third main topic the market forecast from the expert was discussed. Sub-questions addressed factors currently holding the market in Europe back and the probability of different market growth scenarios. In the fourth main topic the expert's expectation on price development was discussed. The sub-questions addressed the scenario of upscaling of production in the industry and the introduction of price premiums to heighten the adoption rate by farmers. The fifth and last main topic addressed revenue increase caused by a switch to the use of microbials. The revenue increase was mainly discussed in terms of increase of yield. The questionnaires were not provided to the experts in advance, except for the expert from Rutgers School of Environmental and Biological Sciences, who explicitly requested to see the questionnaire in advance. The complete questionnaire can be found in appendix B.

Table 3.2: Interview topic guide and sub-questions with related references

Main topics	Sub-questions	Number in questionnaire	Open-/Closed-ended question	Reference
1. Market Composition	Separation among sectors	2.1	Open	
	Sector with most growth potential	2.2	Closed	
	Product category with most growth potential	2.3	Closed	
	Expectation on growth of microbials market	2.4	Closed	
2. Current situation on the market	Cost price comparison [1]	3.1.1, 3.1.2	Open/Closed	
	Indirect costs such as environmental and human health externalities [1]	3.1.3	Open/Closed	(Benjamin et al., 2018)
	Cost price competitiveness in the Netherlands [1]	3.1.4, 3.1.5	Open	(Scheepmaker & De Jong, 2017)
	Increase of profit margins	3.1.7	Open	

		Crops with most benefit from switching to microbials	3.1.8	Open	(Benjamin et al., 2018)
		Potential in organic market	3.1.9	Open	(Benjamin et al., 2018)
		Current adoption in Europe	3.2.1, 3.2.2, 3.2.3	Closed	
		Switching costs	3.2.4	Closed	
		Adoption ceiling	3.2.5, 3.2.6	Open	(Benjamin et al., 2018)
3.	Market forecast	Most important factor holding industry in Europe back	4.1.1, 4.1.2	Closed	
		Expected change in EU regulation	4.1.3	Open/Closed	
		Probability of market growth scenarios	4.2.1, 4.2.2	Open	
		Potential for outperformance of chemicals	4.2.3	Closed	(Pratisolli et al., 2018)
4.	Price development	Price change expectation after upscaling	5.1.1, 5.1.2, 5.1.3, 5.1.4, 5.1.5	Open/Closed	
		Effectivity of price premiums [1]	5.2.1, 5.2.2	Open/Closed	
5.	Revenue increase	Expected amount of yield increase [1]	6.1.1	Open	(Benjamin et al., 2018)
		Crops with most expected yield increase	6.1.2, 6.1.3	Open	

[1] Questions that were clearly answered after the first three interviews and sometimes left out in the rest of the interviews because of time constraints

3.3.2 Selection of experts for interviews

The sample group of this research exists of 14 scientific- and business experts. In total, six scientific experts and eight business experts were interviewed. The background of these experts can be found in table 3.3. A complete overview of the names of the experts can be found in table 6.1. The selection of these experts took place in two steps. In the first round of interviews, six experts were interviewed, of which four scientific experts and two business experts. These experts connected the researcher to eight other experts, with whom interviews took place three weeks later.

Scientific experts

Four of the scientific experts were selected through a method of purposive sampling and two of the scientific experts were selected through the snowballing method. The first expert from Wageningen Plant Research was selected because of his interesting article 'Microbials: The need for a pragmatic approach to the market and to its constraints', which was relevant for this research. The second expert from Wageningen Plant Research was selected because of his function as Business Unit Manager in which he manages the research on microbials and other biologicals in Wageningen. The expert from Wageningen UR was selected because of his scientific article 'A comparison of the EU and US regulatory frameworks for the active substance registration of microbial biological control agents' and his participation in the INBIOSOIL project. The expert from Universiteit Utrecht was selected because his name was mentioned as a keynote speaker in the Plant Bioprotech conference in Marrakesh in November 2019. The researcher was connected to the scientific experts from Rutgers School of Environmental and Biological Sciences and the Georg-August-University Göttingen by the expert from Wageningen UR, which referred to these experts as very relevant for the research.

Business experts

Two of the business experts were selected through a method of purposive sampling and six of the business experts were selected through the snowballing method. The first expert from Koppert Biological Systems was selected because of his publication 'A roadmap to the successful development and commercialization of microbial pest control products for control of arthropods', which has been very important for scientific research in this sector. The business expert from Novozymes was selected because of his paper 'From the lab to the farm: an industrial perspective of plant beneficial micro-organisms', which is a relevant topic for this research. The other business experts were chosen through the snowballing method. The second expert from Koppert Biological Systems and the expert from Aphea.Bio were referred to by the expert from Universiteit Utrecht. The experts from Plantum and Rijk Zwaan Breeding B.V. were referred to by the first expert from Koppert Biological Systems. The experts from Marrone Bio Innovations and EuropaBio were referred to by the expert from Wageningen UR. The expert from EuropaBio was also relevant to contact because of his participation in writing the paper 'A comparison of the EU and US regulatory frameworks for the active substance registration of microbial biological control agents' together with the expert from Wageningen UR.

Table 3.3: Background of the interviewed experts

Experts (n=14), of which:	Description of the group
Scientific (n=6)	➢ Wageningen Plant Research (n=2): two scientists from Wageningen Plant Research were interviewed, both connected to the subdivision Biointeractions and Plant Health. This research division studies harmful and useful insects and microbials and their effect on plants. The research performed by this division also focuses on IPM. ➢ Wageningen UR (n=1): one expert from Wageningen University and Research Centre was interviewed, connected to the Agricultural Economics and Rural Policy Group. The focus of this group lies on the bio-economy with an emphasis on sustainable development in the agricultural sector. ➢ Universiteit Utrecht (n=1): one expert from the Plant-Microbe Interactions department of the Universiteit Utrecht was interviewed. This research group focuses on the interaction between plant immune systems and beneficial microbes, pathogens and insects on a molecular level. ➢ Rutgers School of Environmental and Biological Sciences (n=1): one expert from the Department of Agricultural, Food and Resource Economics of Rutgers School of Environmental and Biological Sciences was interviewed. The goal of this department is to support need of the society for economic analysis and business management in the agricultural sector with a focus on environmental issues.

	➢ Georg-August-University Göttingen (n=1): one expert from the Agricultural Entomology section, which is connected to the Department of Crop Sciences of the Georg-August-University of Göttingen, was interviewed. This department focuses its research on biotic and abiotic interaction between plants, pests and their natural enemies. With the data coming out of this research they develop systems which can be integrated into IPM.
Business (n=8)	➢ Koppert Biological Systems (n=2): two experts from Koppert Biological Systems were interviewed. Koppert is worldwide one of the biggest innovators in biological control. Koppert's business plan focuses on offering combinations between biological products and innovative technological systems to implement the use of the product on farm-level. Currently the biggest sales of microbial products by Koppert are in Latin-America. Their microbials research department focuses on application in arable agriculture. ➢ Novozymes North Carolina (n=1): one expert from Novozymes North Carolina was interviewed. Novozymes originally focus on research, development and production of industrial enzymes, micro-organisms and biopharmaceutical ingredients. The company has recently entered the biological control market and is doing research in North-America together with Monsanto in a collaboration called the BioAg Alliance. ➢ Aphea.Bio (n=1): Aphea.Bio is a young Belgian company which is a spin-off from the universities UGent and KU Leuven. Aphea.Bio focuses on commercialization of research output from the both universities in the fields of biostimulants and biological control agents for maize and wheat. ➢ Plantum (n=1): one expert from Plantum was interviewed. Plantum is the Dutch trade association for seed producers. Over 300 companies are connected to this association in the Netherlands. Plantum's goal is to serve the interests of the seed producers in governmental decision making on national and EU level. ➢ Marrone Bio Innovations (n=1): Marrone Bio Innovations is an American listed company, which focuses on the development of safe IPM solutions for specialty crops, row crops and water systems. ➢ Rijk Zwaan Breeding B.V. (n=1): one expert from the Seed Technology Research department from Rijk Zwaan Breeding B.V. was interviewed. Rijk Zwaan develops vegetable seeds and sells these worldwide. ➢ EuropaBio (n=1): EuropaBio is the European association for bioindustries. EuropaBio makes sure the voices of biotechnology companies are being heard in Brussels.

3.3.3 Data collection

The data collection for this scenario analysis took place by interviews. The interviews each took between one and two hours. The interviews were done in cooperation with Boudewijn Beerkens, who was also collecting data for his industry analysis of the microbials industry. Two separate questionnaires were designed for the separate researches, which were later integrated into one questionnaire with separate subchapters to make the interviews run smoothly. The interviews of four scientific experts took place at their universities (Wageningen Plant Research (n=2); Wageningen UR (n=1); Universiteit Utrecht (n=1)). The other two scientific experts were interviewed on the phone. Of the interviews with business experts, three took place on the location of the company (Koppert Biological Systems (n=1); Plantum (n=1); Rijk Zwaan Breeding B.V. (n=1)). The rest of the interviews with business experts also took place on the phone (Koppert Biological Systems (n=1); Novozymes North Carolina (n=1); Aphea.Bio (n=1); Marrone Bio Innovations (n=1); EuropaBio (n=1)).

As the interviews were semi-structured, the questionnaire was used as a tool to structure the interviews, but also open discussions were held. This was done to get an idea of the view of the expert on the subject. As this was an exploratory research, the questionnaire also provided space for the expert to tell about subjects that were not yet mentioned. All the relevant statements done by the experts during the interviews were noted and categorized to be used as input for the scenario analysis.

3.3.4 Data analysis

As some of the questions from the questionnaire were completely answered in the first couple of interviews already, they were not asked to the other experts. On the questions on quantitative data the experts could mostly not give an exact answer. They indicated that there is simply close to no data openly available on sales and costs of these products compared to their alternatives. As a large part of the questionnaire consists of questions on quantitative data, the questionnaire was in the end used more as a handgrip for the interviews than as a survey. This way, the interviews were in the end more exploratory open discussions than structured interviews and had a different focus per interview, dependent on the expertise of the expert. All the main topics of the questionnaire were still addressed in each interview. This way, Individually Focused Interviews were performed as described by Clausen (2012). Under some conditions, this way of interviewing can enhance the reliability, validity and transparency of the research. The conditions that must be met are: a heterogenous group of interviewees with a breadth range of statements in the data collection, a broad and thorough introduction of the interviewers and their roles to the interviewees, and an explanation of the purpose and methodological aspects of the study. All these conditions were met in the interviews for this research. The notes from the interviews were jointly transcribed by the two interviewers within 24 hours after each interview. In the transcription process, the different views from the interviewers on the statements of the experts were integrated. This way the validity of the data was improved, as according to Bailey (2008) transcribing is an interpretative act rather than just a technical process. The joint interview transcripts were added in a shared document after each interview. The interpreted transcripts influenced the questions that were asked in the following interviews. In the end, the shared document was used by both researchers to filter out the statements that were relevant for their own particular research.

A big amount of qualitative data resulted from the 14 expert interviews. The data consisted of statements made by the experts during the interviews which addressed one of the main topics of the questionnaire. These statements were categorized in the categories: regulation, market growth, application, political influences, costs, organic sector and scientific research. These categories were used to structure the data into tables 4.3 until 4.9. From these tables, conclusions can be made about expectations for development of the microbials industry on the short and long term.

4. Results

4.1 Mapping of current practices

In this chapter the current practices of microbials will be identified. In the first part of the chapter the current legalized substances in the EU will be elaborated on. A complete list of legalized active substances consisting of microbials can be found in table 7.1 in appendix A.1. In the second part of the chapter the current legalized microbial products in the Netherlands will be elaborated on. A complete list of legalized microbial products in the Netherlands can be found in table 7.2 in appendix A.2.

4.1.1 Active substances in the EU

The registration process of microbial biological control agents is in the European Union a lot more complex than in for example the United States of America. The active substance of the products first must be approved by the European Commission. The steps that the product must go through are noted in Regulation No. 283/2013 and Regulation No. 1107/2009 (European Commission, 2009; Frederiks & Wesseler, 2018). The active substance must go through the 'RMS phase', which takes approximately 13.5 to 22.5 months. Then the 'Risk assessment phase' follows, which takes approximately 7 to 8 months and finally the 'Risk management phase' follows, which takes approximately 6 months. After completing this process, the active substance is included in the EU pesticides database. Currently, fifty active substances consisting of microbials are included in the list of legalized active substances of the European Commission (EU pesticides database, 2019). A complete list of these active substances can be found in table 7.1 in appendix A.1. Of these fifty active substances 15 consist of bacteria, 27 consist of fungi, 7 consist of viruses and 1 consists of a yeast.

4.1.2 Current legalized products in the Netherlands

After legalization of an active substance, the substance can be used as main ingredient to produce plant protection products. These products have however also to be assessed on country level in the EU (Frederiks & Wesseler, 2018). In the Netherlands, this assessment is done by the Ctgb (Het College voor de toelating van gewasbeschermingsmiddelen en biociden). The 'Ctgb toelatingenbank', the database of legalized plant protection products in the Netherlands, currently contains 51 microbial products (Ctgb toelatingenbank, 2019). A complete list of these legalized products can be found in table 7.2 in appendix 10.1.2. The 51 different legalized microbial products on the Dutch market are being produced by 25 different producers, which means that there are currently 25 different sellers active on the Dutch market (Ctgb toelatingenbank, 2019). This does not necessarily mean that there are only 25 companies active in the microbial industry in the Netherlands, because there could be products from additional companies that are still in the assessment process and not yet legalized.

4.2 Cost-benefit analysis

In the first part of this chapter the information found in literature on the current costs and benefits of the products will be elaborated on. All the found information in the literature on current knowledge on costs and benefits can be found in table 4.2. The most striking findings are elaborated on more broadly in the second part of the chapter. In the last part of the chapter the issues and opportunities for reducing costs and increasing benefits will be discussed.

4.2.1 Costs and benefits of current practices

The direct costs and benefits of current microbial practices are hard to find out. Wholesalers in the Netherlands do not easily give out indications on the prices of their products and often differentiate their prices per buyer, mostly depending on batch order size (pers. comm. 15). Also, it has been found in literature that a cost-benefit analysis only looking at direct costs and benefits of microbials when comparing to chemical alternatives is not relevant, as the benefit of microbials should mainly be on the long term (Scheepmaker & De Jong, 2017). Because of this great variance in prices and benefits on the short- and longer term, this cost-benefit analysis has not looked at specific current prices and benefits of current products, but on what is currently known in literature on costs and benefits of microbials compared to their chemical alternative. A complete overview on what has been written on this subject from 2010 until now in the literature can be found in table 4.2. The most striking findings from the literature are further discussed in chapter 3.2.1.

4.2.2 Costs and benefits found in literature

A literature review on cost-benefit comparisons between microbials and their chemical alternatives lead to the results that can be found in table 4.2. The biggest findings that have been done on the field of cost-benefit for microbials in recent years, have been done during the INBIOSOIL project: a project that ran from 2013 to 2018, which was funded by the EU and included several studies on feasibility of microbials as alternative for chemical plant protection products (INBIOSOIL Project Fact Sheet, 2012). Nine universities and seven companies took part in this project. The main finding on economic feasibility from this project was that an economic feasibility analysis must be done for each separate active substance on every separate crop, because the variation on costs and benefits is too high to draw a general conclusion (Benjamin et al., 2018). During the INBIOSOIL project, cost-benefit analyses have been done for the use of microbials on maize production, potato production and organic potato production in Germany, Spain, France, Italy, Austria and Romania. For maize production, the revenue could be improved by EUR 197 per hectare with the use of microbials, mainly because of the increase in yield (Benjamin et al., 2018). The microbials in the form of fungi were however in this case used in combination with nematodes: a macrobial application of biological control. In contrast to maize production, the revenue of potatoes would reduce with EUR 1050 per hectare with the use of microbials. The yield even decreases in the case so a switch to the use of microbials would cause a lot of extra costs in this case (Benjamin et al., 2018). The case of organic potato production has high potential but is a bit more complicated. With the use of microbials the yield of organic potatoes would on the average increase from 17.8 tons per hectare to 27 tons per hectare. It can however not yet be assumed that these potatoes can still be sold as organic potatoes after the application of microbials. If the potatoes cannot be sold as organic potatoes, the revenue would drop with EUR 3510 per hectare. If the potatoes can however be sold as organic potatoes, the revenue would increase with EUR 7048 per hectare (Benjamin et al., 2018).

Other benefits that can be considered in comparing microbials with their chemical alternatives, are the Social Incremental Reversible Benefits (SIRB) and the Social Incremental Irreversible Benefits (SIIB) (Benjamin & Wesseler, 2016; Benjamin et al., 2018). These are benefits that occur due to the application of biocontrol, so for example reduce of pest damages. These indirect benefits are also interesting to include in the cost-benefit assessment of microbials: the SIRB of microbial use on maize production in France has for example the potential to reach EUR 1.34 billion on country level (Benjamin et al., 2018). It has also been concluded by the Scheepmaker & De Jong (2017) that the direct costs and benefits are often more beneficial with the chemical alternative, but the indirect costs and benefits of microbials would on the longer term not underperform compared to the chemical alternative (Scheepmaker & De Jong, 2017).

In the Netherlands also several quality marks are already in use to indicate the societal and environmental benefits of microbial crop protection products (Scheepmaker & De Jong, 2017). The quality marks that are already in use can be found in table 4.1.

Table 4.1: Quality marks currently used in the Netherlands for production with the use of microbial crop protection products (Scheepmaker & De Jong, 2017)

Quality mark	Use
MPS	Used in floriculture. System of quality marks in which the crop protection use is considered for acquiring a strict quality mark (A or A+)
EKO	Dutch interpretation of the European quality mark, given out by SKAL. Chemical crop protection is not allowed. Some other substances as azadirachtin, spinosad, cupper, ethylene and sulfur are however allowed as crop protection products
Demeter	Quality mark in biodynamic agriculture. Requires the same as the EKO quality mark, but also goes more into dept
Milieukeur	Asks specific requirements on the use of crop protection products and for example drift reduction. Exceptions can sometimes be made for other crop protection products to use once on a specific area as a correction tool, but only if an outbreak of a plague has been proven. Conditions are however that the IPM balance stays intact and the IPM practices can directly continue after the use of the alternative product

4.2.3 Issues and opportunities for reducing costs and increasing benefits

In the literature review also some additional issues and opportunities were found which are influencing the cost development of microbials. These issues and opportunities should be considered to create a realistic prospect on price- and market development.

Issues

The biggest issue is the high regulation costs of introducing a new product in the EU (Scheepmaker & De Jong, 2017). This is especially a big issue for smaller companies: the products have overall high research and development costs. If the company has to wait 2.5 years until they can finally sell their product, the financial situation is not tenable for smaller companies (Scheepmaker & De Jong, 2017). The bad link between research on the field of microbials and development of actual products in practice is costing a lot of money as well (Scheepmaker & De Jong, 2017).

Opportunities

There are also positive developments that are pushing the potential for growth of market share for microbials. When an active substance is legalized after the assessment of the EU, it is legalized for 15 years (Frederiks & Wesseler, 2018). In recent years the European Commission has started to increasingly consider if they would extend legalizations or not: has no more environmentally friendly alternative active substance been developed yet? Is this substance still the best option? Here are of course opportunities for microbials (Scheepmaker & De Jong, 2017). If the microbial alternative is feasible and a full developed product, the legalization of the chemical alternative might not be extended.

Looking at the prices of the products in the Netherlands, producers say that the products are already price competitive for the end user. The production costs are however higher, so the profit margin for the producer is lower than for chemical alternatives (Scheepmaker & De Jong, 2018). Another cost advantage in the Netherlands is that since 2017 the product group of microbials has been included in the 'innovation box' of the Dutch government. This means tax advantages on research and development on the field of microbials (Wiebes, 2017).

According to Scheepmaker & De Jong (2017), the biggest potential for microbials in the Netherlands is in horticulture. In this sector already a lot of biological control is being used in the form of macrobials. Also, the temperature and humidity level can easily be regulated in the greenhouses. This is favorable for the use of microbials, because of the importance of optimal growth conditions for the products (Scheepmaker & De Jong, 2017).

Table 4.2: Overview of findings on costs and benefits and barriers and enablers influencing the costs and benefits of microbial plant protection products compared to their chemical alternatives in existing literature [1]

Reference	**Country**	**Costs [2]**	**Benefits [2]**	**Additional [2 3]**
Abott et al. (2018)	Australia			Inoculation via legume nodulation historically seen as most successful method
Barratt et al. (2017)	Worldwide		- Farmers tend to not use the products because they often do not see direct results	
Benjamin & Wesseler (2016)	Germany, Spain, France, Italy, Austria		+ SIRB (social incremental reversible benefits) for biocontrol of Western corn rootworm could be well above 150 €/hectare	
			+/- Simple cost-benefit analysis is inadequate because they neglect uncertainty in efficacy of biological control and indirect costs of chemicals	
Benjamin et al. (2018)[4]	Germany, Spain, France, Italy, Austria	+/- Differs per crop and country	+/- Differs per crop and country	
			+ For fighting Western Corn Rootworm in maize production economically more attractive to use nematodes and fungi than conventional products: 146 €/ha more revenue and 197 €/ha more gross margin than conventional crop management products	
			- For fighting wireworms in conventional potato production economically less attractive to use nematodes and fungi than conventional products: 1050 €/ha less revenue and 1550 €/ha less gross margin	

than conventional crop management products

+ Can be attractive for production of organic potatoes because of higher selling price (must be certified organic selling)

+ SIRB (social incremental reversible benefits): benefits by using biocontrol, like reduction in pest damages. These benefits disappear once the use of biologicals is stopped

+ SIIB (social incremental irreversible benefits): analyzed by potential reduction of active ingredient due to application of biological control

+ Present value for the selected countries till infinity ranges between EUR 227 million for Austria and EUR 1.46 billion for France and annually EUR 9.5 million for Austria and EUR 61.5 for France. The total of all six countries is EUR 4.4 billion. Within selected countries, the SIRB from France would mainly benefit from introducing biocontrol in the maize industry.

+ Even with lower adoption rate and adoption ceiling in alternative scenario still positive present values summing up to a 1.1 billion benefit for maize

+ Aggregated total welfare gain (SIRB and SIIB together) in maize production within the selected countries of EUR 4.5 billion and annual welfare gain of EUR 190 million.

			+ Present value of SIRB for organic potatoes ranges between EUR 310,000 (Spain) and EUR 54.4 million. This relatively low amount is due to a low adoption rate and ceiling and small amount of organic potatoes produced in the countries selected. PV of SIRB is highest in Germany.	
			+/- Increasing the adoption ceiling has a relatively stronger effect on the SIRB than increasing the adoption speed (increase of SIRB from EUR 54.4 million to EUR 120 million with an adoption rate increase from 10% to 30% for organic potato production)	
Blum et al. (2011)	Worldwide	- Production costs of a microbial control agent were in 2011 on average 2.5 times as high as the chemical alternative.	- In 2011, the business profitability of producing a chemical pesticide was nine times as high as for a microbial control agent	
		+ The registration costs of a microbial control agent were in 2011 EUR 860 000, while for a chemical alternative it was EUR 1 410 000		
De Jong (2017)	Netherlands		- Most of the times not as effective as alternatives, but could contribute to a healthy and resilient crop	
			+ Possibly a lot of favorable uses of fungi for production of tulips and strawberries. More research is needed	

Hanudin et al. (2017)[5]	Indonesia		+ Use of bio fungicides gives the same plant growth and health as chemical fertilizer and fungicides. Is also more beneficial because of higher profit margin resulting from cost efficiency	
Koch & Roberts (2014)		- Few examples of commercial use in seed treatment, mainly because of high development and registration costs in comparison to market size	+ Use of microbial inocula can provide seeds with a "green" label which is used for marketing	
Lacey et al. (2016)	Worldwide			- Research on using entomopathogens as biological control has been conducted for more than 150 years, but has still not lead to much commercial success
Lugtenberg et al. (2016)	Worldwide		+ In New Zealand, novel endophyte strains have been rapidly adopted by farmers for protecting their crops against biotic and abiotic stress and this is now estimated to contribute USD 130 m per year to the New Zealand economy	
			+ The product BioEnsure®-Corn is promoted to use have a 25-80 percent yield increase under heavy drought stress and a 7 percent increase of yield under low drought stress. Plants also use 25-50 percent less water after the seed has been treated with this product	
			+ The product BioEnsure®-Rice is promoted to increase yield under drought and salt stresses and use 25-40 percent less water	

Marian & Shimizu (2019)	Worldwide			+ Biological control with the use of beneficial microorganisms will become a more important method for sustainable pest management worldwide. Field performance tests and usability tests should however be improved to show the full potential
MarketsandMarkets Research Private Ltd. (2016)	Worldwide			+ Expected compound annual growth rate of microbial market of 15% from 2016 until 2021
Ravensberg (2011)	Worldwide			+/- Extremely difficult and nearly impossible to economically review various biopesticides, even within one group of pathogens. Economics of production and product costs need to be analyzed case by case, because of dependence on type of product, the market and the company
Rauch et al. (2017)	Germany, Spain, France, Italy, Austria, Romania		+ Fungi used in combination with nematodes for Western corn rootworm control in maize production increased yield by 23% in Austria	
Reddy & Saravanan (2013)	Worldwide			+ Need for technologies using natural occurring bacteria and fungi, because of growing consensus on the non-sustainability of chemical fertilizers and pesticides to increase crop yields, and because of considerable resistance against genetically engineered crops to increase production of food
Scheepmaker & De Jong (2017)	Netherlands	- Direct costs of microbials are higher	- Less efficacy than alternatives	+ Chemicals industry sees opportunity in a slow movement towards microbials: start with use microbials for last spraying to

		prevent chemicals from staying in the product
+ With a complete cost-benefit analysis in an integrated way, microbials would on the long term not be more expensive than chemicals	- Direct effect of microbials is most of the times lower	- Poor link between research and practice
- Costs and length of legalization process keeps companies from introducing new products	+/- Current microbial products mainly focus on specific problems on specific crops. Big environmental progress could be booked when they focus on a broader perspective	+ High chance of adoption in horticulture: easy regulation of climate conditions
+ Producers say that products are currently already price competitive, but production costs are higher, so margin is lower for producer	+ Some products have other favorable features as well, like boosting the yield because of growth stimulants in the product itself (like Pseudomonas)	+ Demand by consumers and supermarkets for products produced without chemicals
- For producers: long time to regulate the products can be too long for small producers to handle the costs		- Requires specific knowledge about conditions for usage
		- Lack of trust because of unfamiliarity
		- Lack of knowledge in large part of the sector
		- Not for all pests and diseases microbials available
		+ Opportunities to increase effectivity of products with seed treatment technology
		+/- Mostly used in horticulture

				+ Long-term favorable factors: resistance, residues, effects on soil ecosystem
Van Lenteren et al. (2017)	Worldwide			+/- Europe biggest market for invertebrate biological control and North America for microbials. The strongest growth of the use of microbials is happening in Latin America, followed by Asia
Wesseler & Fall (2010)	Twenty EU countries	+ For a benefit of EUR 472 million from biocontrol of Western Corn Rootworm, the costs should not exceed EUR 273 million. This implies a cost-benefit ratio of 1:2.		
Wiebes (2017)	Netherlands	+ Since 2017 microbials have been included in the innovation box of the Dutch state, which means tax advantages for research		

[1] Columns 'Costs', 'Benefits' and 'Additional' are not linked. The findings are listed per article; [2] The '+', '-' and '+/-' in the columns indicate respectively positive, negative and neutral influences on this category; [3] Statements found in literature that do not directly relate to costs or benefits of the products, but are relevant to take into account in the research; [4] Research for maize done with fungi in combination with nematodes. For the potato research only fungi were used; [5] Focused on Chrysantherum production

4.3 Scenario analysis: expectations on developments that will negatively influence and positively contribute to the growth of the microbials market share

To lead the interviews in the right direction, a questionnaire was developed which can be found in appendix B. This questionnaire was however not strictly followed, but used as a thread through an open discussion, as this is an exploratory research.

The purpose of this chapter is to test the findings of the cost-benefit analysis through a scenario analysis to create an expectation on price- and market development of the microbials industry. As currently there are little numbers available, the scenario analysis has been done with statements of the experts which might influence the price- and market development of the microbials industry. All the relevant statements made by the experts can be found in tables 4.3 until 4.9. The statements are divided into subcategories per table and per subcategory into three scenarios: statements on developments that will negatively influence the development and growth of the industry, statements on developments that do not negatively influence nor contribute to the development and growth of the industry but are of significant importance, and statements on developments that will contribute to the development and growth of the industry. The results for the separate subcategories are further elaborated on in the subchapters of this chapter.

4.3.1 Regulatory issues

A problem that is often named, is that new microbials that companies try to bring to the market are assessed by EU regulators in the same way as chemicals are assessed to become legalized. This framework is according to the experts however not applicable to microbials as it does not assess properties that are relevant for these substances. Because of this lack of applicability, this process takes very long and must be shortened to make it easier for microbial products to enter the market. The registration process currently takes too much time, effort and money. As chemical products are disappearing from the market because of expiring licenses that are not being extended, farmers are begging companies for microbial alternatives.

The registration process is also different per product category. The process for biostimulants is currently shorter than for biopesticides. Because of the unclarity in the regulatory framework, entrepreneurs are trying to find loopholes in the registration process, like introducing biostimulants on the market, which have protectory side effects. These products can serve as pesticide but are assessed as stimulants. These loopholes can be a danger as well: biological products are not necessarily always safe as nature is also capable of producing very harmful substances. According to the experts, the regulation should loosen, but not too much, keeping this in mind. Concluding, the necessity of a revised registration process applicable to these products is required. The new European Commission will release their commission workplan for the upcoming four years around April 2020. In this workplan it will become clear if they will invest time and money in changing this registration process. The experts agree that regulation in the EU will change in a range from two to ten years. An expert stated that Europe will miss the boat in this innovative industry if regulations are not changed within ten year (pers. comm. 12).

Table 4.3: Expectations from the experts on development of the microbials market with regard to regulations

Regulation

Negative impacts	Neutral	Contributing
➢ Biopesticides as a product category have been dumped in the same regulations as chemicals in the EU (pers. comm. 7) ➢ The same product implemented in the	➢ The regulation process is different for the different product categories (crop protection, stimulants and fertilizers) (pers. comm. 1) ➢ Regulation in horticulture is a little bit easier because	➢ Licenses of several chemicals are expiring and not being extended (pers. comm. 7) ➢ There will be a referendum in Switzerland in 2020 for a complete ban of synthetic

European and American market, took 1 year and 8 months in the US and 5 years and 2 months in the EU. In this regulation period the market has completely changed. Not possible to react to the market in this way. Innovative products need innovative regulation (pers. comm. 7)

- Registration and regulation is very complex and takes a lot of time and investment: especially a big barrier for smaller companies with less capital (pers. comm. 2)
- Industry is very worried about EU regulation, which has not been changed on this topic since 2001 (pers. comm. 3)
- To change the regulation in the EU, a commissioner will have to prepare a proposal which has to go through the standing committee and the appeal committee. This is a long and time-consuming process which takes on the average five to ten years (pers. comm. 3)
- Current regulation is based on chemicals: product should be applied, kill the pests and then disappear as fast as possible without doing more harm to the environment. The biological products should however stay in the soil. This is a mismatch with the current regulation rules (pers. comm. 4)
- Current regulation is also very unpredictable: delivered studies can lead to questions for more studies (pers. comm. 4)

of less Ecotox procedures (pers. comm. 1)

- To avoid the long registration process, different companies are now making use of an emergency clausula to get their products registered: if a pest or disease suddenly becomes resistant against certain pesticides and currently no alternative exists, microbials can get an immediate license (pers. comm. 3)
- The registration procedure from the individual countries in the EU would be enough and it should not be regulated on continental level. Also, because companies do not have the intention to bring harmful products to the market (pers. comm. 3)
- Biological products are not necessarily always safe, there are also some very harmful substances coming from nature. If something goes wrong with one product, the whole industry can stop, so regulations should also not be too loose (pers. comm. 4)
- Regulation of pesticides in the EU is done by the DG santé, which is a bit of an old-fashioned department which is not very agile and has difficulties deciding what decision is right (pers. comm. 14)
- The new European Commission will release their commission workplan around April 2020. Then it will be

crop protection products (pers. comm. 7)

- "Green deal" could be beneficial (pers. comm. 7)
- A way to currently dodge the long registration period and high related costs to this is to label your new product as plant strengthener, while they actually also might have some protective functions. Some companies are currently doing this (pers. comm. 6)
- Expectation is that European regulation will change in two to three years, which will most likely smoothen the registration of new microbial products (pers. comm. 6)
- Every isolate of the active ingredient needs to be registered separately. When however a couple of isolates have been registered, this will lead to easier registration of new products with the same isolates (pers. comm. 6)
- Regulation will be changed definitely in the upcoming 5 years and will drive growth of the microbials industry globally (pers. comm. 11)

- Companies take a risk when they start developing a product on the European market, because it is not clear when the regulations will change. Companies are moving out of Europe because of this uncertainty (pers. comm. 12)
- clearer if the EU is going to invest time and money in changing this regulation in the upcoming years (pers. comm. 14)

4.3.2 Expectations on market growth

The regulatory issues are often stated as main barrier for the industry against further growth. On some other continents the registration is easier and products are rapidly becoming available on the market. In the United States around 450 products are currently on the market and 40 to 50 new products are entering the market each year. In Brazil currently around 300 products are on the market and 40 to 50 products are entering each year. In the EU, only around 100 products are currently available on the market, with 4 to 5 new entrants each year. This indicates the current regulatory barrier that is present in the EU.

The experts agree that the market has the potential to grow a lot. All the experts agree with a 100% certainty level that the market share of microbials will grow in the upcoming three years. An expert predicted a 1,5% growth of the market share in the upcoming three years and a 10% growth of the market share in the upcoming ten years (pers. comm. 3). This increase of growth level is due to the EU regulation that is predicted to change in the years between, after which the growth of the market share should increase. After this expert did this prediction, this forecast was tested on two other experts during the interviews and they both could see this scenario happen (pers. comm. 4; pers. comm. 6). An expert stated that the industry currently has a compound annual growth rate of between 15 and 20% (pers. comm. 6). A different expert stated that if for example 20% of the current chemical legalized products are harmful for the environment, the adoption ceiling for microbials is 80% of the total market (pers. comm. 10). This is due to an increasing demand for sustainable agriculture and disappearing chemical products from the market. Market growth seems to be dependent on the disappearance of chemical products and the need for new alternatives as some experts say that farmers will not adopt the microbial products if they are not forced to. The possible growth of this market will be based on a market push and not on a market pull. The business experts however said that they are already experiencing the disappearance of chemicals from the market, so this is already an ongoing trend.

While current speed of adoption of the products is higher in for example the United States and Latin-America, most of the experts agree that Europe is the most promising markets for these products. This is due to a couple of reasons. The first reason is that a lot of different crops are being produced in Europe. Microbial products are currently applicable for specific products and pests and not yet widely applicable for several pests with one product. More different crops means more market potential for specific products. The second reason is the political pressure on shifting to more sustainable agriculture and the political stability on this subject. The third reason is that the big European pesticide producers own huge marketing networks all over the world. Once these companies start adopting these products as well, the European market could let the rest of the world follow this development. Markets where the most environmental benefit can be achieved with a shift to microbial products are Africa and Asia. They will however probably follow the developments in a later stage. China has also often been named as a growth market, but little numbers and information is known on adoption of microbials in China. What is known however, is that the Chinese chemical producer ChemChina acquired Syngenta, a company that is working on microbials. An expert however assumed that the microbials part of the company was not the main reason for the acquisition, but the seed breeding department (pers. comm. 13).

The arable agriculture sector is seen as the sector with the most potential for growth of microbials use. As biological products are already broadly being used in horticulture, especially macrobials, little gain is to be made here. This is why for example the microbial research department from Koppert Biological Systems is situated in the arable agricultural department, while the macrobials are situated in the horticultural department (pers. comm. 13).

Table 4.4: Expectations from the experts on development of the microbials market with regard to the potential of market growth

Market growth		
Negative impacts	**Neutral**	**Contributing**
➢ Currently there are in the United States around 450 products on the market and this is increasing by 40-50 per year. In Brazil there are currently 300 products on the market, and this is increasing by 40-50 per year. In Europe there are currently around 100 products on the market, and this is increasing with 4-5 new ones per year. This must chance because otherwise the European market will get behind on innovation (pers. comm. 7) ➢ The food chain is not cooperating in development: supermarkets are telling farmers to not use chemicals anymore, but are not compensating for this in margins for farmers (pers. comm. 7) ➢ Public image on product reliability is still pretty low (pers. comm. 2) ➢ Big companies are not really cooperating to innovate the regulation. Currently already marketable products are a lot more profitable for them (pers. comm. 3) ➢ Zero tolerance in floriculture makes use of microbials hard: no inconsistencies on the	➢ Success of Koppert caused by combining the available biologicals with innovative technology (pers. comm. 7) ➢ Most potential lies in arable agriculture, because of the volume (pers. comm. 2) ➢ Biopesticides are the product category with most potential: this is the category in which most licenses are expiring (pers. comm. 2) ➢ Chemicals will never completely disappear from the market, but the market deviation will change (pers. comm. 2) ➢ The microbials market is growing due to technological improvement and gain in popularity of IPM (pers. comm. 4) ➢ Growth will probably mostly happen in horticulture, because technologically this sector is easier, and the crops have higher margins (pers. comm. 4) ➢ A lot of potential for microbials lies in increasing nutritional value of products and research in the United States is focusing on this as well. Farmers however get paid per kilo of produced crops, and not per nutritional value. A change is required in this way of	➢ Biggest opportunities for growth lies in arable agriculture (especially arable production of fruit) (pers. comm. 1) ➢ It is a lot more costly to find new working chemicals than microbials, so this is a growth opportunity (pers. comm. 1) ➢ Prediction is that in 2050 more biologicals are used than chemicals (pers. comm. 1) ➢ Potential for growth in the Netherlands lies especially in horticulture because of the high value crops. In this market there is more margin to use the integrated biological control packages (pers. comm. 7) ➢ Expectation is that in thirty to forty years we only use biologicals (pers. comm. 7) ➢ Biggest growth is expected in Latin-America (pers. comm. 7) ➢ Dutch farmers are interested in bio alternatives and want to learn (pers. comm. 2) ➢ A lot of benefit can be gained on cash crops because of production volumes, but margins will be higher for high value crops (pers. comm. 2)

products because of use of biologicals instead of chemicals are allowed (pers. comm. 4)

- Scalability will be a problem. Microbials will probably have to stay focused on smaller markets because there probably will not be one widely usable product. Products will have to be developed for specific crops, soils and climates. Therefore, products will probably stay more expensive (pers. comm. 5)
- Big chemical companies have the advantage that they already control a worldwide marketing network and supply chain via which they can sell new products and at the same time protect their own chemicals (pers. comm. 5)
- As long as chemical alternatives are available, conventional farmers will not switch to microbials. The problem is that the synthetic alternative just always works. Only with a market- and political push the farmers will start using it (pers. comm. 6)
- With upscaling of the production, the chance will grow that in the end somewhere pests will develop resistance against microbials as well (pers. comm. 10)
- Regulation and access to creative knowledge are biggest hurdles for the industry (pers. comm. 10)

product valuation (pers. comm. 8)

- Biopesticides will be the category with biggest growth. This is due to an increase of interest in organic production, social pressure for environmentally friendly products, professionalization of science on the field and since five years big companies are moving into the industry (pers. comm. 5)
- Industry is being hyped because of crisis of disappearing chemical substances. A lot of research still must be done, and regulation must change drastically, but the call for new products is huge (pers. comm. 10)
- Europe is a very interesting market because of variety of crops being produced (pers. comm. 10)
- Biopesticides is currently the product category that is growing the fastest. Biostimulants are also increasing in popularity, but have a history of being a 'snake oil' (pers. comm. 11)
- To further grow, the commercialization of the products is very important, as well as the distribution channels (pers. comm. 11)
- Europe could lead this market development. If regulation changes, Europe can start using these products broadly and the rest of the world will probably follow over time (pers. comm. 12)
- Biggest profit can be made in regions where production is currently suboptimal. A lot can be improved here by the right use of microbials. Production in Europe is often so close to optimal that the room for improvement is very limited (pers. comm. 2)
- Upscaling of the microbial market is very probable, but more in the US than in Europe. It is however probably not going to happen that products from the US come to the EU market, because this registration would probably even be slower than for products from the EU itself (pers. comm. 3)
- A lot of investments are being made in China, especially by ChemChina. This is however a little bit of a blind spot in the industry: no scientific publications available and nearly no known numbers on this part of the industry (pers. comm. 3)
- The current market share of microbials is 1%. One of the experts estimates this to be 1,5% in three years, but 10% in 10 years, because the market share will get a huge impulse once the regulation has been changed (pers. comm. 3)
- Agrees with the estimation of the market share development by personal communication source 3 and the estimation of 5 to 10 years until a regulation

change (pers. comm. 4; pers. comm. 6)

- Europe has the biggest opportunity for growth, because this market has the most focus on shifting towards chemical free production (pers. comm. 3)
- In the United States social pressure is increasing on banning of chemical products because of health risks (pers. comm. 8)
- The market in Latin-America is growing. A lot of chances lie in Asia. The main market to focus on is however Africa: the big gain can be achieved here because of the big amount of degraded land and deprived soil (pers. comm. 8)
- The big companies are not really interested in the smaller niche markets, so here are chances for microbials (pers. comm. 6)
- Supermarkets like Aldi and Lidl are pushing the organic market, in which lie a lot of chances for microbials. This would increase the adoption ceiling (pers. comm. 6)
- Köhl has estimated the CAGR at 15% at the start of the 2010's, but this has become higher, probably close to 20% (pers. comm. 6)
- Demand for sustainable agriculture in Europe is increasing (pers. comm. 9)
- Farmers must start adopting microbials, because of banning of chemical pesticides and

limitations on use of chemical fertilizer (pers. comm. 9)

- This market will grow a lot. Big companies have started investing in it and it is still a very young market (pers. comm. 9)
- If for example 20% of all the chemicals on the market is not environmentally harmful, the market potential for microbials is 80% of the market. On the long term all the environmentally harmful chemicals will be banned in Europe (pers. comm. 10)
- Conventional farmers start to learn that soil health is very important and are looking for ways to improve the health of their soil (pers. comm. 11)
- Latin-America and China are important growth markets (pers. comm. 11)
- Chemical products are getting banned very rapidly. In the past 10 years, at least half of all the products has been banned and it is expected that in the upcoming years another 25% of the products will disappear from the market (pers. comm. 12)
- Because of political push, chemical products are disappearing from the market. Companies and farmers are asking microbials sector for help and new products, because they foresee their usual products to disappear (pers. comm. 13)

		➢ 100% certainty that the market share of microbials will grow in the upcoming three years (pers. comm. 1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13)

4.3.3 Developments in application

For the complete adoption of IPM with integrated use of biologicals, the agricultural system will have to change. The Dutch government has recently published a plan to move towards a new system of intensive agriculture with an optimal IPM system for every farm. The main idea of this new system is increasing the strength of the crops itself. This can for example be done with biostimulants. A bright future for biostimulants is expected, as this is a whole new category of products focusing on strengthening the plant itself. These products however currently only cause a 5-10% yield increase and, in some cases, even no yield increase. This is not yet worth the investment so the products will have to become more effective. The product category with the highest currently expected potential is biopesticides, as these products are already highly developed and have proved to be effective.

A barrier for adoption of these products, are technological issues. According to one of the experts, worldwide demand is present for these products (pers. comm. 13). It is however easier to adopt these products for for example Dutch farmers than for Southern European farmers, as Dutch farms are generally more technologically advanced, which makes it easier to implement the use of these new products. Currently the biggest market for microbial products is the soybean market, especially in North- and Latin-America. The active substance *Trichoderma,* which is a fungus, is already being used on millions of hectares for soybean production in Latin-America. Farmers here were forced to start using microbials, because the pests became resistant against their chemicals so quickly, that in the end there were no chemical alternatives left to use. For microbials, only two rare cases have occurred in the laboratory of pests becoming resistant against the microbial substance (pers. comm. 1).

Table 4.5: Expectations from the experts on development of the microbials market with regard to product application

Product application

Negative impacts	Neutral	Contributing
➢ Microbial products from horticulture should not be taken outside: microbials for arable agriculture should be outside from the start of the research (pers. comm. 1) ➢ The whole agricultural system will have to chance to offer a chance to microbials: intensive agriculture with innovative methods as crop rotation with an integrated biological crop protection system. This system is focused on increasing	➢ Trichoderma is currently already being used on millions of hectares in Brazil (pers. comm. 1) ➢ Protected crops (i.e. horticulture or protected by plastic) is currently by far the biggest market for biological control. There are however not really hard numbers on market shares available, because companies do not want to release them. IBMA global tried multiple times to create a good market overview but did not yet	➢ Pests become resistant to chemicals quickly. Only two cases of pests becoming resistant against microbials have been shown, but these were highly exceptional cases because the microbials were only producing one substance, just like the chemical alternatives, against which the pests became resistant after some generations (pers. comm. 1) ➢ Effectivity of the products is growing, and with this

strength and resistance of crops (pers. comm. 1)

- Effectivity of the microbial products is very dependent on external factors. Their performance is affected by temperature, type of soil, the composition of the microbiome and other variables. Product performance is not very reliable because of this (pers. comm. 8)
- There is only so much space on a seed for seed treatment. This makes technology in seed treatment very complicated (pers. comm. 8)
- Production companies must work very precise and make sure their products work optimally. If non-effective products will enter the market, the market will get a 'snake oil' reputation and the confidence in the products will be done for (pers. comm. 8)
- In history microbials (especially biostimulants) have been produced which worked less than expected, which gave the industry a little bit of a 'snake-oil' reputation (pers. comm. 5)
- Biostimulants only give 5-10% yield increase and there have been examples of products that were not effective at all. Products must become more effective (pers. comm. 9)
- Biologicals are nature, but nature is not always safe. Should be kept in mind (pers. comm. 10)

succeed. They are trying again in 2020. IBMA France is one of the exceptions that do have specific numbers of their market (pers. comm. 7)

- Use in the Netherlands currently only 1% of the market (pers. comm. 7)
- Koppert is selling a lot in Brazil for soy and maize production. Pests and diseases here are becoming resistant to nearly all the chemicals. Chemistry opportunities are finite, especially in the tropics because of the favorable temperature and humidity. Microbials work good here because of the environmental factors (pers. comm. 7)
- Adoption differs a lot per sector, from 1 to 20% (pers. comm. 7)
- A lot of farmers that currently shift to biologicals do this because of emergence: they are simply out of chemical options that work against the pests and diseases (pers. comm. 7)
- Products are being used in floriculture because of yield increase, for example for roses (pers. comm. 7)
- Most potential in increasing reliability can be gained by combining different microbials in the microbiome of the crop (pers. comm. 2)
- Microbials market mainly focuses on horticulture in the Netherlands (pers. comm. 2)

the confidence in the products (pers. comm. 5)

- A bright future for biostimulants is expected: this is a new range of products for which there not really are competitors (pers. comm. 9)
- Once farmers use IPM with microbials integrated in the system they are very satisfied. They must integrate all the tools to achieve success though: it is a new way of farming (pers. comm. 11)
- Estimated yield increases of 5-20% with the use of biostimulants (pers. comm. 11)
- Biopesticides, biostimulants and biofertilizers are all categories with a lot of potential. The sector wants to get rid of chemical products. The biggest chances lie in the food industry. In floriculture there are less worries about the chemicals (pers. comm. 12)

- As long as the chemical alternative is available, there is no market potential for the microbial alternative: these products are always second best and will never reach the average effectivity of 90% of chemicals (pers. comm. 12)
- Microbials might be 'natural', but 'natural' is not always safe (pers. comm. 12)
- The adoption rate is very variable per crop, but an important factor to consider. A bigger impact can be made with raising the adoption ceiling than increasing the adoption speed (pers. comm. 3)
- Microbials are currently mostly used in horticulture: easier with margins like those of high value crops like tomatoes (pers. comm. 4)
- For success in this market companies should look at Koppert: not selling a separate product, but a whole system with corresponding technology to fully implement at once (pers. comm. 4)
- Soybean production is the biggest market for microbials at the moment, especially in Latin-America and China (pers. comm. 5)
- With seed treatment, multiple coats can be applied to a seed with multiple functions (pers. comm. 10)
- In the Netherlands farmers are educated enough to start implementing this new farming method. Might cause trouble in other areas in the EU (pers. comm. 10)
- For wide effectivity of the products, combinations of different microbials will have to be used and developed into products. These products work per definition not broadly (pers. comm. 12)

	➢ Knowledge is most advanced on biopesticides. These products will lead the way and the stimulants and fertilizers will follow. Currently too little is known on stimulants to produce effective and reliable products (pers. comm. 13) ➢ Demand is worldwide: not more demand in the Netherlands than for example Southern Europe. However, farms in the Netherlands are technologically more advanced than for example in Southern Europe, which makes the new microbial products easier to implement (pers. comm. 13)	

4.3.4 Political influences

A statement that has been made by multiple experts is that the growth of the microbial market is dependent on political pressure. The whole industry is waiting for the EU to smoothen the registration process and ban the chemical alternatives to create market space for microbial products. The experts expect less from the American market than for the European market just because of the political pressure from the EU, while the registration process is a lot easier and shorter in the United States. There are already a couple of examples for this pressure in the EU. In Denmark the government is implementing true cost prices on pesticides: the tax level is dependent on the environmental impact of the product. In France there is a lobby going on to obligate a distinction between advisors and sellers, as advisors counteract the microbial industry as advising chemicals is more profitable for them. The Dutch government has presented a plan for development of the agricultural sector until 2030 with less dependency on chemicals and more integration of IPM. In Switzerland there will be a referendum upcoming year on banishment of all chemical pesticides. These examples of stable political pressure on banishment of environmentally harmful chemicals are the reason why the expectation of the development of the microbials industry in Europe is high.

On for example the US market the number of microbial products is a lot higher, but the speed of adoption is not that much higher. This has been said to be caused by less political pressure on the banishment of harmful chemical products than in the EU.

Table 4.6: Expectations from the experts on development of the microbials market with regard to politics

Politics

Negative impacts	**Neutral**	**Contributing**
➢ Farmers' crop protection advisors are counteracting the industry. It is easier and more beneficial for them to	➢ There is enough political pressure on the chemicals market to decrease chemicals production and	➢ There is a lobby going on in France for an obligated distinction between advisor and seller (pers. comm. 7)

advise chemical products. This is an important actor to stimulate and learn about the industry (pers. comm. 1)

- In current European regulation too much questions are being asked by the regulators. Decisiveness of the EU is not working well: the required studies have to go too deep and are not relevant for the product. The regulation period should decrease a lot, just like in the United States. This will not change on the short term, but definitely on the long term (pers. comm. 1)
- Active ingredients of chemicals are not being banned, but only the products. At the same time as products are being banned, new ones are entering the market (pers. comm. 6)
- Microbials will always depend on politics. They have for example been doing good in Brazil, but now the situation has changed when Bolsonaro became president and does not really care about the environment (pers. comm. 6)

offer a chance to biologicals (pers. comm. 1)

- It is not beneficial for microbials to introduce quality marks for using only microbials. Quality mark for correctly practicing IPM or an integrated biological crop protection system would have more effect (pers. comm. 1)
- Regulation on the European market must change within 10 years, otherwise Europe is going to miss the boat in this industry (pers. comm. 12)
- Denmark is currently implementing true costs in the cost prices of the products: tax on the product is dependent on environmental impact (pers. comm. 7)
- A new initiative by the Dutch government exists on developing more resilient crops (pers. comm. 2)
- The Dutch government wants to become less dependent on chemical pesticides (pers. comm. 4)
- Subsidies could give a big impulse in adoption, just like it did for natural strips around the crops. Side note is however that a lot of farmers immediately stopped practicing this when the subsidies were stopped (pers. comm. 4)
- The EU wants the market share of organic production to increase, which unlocks market potential for microbials because chemicals cannot be used in organic production. The adoption ceiling will increase because of this (pers. comm. 6)
- Europe is a very promising market because the political situation is stable (pers. comm. 6)
- "Green deal" will probably have a positive effect on development of regulation (pers. comm. 10)
- The Dutch government has presented a plan for development of the agricultural sector until 2030: less dependency on chemicals and more

integration of IPM (pers. comm. 12)

4.3.5 Expectations on cost development

The results show clearly that in the current situation, microbials are generally more expensive for the end user than their chemical alternative. Upscaling of the production can decrease the production costs per product quite a bit, but not as much as for example was the case for biofuel, as for biofuel a much bigger initial investment was needed for the producer and because of this the effect of economies of scale was a lot bigger. The production costs will however stay high because of checks and refreshing of the production. Cost price can be decreased quite a bit but will never be as low as the cheap chemical products. In some cases, the return on investment can however be increased by switching to microbials because of yield increase, but this is very crop dependent. One of the experts stated that for for example strawberry production in the US the return on investment can be nine times the input, for potatoes five times and for rice four times (pers. comm. 11). The direct costs and benefits are the most important decision factor for the end users. It has however turned out from the other results that the cost price of the product is not the most important factor when assessing the growth potential of this market, as the chemical alternatives are disappearing from the market. This means that the decisiveness lies mainly at political level and for a decreasing amount at the end user.

Table 4.7: Expectations from the experts on development of the microbials market with regard to costs

Costs

Negative impacts	**Neutral**	**Contributing**
➢ Direct costs of chemicals are of course lower, because they are applicable on a much bigger scale. The microbials are more specific per crop and soil type (pers. comm. 1) ➢ Learning- and switching costs are significant so actually an issue for adoption (pers. comm. 7) ➢ Production costs of microbials will never match costs of chemicals, especially chemicals of which the patents have been expired (pers. comm. 7) ➢ The crop protection supply chain must be adjusted for microbial products, because of shorter shelf life of the products (pers. comm. 8)	➢ True costs of products are currently not considered. There is a political boost going on to take these costs into account, so this might change (pers. comm. 1) ➢ Learning costs are not higher than for chemical products, so this should not be an issue (pers. comm. 1) ➢ To upscale the industry, a mind chance by the big companies is needed, or a venture capital activity in the SME market. This is however more likely to happen in the US due to venture capital constraints in the EU and tax advantages in the US (pers. comm. 3)	➢ Upscaling of the production would definitely reduce costs per product. Production is mainly happening by small companies. The big companies do not have microbials as core business so a lot of cost can be reduced here (pers. comm. 1) ➢ Microbials are produced in one batch at a time in a fermenter. When a bigger fermenter is used, a lot of production costs per product can be saved (pers. comm. 1) ➢ A lot of profit can be made with upscaling of the production (pers. comm. 7) ➢ Use of microbials can save tilting costs: in some cases tilting is not necessary anymore (pers. comm. 2)

- Yield will probably be around the same with optimal use of microbials, but they will be more expensive (pers. comm. 8)
- Learning costs are a barrier for farmers. They are also skeptical on the products as these products in the past did not work as promised. Chemicals also often have more direct results, which seems more reliant to the farmer (pers. comm. 5)
- Upscaling of microbials will not be comparable to how for example biofuels have been upscaled. For biofuel much bigger investments were needed and so the economies of scale were a lot bigger (pers. comm. 5)
- Production of the biological control agent takes about 40% of the total costs of the product. Upscaling from lab to the factory will not reduce the end price of the products. You will always have to check and refresh production a lot, which will stay costly (pers. comm. 6)
- If politics demand that chemicals are banned, microbials can be a substitute. They will however stay more expensive. Costs can maybe approach the costs for the chemical alternative in some cases, but for most it will not (pers. comm. 6)
- Costs would definitely decrease after upscaling (pers. comm. 2)
- Upscaling of the production would decrease costs per product. In the future there will be products that can be more widely used, but it needs time because a lot of research is needed (pers. comm. 9)
- Products of Marrone Bio Innovations have proven to be able to deliver a considerable return on investment when changing to microbials: strawberries 9x ROI, rice 4x ROI, corn 3x ROI, potatoes 5x ROI, almonds 5-9x ROI (pers. comm. 11)
- Getting a new chemical product on the market can cost 400-500 million euros. This risk is too big for chemical companies considering chemical products are being banned. They are realizing they must shift (pers. comm. 12)
- Products will become cheaper as the registration process gets shorter and cheaper (pers. comm. 12)
- Upscaling of the production is helping the costs of the products to decrease and reach viable prices. After upscaling the costs will still be higher, but not really a barrier for adoption (pers. comm. 13)

4.3.6 Potential in the organic sector

The organic market seems to be a very attractive market for microbial products. As no chemical products are allowed in organic production and all the current legalized microbial products are allowed in organic production, a lot of potential gain can be made on this market segment. The use of microbials can in most cases increase yield in the organic sector by around 50%. In this market higher prices can be demanded because of exclusive products. In this case a 50% yield increase means a huge revenue increase, as big yield losses are normally taken for granted in this market segment. It should however be considered that the organic market is currently less than 20% of the total market in the EU, which means that macro-economically speaking it is not really an interesting market. The organic market can however be used as a boost for the industry to later penetrate the conventional market. Another side note that should be considered is that 'organic' is a subjective term. This means that even if the products are legalized in the sector, some organic farmers will not use the products as they do not fit in their perception of the term 'organic'. This means that the adoption ceiling for microbials in the organic sector is less than 100%.

Table 4.8: Expectations from the experts on development of the microbials market in the organic sector

Organic sector		
Negative impacts	**Neutral**	**Contributing**
➢ GMO on microbials is a no go in Europe, because it would harm the image of the industry, which is very important. In the United States there are opportunities for GMO and companies there are already working on it (pers. comm. 1)	➢ Organic production' is a political and not a scientific term. This means that allowance of microbials in organic production is subjective and will not be adopted by everyone (pers. comm. 3) ➢ Organic market can only ask a higher price if the market remains small (pers. comm. 12)	➢ All the currently produced microbials are allowed in organic production (pers. comm. 1; pers. comm. 7) ➢ A lot of profit can be made on the organic market. As shown in the study by Benjamin et al (2018) yield in organic production can drastically be improved as well as profit levels. Market cap of organic production is however at 20% of the market so this will also be the maximum for microbials use here, which means that from a macro-economic perspective it is not a really interesting market. To make a real impact it is better to focus on producing for the conventional market. It should however not be forgotten that organic production can be drastically improved with the use of microbials (pers. comm. 3) ➢ The organic market has no alternatives for crop protection, fertilization and stimulation. There are a lot of chances here because yield can in most cases be

		increased by 50% (pers. comm. 6) ➢ The organic sector will push the microbial market. The microbial market will first mainly focus on organic production and with this the products will develop to eventually penetrate the conventional market (pers. comm. 12)

4.3.7 Developments in scientific research

The industry is young and still a lot of research is needed. One of the experts identified the industry to still be in the early growth stage and the big investments still must come (pers. comm. 7). Researchers believe that currently only the tip of the iceberg on usability of microbials is known. A lot of research still must be done to especially increase the shelf life, ease of use and effectivity of the products. Increasing effectivity is often named as an important factor for the industry to succeed. The gap between lab and field is still too big and research should be done in cooperation between universities and companies to develop commercially desirable substances. Research is however already professionalizing. The plant-microbe department of the University of Utrecht does for example already around 30% of their research in cooperation with companies. Governments in the EU are investing in research on microbials by universities as well. The research is also becoming more problem solving, instead of opportunity seeking. This should be beneficial for product development.

Table 4.9: Expectations from the experts on development of the microbials market with regard to scientific research

Scientific research

Negative impacts	**Neutral**	**Contributing**
➢ Shelf life of the products can be difficult. The worldwide supply chain is not a big issue, but especially the local distances are hard: from Amsterdam to Tokyo is no problem, but from Tokyo to a small Japanese farmer is logistically hard to manage from the Netherlands (pers. comm. 7) ➢ Shelf life difficult logistic factor. *Bacillus* has a relative long shelf life (pers. comm. 2) ➢ Product group has a 'snake oil' reputation. This means that the common image is	➢ Research is also being done on how to improve current products (pers. comm. 2) ➢ Research is being done more and more together with companies to create more competitive and reliable products (pers. comm. 2) ➢ Utrecht University is currently already doing around 30% of their research in cooperation with companies (pers. comm. 2) ➢ A lot of research still must be done on shelf life, ease of use and field life (pers. comm. 11)	➢ Focus of scientific research on microbials is getting more focused on product development instead of writing articles for journals. Science is getting more commercial in this market (pers. comm. 1) ➢ Investments are being made by national governments within the EU: EUR 21m in NL (gravity project), EUR 50m in Germany, EUR 40m in Denmark and between EUR 40m and EUR 50m in Switzerland (pers. comm. 2) ➢ Research has become more problem solving than opportunity seeking. This is

that the reliability is low (pers. comm. 2)

- When a concept of an active ingredient is finalized in scientific research, capital is needed to bring it to the market, but investors are holding back (pers. comm. 6)
- More scientific researchers are needed to fully understand the microbiome of the plant (pers. comm. 6)

- The last phase of the research is the most time consuming, but very important: testing the products in the open field in all situations and seasons. This must be done together with companies (pers. comm. 13)

beneficial for product development (pers. comm. 2)

- Research is becoming more and more professional (pers. comm. 2)
- Big research projects are being done in the United States by for example a coalition between Novozymes and Monsanto. This research is especially interested in application on cash crops because of volume (pers. comm. 2)
- There has become a strong link between basic research and something that can be marketed (pers. comm. 6)
- We now only know the tip of the iceberg. Koppert was in the same situation with macrobials 50 years ago and now they have conquered the horticulture market. Trust exists that microbials can do the same on the arable agriculture market (pers. comm. 13)

4.4 Results from literature in the light of the expert interviews

To see if the experts agreed on the statements found in literature, the subjects from the literature statements were addressed in open- and closed questions during the interviews. Afterwards, the outcomes from the literature review and the interviews were compared. In most cases the statements from the experts matched with the statements in found literature. In some cases, they did not totally agree with these statements though. All the statements from the experts that relate to relevant statements that were found in literature, can be found in table 4.10.

Table 4.10: Statements made by experts during the interviews related to statements found in literature

Reference	Statement in literature	Review by expert
Frederiks & Wesseler (2018)	Registration of a new pest control product takes in the EU on the average 1.6 years longer than in the US	➢ The same product implemented in the European and American market, took 1 year and 8 months in the US and 5 years and 2 months in the EU. In this regulation period the market has completely changed. Not possible to react to the market in this way. Innovative products need innovative regulation (pers. comm. 7)
Barratt et al. (2017); De Jong (2017); Scheepmaker & D Jong (2017)	Farmers tend to not use the products because they often do not see direct results; Most of the times not as effective as alternatives, but could contribute to a healthy and resilient crop; Less efficacy than alternatives	➢ Effectivity of the microbial products is very dependent on external factors. Their performance is affected by temperature, type of soil, the composition of the microbiome and other variables. Performance is not very reliable because of this (pers. comm. 8) ➢ Production companies must work very precise and make sure their products work optimally. If non-effective products will enter the market, the market will get a 'snake oil' reputation and the confidence in the products will be done for (pers. comm. 8) ➢ In history microbials (especially biostimulants) have been produced which worked less than expected, which gave the industry a little bit of a 'snake-oil' reputation (pers. comm. 5) ➢ Biostimulants only give 5-10% yield increase and there have been examples of products that were not effective at all. Products must become more effective (pers. comm. 9) ➢ As long as the chemical alternative is available, there is no market potential for the microbial alternative: these products are always second best and will never reach the average effectivity of 90% of chemicals (pers. comm. 12) ➢ For wide effectivity of the products, combinations of different microbials will have to be used and developed into products. These products work per definition not broadly (pers. comm. 12) ➢ Effectivity of the products is growing, and with this the confidence in the products (pers. comm. 5)

Benjamin et al. (2018)	Costs and benefits differ per crop and country	➢ Products of Marrone Bio Innovations have proven to be able to deliver a considerable return on investment when changing to microbials: strawberries 9x ROI, rice 4x ROI, corn 3x ROI, potatoes 5x ROI, almonds 5-9x ROI (pers. comm. 11)
Benjamin et al. (2018)	Can be attractive for production of organic potatoes because of higher selling price (must be certified organic selling)	➢ All the currently produced microbials are allowed in organic production (pers. comm. 1; pers. comm. 7) ➢ A lot of profit can be made on the organic market. As shown in the study by Benjamin et al (2018) yield in organic production can drastically be improved as well as profit levels. Market cap of organic production is however at 20% of the market so this will also be the maximum for microbials use here, which means that from a macro-economic perspective it is not a really interesting market. To make a real impact it is better to focus on producing for the conventional market. It should however not be forgotten that organic production can be drastically improved with the use of microbials (pers. comm. 3) ➢ The organic market has no alternatives for crop protection, fertilization and stimulation. There are a lot of chances here because yield can in most cases be increased by 50% (pers. comm. 6) ➢ Organic sector will push the microbial market. The microbial market will first mainly focus on organic production and with this the products will develop to eventually penetrate the conventional market (pers. comm. 12)
Benjamin et al. (2018)	Increasing the adoption ceiling has a relatively stronger effect on the SIRB than increasing the adoption speed (increase of SIRB from EUR 54.4 million to EUR 120 million with an adoption rate increase from 10% to 30% for organic potato production)	➢ Adoption rate is very variable per crop, but an important factor to consider. Bigger impact to raise the adoption ceiling than increasing the adoption speed (pers. comm. 3)
Blum et al. (2011)	➢ Production costs of a microbial control agent were in 2011 on average 2.5 times as high as the chemical alternative	➢ Production costs of microbials will never match costs of especially chemicals of which the patents have been expired (pers. comm. 7) ➢ If politics demand that chemicals are banned, microbials can be a substitute. They will however stay more expensive. Costs can maybe approach the costs for the chemical alternative in some cases, but for most it will not (pers. comm. 6)

	➢ In 2011, the business profitability of producing a chemical pesticide was nine times as high as for a microbial agent	
Blum et al. (2018)	The registration costs of a microbial control agent were in 2011 EUR 860 000, while for a chemical alternative it was EUR 1 410 000	➢ Getting a new chemical product on the market can cost 400-500 million euros. This risk is too big for chemical companies considering chemical products are being banned. They are realizing they must shift (pers. comm. 12)
MarketsandMarkets Research Private Ltd. (2016)	Expected compound annual growth rate of microbial market of 15% from 2016 until 2021	➢ Köhl has estimated the CAGR at 15% at the start of the 2010's, but this has become higher, probably close to 20% (pers. comm. 6)
Scheepmaker & De Jong (2017)	➢ Costs and length of legalization process keeps companies from introducing new products ➢ For producers: long time to regulate the products can be too long for small producers to handle the costs	➢ In current European regulation too much questions are being asked by the regulators. Decisiveness of EU is not working well: the required studies have to go too deep and are not relevant for the product. Regulation period should decrease a lot, just like in the United States. Will not change on the short term, but definitely on the long term (pers. comm. 1) ➢ Registration and regulation is very complex and takes a lot of time and investment: especially a big barrier for smaller companies with less capital (pers. comm. 2) ➢ Industry is very worried about EU regulation, which has not been changed on this topic since 2001 (pers. comm. 3) ➢ To change the regulation in the EU, a commissioner will have to prepare a proposal which has to go through the standing committee and the appeal committee. This is a long and time-consuming process which takes on the average five to ten years (pers. comm. 3) ➢ Current regulation based on chemicals: product should be applied, kill the pests and then disappear as fast as possible without doing more harm to the environment. The biological products should however stay in the soil. This is a mismatch with the regulation rules (pers. comm. 4)

		➢ Current regulation also very unpredictable: delivered studies can lead to questions for more studies (pers. comm. 4) ➢ Companies take a risk when they start developing a product on the European market, because it is not clear when the regulations will change. Companies are moving out of Europe because of this uncertainty (pers. comm. 12)
Scheepmaker & De Jong (2017)	➢ High chance of adoption in horticulture: easy regulation of climate conditions ➢ Mostly used in horticulture	➢ Will probably mostly happen in horticulture, because technologically this sector is easier, and the crops have higher margins (pers. comm. 4) ➢ Potential for growth in the Netherlands especially in horticulture because of the high value crops. In this market there is more margin to use the integrated biocontrol packages (pers. comm. 7) ➢ Protected crops (i.e. horticulture or protected by plastic) currently by far biggest market for biocontrol. However not really hard numbers on market shares, because companies do not want to release them. IBMA global tried multiple times to create a good market overview but did not yet succeed. They are trying again in 2020. IBMA France one of the exceptions that do have specific numbers of their market (pers. comm. 7) ➢ Market mainly focused on horticulture in the Netherlands (pers. comm. 2) ➢ Horticulture currently most use of microbials: easier with margins like those of high value crops like tomatoes (pers. comm. 4) ➢ Most potential in arable agriculture, because of the volume (pers. comm. 2) ➢ Biggest opportunities for growth in arable agriculture (especially arable production of fruit) (pers. comm. 1)
Van Lenteren et al. (2017)	Europe biggest market for invertebrate biological control and North America for microbials. The strongest growth of the use of microbials is happening in Latin America, followed by Asia	➢ Biggest growth expected in Latin-America (pers. comm. 7) ➢ Europe could lead this market development. If regulation changes, Europe can start using these products broadly and the rest of the world will probably follow over time (pers. comm. 12) ➢ Europe the biggest opportunity for growth, because this market has the most focus on shifting towards chemical free production (pers. comm. 3)

- In the United States increasing social pressure on banning of chemical products because of health risks (pers. comm. 8)
- Market in Latin-America is growing. A lot of chances in Asia. The main market to focus on is however Africa: the big gain can be achieved here because of the big amount of degraded land and deprived soil (pers. comm. 8)
- Soybean production biggest market for microbials at the moment. Especially in Latin-America and China (pers. comm. 5)
- Demand is worldwide, not more demand in the Netherlands than for example Southern Europe. However, farms in the Netherlands are technologically more advanced than for example in Southern Europe, which makes the new microbial products easier to implement (pers. comm. 13)
- The EU wants the market share of organic production to increase, which unlocks market potential for microbials because chemicals cannot be used in organic production. The adoption ceiling will increase because of this (pers. comm. 6)
- Europe a very promising market because the political situation is stable (pers. comm. 6)
- Green deal will probably have a positive effect on development of regulation (pers. comm. 10)
- Dutch government has presented a plan for development of the agricultural sector until 2030: less dependency on chemicals and more integration of IPM (pers. comm. 12)

5. Discussion, conclusions and recommendations for further research

5.1 Discussion

The focus that has been set at the start of this research was on microbial applications in the European market of arable agriculture. The European market seemed to be the right market to have the focus on during this research. Most of the experts agreed that the European market is the market with the most potential for microbial products on the short term. This is mainly because of the stable political push on sustainability by the European Union and the big influence of European companies on the worldwide crop protection market. The market is most likely to first shift in Europe as the political push is the highest here, which is necessary for feasibility of these products. This does however not mean that the rest of the continents are not worth looking at, as adoption rates are currently higher in the United States and Latin-America, but the experts see the most potential for short-term growth in Europe.

The focus on the arable market also seems to have been a right focus. As biologicals have already been highly adopted in horticulture, mostly in the form of macrobials, there is not too much space for growth of the microbial market in this sector. The experts see the most room for improvement in arable agriculture as in this sector still tons of chemical pesticides are being used and harming the environment. For example, Koppert Biological Systems, one of the market leaders in the microbials industry, has gathered their whole microbials R&D department in their arable agriculture department, while their macrobials R&D department is situated in their horticulture department. Arable agriculture seems to be the sector with most potential for market growth.

The results from the interviews mainly matched the outcomes of the literature study. Two remarkable differences between statements from literature and statements from the interviewed experts have been shown. In the market report by MarketsandMarkets Research Private Ltd. (2016) it was stated that the expected CAGR between 2016 and 2021 would be 15%. One of the experts indicated that the CAGR is currently higher than this, probably closer to 20%. Secondly, two of the experts indicated that most potential for growth of the market lies in arable agriculture, while it was stated by Scheepmaker & De Jong (2017) that this would be in horticulture. The results from this research extend current scientific knowledge by emphasizing the big influence of the political push in Europe which is essential for the market to further develop. The influence from politics have been named as an important factor for future market growth but has not been emphasized as the main required push factor. From the results it turned out that this political push is required for further growth of the market, because of the low adoption speed by farmers. This low adoption speed has been found to be mainly caused by the higher costs for microbial products and the lower effectivity than when chemicals are used.

The research questions for this research addressed the direct costs and benefits related to microbial products in comparison to those of chemical products to find out which one is currently more favorable for the farmer and if this can change in the future. After the first couple of interviews these questions were however already answered, and it turned out that these questions were not the most relevant to ask when researching the economic feasibility of these products, because it is not a key factor in economic feasibility and market development of these products. Therefore, the interviews with the experts started to focus more on different factors in the economic climate that influence adoption of the products instead of limiting the interviews to questions on price development, as these were found to be not so relevant. Because of this shift from the focus to a broader view of the economic climate, the results that came out of the research in the end were more qualitative instead of quantitative, which was the initial idea of the research. This change of research focus was also caused by no availability of quantitative data on costs and benefits of the products. Because of this lack of quantitative data, the research in the end focused on developing a more global perspective of development of the industry and its issues and opportunities. A factor that might have influenced the external validity of the qualitative data output from the interviews is the unclarity of terminology in this industry. In literature a lot of different terminology is used, and this was the same for the experts during the interviews. This can mean that the perception on topics could have been intertwined in the interpretation by both the interviewees and the interviewers. This might have influenced statements made by the experts and thus the external validity of the results.

As a result of the lack of available quantitative data, the cost-benefit analysis and scenario analysis both were performed differently than was planned. The more global- and qualitative research approach that was used in the end performed both analyses with statements on factors influencing the costs and benefits of the products instead of exact quantitative data. This method was the most that the researcher could do with current known information on the market. When more quantitative data on costs and benefits of these products becomes available for the public, a quantitative cost-benefit analysis and scenario analysis can be carried out.

As some of the questions in the questionnaire that were mainly focused on costs and benefits of the products were quickly answered by the first expert interviews, they became less interesting to ask to the remaining experts. This resulted in the interviews becoming more open discussions over time because of the shift from the focus to a broader perspective of the industry. If this would have been known on the forehand, it would have been more appropriate to perform in-depth interviews instead of semi-structured interviews that partly consist of closed questions. In-depth interviews would also have been a good way to overcome the differing backgrounds from the interviewed experts. This way the focus of the interviews could have been more on their particular expertise.

The last limiting factor of the interviews was that no expert from the chemical industry has been interviewed. All the interviewed experts seemed excited about developments in this industry and the market share of microbial products getting bigger. This one-sided view of the industry can possibly have caused the results to be biased. It would have been interesting to have talked with someone from the chemical industry to see the developments from the competitor's perspective. The researcher tried to come in contact with experts from the chemical industry, but they were not as keen on giving interviews on this subject as the other experts and never replied to the sent e-mails. An idea for follow-up research could be to have a look at the developments in this industry from the perspective of the chemical companies.

For this research six scientific experts and eight business experts were interviewed. No real notable differences have been found between statements from scientific experts and business experts. The scientific- and business perspective seemed to agree that both sectors should work together to let this market flourish as this is a R&D based industry. For example, Rijk Zwaan, a company active in seed treatment, spends around 40% of their total revenue on research (pers. comm. 10).

5.2 Conclusions

The main objective of this research was to conduct an economic feasibility analysis on the different current applications of microbial biological control agents to replace chemical pesticides in agriculture and create a future prospect on its market potential. In the first research question all the current legalized microbial substances in the European Union and the corresponding legalized products in the Netherlands were mapped. With 50 legalized active substances in the EU and 51 legalized products, the sector already has quite a number of products on the European market. This is however nothing compared to the available chemical products on the market, so the market can be considered to be in the early growth stage.

The second sub-research objective especially focused on the costs and benefits of current and future practices of these products in comparison to their chemical alternatives. It turned out from the research that the costs for microbial products are indeed higher on average. This is mainly caused by higher production costs because of working with more complex active ingredients than with chemical products. Also, the challenging shelf life of microbial products causes higher logistics costs. Another factor that makes chemical products cheaper, is their high sales level, because the products can be used broadly for a lot of different crops in a lot of different soils. The microbial products are more environment-, soil-, and crop specific and thus less broadly usable. The yield levels with the use of microbial products have not been proven to be higher than with the use of chemical products, which was expected from the results of the literature study. These outcomes mean that the cost-benefit ratio of microbial products is on the average less beneficial than for chemical products when only direct costs and benefits are considered. The products can get cheaper with upscaling of the production, so the difference in cost-benefit ratio could become smaller, but the products will never be as cheap as the cheapest chemical variants available on the market if indirect costs and benefits are not considered. The indirect costs of the product will however be a lot lower for microbials than for chemicals. This is due to an environmental impact that is much lower for microbials than for chemicals. These costs are however not yet integrated in the cost-prices of the products.

It has however turned out from the third sub-research objective that the direct cost-benefit ratio of the products is not essential for the industry to succeed. The political pressure in the EU on more 'green' agriculture is that high, that chemical products are being banned from the market and market space is being created for the microbial products. Since there are close to no alternatives, farmers are nearly being forced to start applying the microbial products, despite the average higher price of the products. The pressure on the farmers is getting higher because their margins will become even lower this way. This is especially a problem in arable agriculture, as high value crops in horticulture have more room in their margins for higher prices of crop protection products. To keep beneficial agriculture in the EU feasible, products in the supermarket should become more expensive, to provide a higher margin for the farmers. The prediction is however that the real shift towards the use of microbial products in the EU will start once the EU regulation process of biologicals has been adjusted and products can be introduced on the market cheaper and more rapidly. The process is currently based on assessing chemical products and requires a lot of studies that are not even relevant for biologicals. Also, the assessment of the active ingredients is first being done on EU level and then the assessment of the separate products is being done on national level, which is seen as an inefficient process. The experts expect these regulations to change within the next two to ten years. The European Commission will present their workplan around April 2020. In this workplan it will become clearer if they will invest time and money in adjusting the biologicals registration process in the upcoming term. The microbial products can be divided into three product categories: biopesticides, biostimulants and biofertilizers. The product category that is currently expected to have the highest potential on the short term on the European market, is biopesticides. These products are currently the most developed and have the highest reliability and field effectivity. Biostimulants are also being seen as a category with potential, but more on the longer term as still a lot of research is needed on this product category to make the products reliable. As these products however not really have competitors, there is market space available. For all the different product categories the effectivity and reliability should however get higher. To achieve this, the gap between science and product development should be narrowed. In the organic market lie a lot of opportunities for microbial products. No chemical products can be used in organic production, but all the microbial products are allowed in this sector. With the use of microbials, the yield in organic production can on the average be increased by 50% compared to when no crop protection products are used.

Concluding, the market share of microbials in the EU is expected to grow in the upcoming years, but the speed of growth is dependent on when the EU regulation on this product category will be adjusted. The products are very dependent on a political push, as they are less attractive to apply for the end users in terms of direct costs and benefits. A lot of opportunities however currently already lie in the organic industry, as yield levels, and resulting from this, profitability, can in most cases be increased dramatically.

5.3 Recommendations for further research

The most important in this research identified issue currently holding the microbial industry back in Europe is the regulation process from the EU. A recommendation for the European government would be to investigate this regulation process and adjust it more to the characteristics of microbial products instead of performing the same tests as for chemical products. This would make it easier and less costly for innovative products to enter the market. Until this has been done, a recommendation for microbial producers would be to mainly focus on improving efficacy and broad usability of their products. Investors should closely watch when the EU regulation will change, because this is most likely going to give a big impulse on growth of the market share from these products.

A lot of scientific research in this industry still must be done to improve field effectivity of the products, as difference of the effectivity of the products often is too big between practices in the laboratory and in the field. On the cost-benefit level of the products also still a lot of research must be done. This research should however be focused on particular products for particular crops. The goal of this research to compare the cost-benefit ratios of all current applications of microbials with their chemical alternatives turned out to be way out of the scope of a Master thesis. The only large-scale study that has been done on this market in Europe, the INBIOSOIL study, was a series of studies during five years done by nine universities and seven companies and funded by the EU. This clearly shows what research scope is needed to perform a relevant cost-benefit analysis on these products in the EU, mostly due to the difficulty of acquiring numbers on costs and yield levels.

As it turned out from this research, growth of the market share of microbials is mostly dependent on a political push. A recommendation for further research is to talk with EU- and national level politicians on their expectation on the political climate around the pesticide industry. This way it should be possible to make a forecast of the time that it is going to take until a regulation change in the EU will be made.

Another perspective that has not been included in this research and which is very relevant to look at in this market, is the perspective from the chemical industry. It is important to understand the view from the big chemical companies on these developments, as they are globally very powerful in this industry.

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Table 6.1: background information of personal communication sources

Personal communication	Expert name	Background	Institute/company name	Position	Interview date
1	Jurgen Köhl	Scientific	Wageningen Plant Research (Biointeractions and Plant Health)	Senior Scientist	16-12-2019
2	Corné Pieterse	Scientific	Universiteit Utrecht (Plant-Microbe Interactions)	Professor	17-12-2019
3	Justus Wesseler	Scientific	Wageningen UR (Agricultural Economics and Rural Policy Group)	Professor and Chair Holder	17-12-2019
4	Willem-Jan de Kogel	Scientific	Wageningen Plant Research (Biointeractions and Plant Health)	Business Unit Manager	17-12-2019
5	Carl Pray	Scientific	Rutgers University (Department of Agricultural, Food, and Resource Economics)	Distinguished Professor	06-01-2020
6	Stefan Vidal	Scientific	Georg-August-University Göttingen (Department of Crop Sciences)	Professor	07-01-2020
7	Willem Ravensberg	Business	Koppert Biological Systems	Corporate Senior Regulatory and Governmental Affairs Manager	16-12-2019
8	Jacob Parnell	Business	Novozymes	Senior Scientist	19-12-2019
9	Steven van den Abeele	Business	Aphea.Bio	Chief Technology Officer	07-01-2020
10	Niels Louwaars	Business	Plantum	Chief Executive Officer	08-01-2020
11	Pam Marrone	Business	Marrone Bio Innovations	Chief Executive Officer/Founder	08-01-2020
12	Ronald Driessen	Business	Rijk Zwaan Breeding B.V.	Team Leader Seed Technology Research	09-01-2020

13	Sjoerd van der Ent	Business	Koppert Biological Systems	Business Unit Manager Microbiology	10-01-202
14	Coen Frederiks	Business	EuropaBio	Regulatory Affairs Officer	10-01-2020
15	Maartje de Boer	Business	AS de Boer	Unknown	20-11-2019

7. Appendices

Appendix A: Lists of current microbial practices

A.1 List of current legalized microbial active substances in the EU

Table 7.1: All current legal microbial active substances in the EU (EU Pesticides database, 2019)

Type	Number of products on Dutch market	Active substance
Bacteria	2	**Bacillus amyloliquefaciens** (former subtilis) str. QST 713
Bacteria	3	**Bacillus amyloliquefaciens** MBI 600
Bacteria	1	**Bacillus amyloliquefaciens** strain FZB24
Bacteria	0	**Bacillus amyloliquefaciens subsp. plantarum** D747
Bacteria	1	**Bacillus firmus** I-1582
Bacteria	1	**Bacillus pumilus** QST 2808
Bacteria	0	**Bacillus subtilis** strain IAB/BS03
Bacteria	4	**Bacillus thuringiensis subsp. Aizawai** strains ABTS-1857 and GC-91
Bacteria	1	**Bacillus thuringiensis subsp. Israeliensis** (serotype H-14) strain AM65-52
Bacteria	4	**Bacillus thuringiensis subsp. Kurstaki** strains ABTS 351, PB 54, SA 11, SA12 and EG 2348
Bacteria	0	**Pasteuria nishizawae** Pn1
Bacteria	1	**Pseudomonas chlororaphis** strain MA342
Bacteria	1	**Pseudomonas sp**. Strain DSMZ 13134
Bacteria	1	**Streptomyces K61** (formerly S. griseoviridis)
Bacteria	0	**Streptomyces lydicus** WYEC 108
Fungus	1	**Ampelomyces quisqualis** strain AQ10
Fungus	1	**Aureobasidium pullulans** (strains DSM 14940 and DSM 14941)
Fungus	0	**Beauveria bassiana** IMI389521
Fungus	0	**Beauveria bassiana** PPRI 5339
Fungus	0	**Beauveria bassiana** strain 147

Fungus	0	**Beauveria bassiana** strain NPP111B005
Fungus	3	**Beauveria bassiana** strains ATCC 74040 and GHA
Fungus	1	**Candida oleophila** strain O
Fungus	1	**Cerevisane**
Fungus	2	**Clonostachys rosea** strain J1446 (Gliocladium catenulatum strain J1446)
Fungus	1	**Coniothyrium minitans** Strain CON/M/91-08 (DSM 9660)
Fungus	1	**COS-OGA**
Fungus	0	**Isaria fumosorosea Apopka** strain 97 (formely Paecilomyces fumosoroseus)
Fungus	1	**Lecanicillium muscarium** (formerly Verticillium lecanii) strain Ve6
Fungus	3	**Metarhizium anisopliae var. anisopliae** strain BIPESCO 5/F52
Fungus	1	**Paecilomyces fumosoroseus** strain Fe9901
Fungus	0	**Paecilomyces lilacinus** strain 251
Fungus	0	**Phlebiopsis gigantea** (several strains)
Fungus	0	**Pythium oligandrum** M1
Fungus	1	**Trichoderma asperellum** (formerly T. harzianum) strains ICC012, T25 and TV1
Fungus	2	**Trichoderma asperellum** (strain T34)
Fungus	0	**Trichoderma atroviride** (formerly T. harzianum) strain T11 and IMI 206040
Fungus	0	**Trichoderma atroviride** strain I-1237
Fungus	1	**Trichoderma atroviride** strain SC1
Fungus	1	**Trichoderma gamsii** (formerly T. viride) strain ICC080
Fungus	2	**Trichoderma harzianum** strains T-22 and ITEM 908
Fungus	1	**Verticillium albo-atrum** (formerly Verticillium dahliae) strain WCS850
Virus	0	**Adoxophyes orana** GV strain BV-0001
Virus	5	**Cydia pomonella** Granulovirus (CpGV)
Virus	0	**Helicoverpa armigera** nucleopolyhedrovirus (HearNPV)

Virus	1	**Mild Pepino Mosaic Virus** isolate VC 1
Virus	1	**Mild Pepino Mosaic Virus** isolate VX 1
Virus	1	**Pepino mosaic virus** strain CH2 isolate 1906
Virus	0	**Spodoptera littoralis** nucleopolyhedrovirus
Yeast	0	**Saccharomyces cerevisiae** strain LAS02

A.2 List of current legalized microbial products in the Netherlands

Table 7.2: all current allowed microbial products in the Netherlands (Ctgb toelatingendatabank, 2019).

Product	Manufacturer	Active ingredient	Sectors used in
AQ10	CBC (Europe) Ltd.	Fungus	Horticulture
ASPERELLO T34 Biocontrol	Biocontrol Technologies, S.L.	Fungus	Floriculture, horticulture
BIO 1020	Novozymes France S.A.S.	Fungus	Arboriculture, floriculture, horticulture
Blossom Protect	Bio-ferm Biotechnologische Entwicklung und Produktion GmbH	Fungus	Horticulture
BotaniGard vloeibaar	Mycotech Europe Ltd. p/a Certis Europe B.V.	Fungus	Floriculture, horticulture
BotaniGard WP	Mycotech Europe Ltd. p/a Certis Europe B.V.	Fungus	Floriculture, horticulture
CARPOVIRUSINE EVO 2	Arysta LifeScience S.A.S.	Virus	Horticulture
Cedress	Koppert B.V.	Bacteria	Agriculture, horticulture
CERALL	Koppert B.V.	Bacteria	Agriculture
Contans	Bayer CropScience S.A.-N.V.	Fungus	Agriculture, floriculture, horticulture
CoStar WG	Mitsui AgriScience International S.A./N.V.	Bacteria	Agriculture, herb growing, horticulture
Cyd-X	Certis Europe B.V.	Virus	Horticulture
Cyd-X Xtra	Certis Europe B.V.	Virus	Horticulture
DELFIN	Mitsui Agriscience International S.A./N.V.	Bacteria	Agriculture, arboriculture, floriculture, horticulture

DiPel DF	Sumitomo Chemical Agro Europe S.A.S.	Bacteria	Agriculture, floriculture, herb growing, horticulture
Dutch Trig	BTL Bomendienst B.V.	Fungus	Amateur use, public parks
Fado	Nufarm B.V.	Fungus	Agriculture, horticulture
FLORBAC	Sumitomo Chemical Agro Europe S.A.S.	Bacteria	Agriculture, floriculture, horticulture
Gnatrol SC	Sumitomo Chemical Agro Europe S.A.S.	Bacteria	Floriculture
Integral Pro	BASF Nederland B.V.	Bacteria	Agriculture
Lepinox Plus	CBC (Europe) Ltd.	Bacteria	Agriculture, horticulture
MADEX Plus	Koppert B.V.	Virus	Horticulture
Madex Top SC	Andermatt Biocontrol AG	Virus	Horticulture
Met52 granular	Novozymes Frances S.A.S.	Fungus	Amateur use, horticulture, Public parks
Met52 OD	Novozymes Frances S.A.S.	Fungus	Agriculture, floriculture, herb growing, horticulture
MYCOSTOP	Danstar Ferment AG	Bacteria	Agriculture, floriculture, herb growing, horticulture
MYCOTAL	Koppert B.V.	Fungus	Floriculture, horticulture
Naturalis-L	CBC (Europe) Ltd.	Fungus	Agriculture, floriculture, horticulture
NEXY	Bionext s.p.r.l.	Fungus	Horticulture
PMV-01	De Ceuster Meststoffen nv	Virus	Horticulture
PreFeRal	Biobest Group N.V.	Fungus	Floriculture, horticulture
Prestop	Danstar Ferment AG	Fungus	Agriculture, floriculture, herb growing, horticulture
PRESTOP 4B	Danstar Ferment AG	Fungus	Agriculture, floriculture, herb growing, horticulture
Proradix Agro	SP Sourcon Padena GmbH	Bacteria	Agriculture
ROMEO	Agrauxine S.A.	Fungus	Agriculture, horticulture
Serenade	Bayer CropScience S.A.-N.V.	Bacteria	Agriculture, floriculture, herb growing, horticulture
Serifel	BASF Nederland B.V.	Bacteria	Agriculture, horticulture

Sonata	Bayer CropScience S.A.-N.V.	Bacteria	Agriculture, horticulture, herb growing, horticulture
T34 Biocontrol	Biocontrol Technologies, S.L.	Fungus	Floriculture, horticulture
Taegro	Novozymes Frances S.A.S.	Bacteria	Agriculture, horticulture
Tellus	Isagro S.p.A.	Fungus	Agriculture, floriculture, herb growing, horticulture
Texio	SBM Développement SAS	Bacteria	Agriculture, amateur use, horticulture
Toreda	BASF Nederland B.V.	Bacteria	Floriculture, horticulture
TRIANUM-G	Koppert B.V.	Fungus	Agriculture, floriculture, herb growing, horticulture, public parks
TRIANUM-P	Koppert B.V.	Fungus	Agriculture, floriculture, herb growing, horticulture, public parks
Turex spuitpoeder	Mitsui AgriScience International S.A./N.V.	Bacteria	Agriculture, floriculture, herb growing, horticulture, public parks
Turex WG	Mitsui AgriScience International S.A./N.V.	Bacteria	Agriculture, floriculture, herb growing, horticulture, public parks
V10	Valto B.V.	Virus	Horticulture
VINTEC	Bi-Pa N.V.	Fungus	Horticulture
VOTiVO	BASF Nederland B.V.	Bacteria	Agriculture
XenTari	Sumitomo Chemical Agro Europe S.A.S.	Bacteria	Agriculture, floriculture, horticulture, public parks

Appendix B: Complete questionnaire

Name of interviewee: ………………………………………………………………………………

Date: ……………………………………………………………………………………………………

1. General introduction

Topic overview

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Thank you for taking time to participate in our thesis research.

In our master theses, we are looking into the market potential of microbial products in agriculture. Boudewijn is looking into the competitive climate and the financial performance of the industry, whilst Luc is researching the market potential of microbial products based on price development. The focus is on the European market.

The purpose of this interview is to gain an insight on the expectation of several experts in the microbial industry on the development of the market in the upcoming years and to verify data found in literature.

The results of this interview will be used to provide a prospect on development of the microbial market in the European Union in the upcoming years for the Wageningen University and Research Centre and Roland Berger Amsterdam.

This interview will approximately take one hour.

2. Market composition

2.1 How big do you estimate the market shares of the following market segments in the use of microbials in the EU?

…% Arable agriculture …% Floriculture …% Horticulture …% Amateur use
…% Herb growing …% Other: …

2.2 Which market segment do you expect to have the most potential for a growth of use of microbials?

□ Arable agriculture □ Floriculture □ Horticulture □ Amateur use
□ Herb growing □ Other: …

2.3 Microbials are divided in biopesticides, biostimulants and biofertilizers. In which product category lies the most potential for growth within the microbials industry and how big do you estimate this growth?
□ Biopesticides □ Biostimulants □ Biofertilizers …%

2.4 Will the microbials market according to you grow, decline or remain steady?

In the next three years:
□ Grow □ Decline □ Remain steady

And with how many percent? …%

b) In the next ten years:
□ Grow □ Decline □ Remain steady

And with how many percent? …%

Additional comments:

…

3. Current situation on the market

3.1 Balance current prices

3.1.1 Which crop protection products have currently higher purchasing costs?

□ Synthetic □ Microbial □ Prices are similar

3.1.2 And how much higher?

□ The costs are similar □ Between 1 and 2 times as high □ More than 2 times as high

3.1.3 It has often been stated in literature that a normal cost-benefit analysis (only direct costs and benefits are taken into account) is not sufficient to compare microbials with their chemical alternatives to decide which one to use. Do you agree on this, and why (not)?

…

3.1.4 Which crop protection products have currently higher indirect costs (for example environmental and human health externalities)?

□ Synthetic □ Microbial □ Prices are similar

3.1.5 And how much higher?

□ The costs are similar □ Between 1 and 2 times as high □ More than 2 times as high

3.1.6 Scheepmaker & De Jong (2017) have stated that microbial products in the Netherlands currently already are price competitive for the end user, but the production costs are higher, so the profit margin for the producer is lower than for when they produce chemical products. Do you agree on this, and why (not)?

…

3.1.7 Do you think the profit margin for the producer can get bigger for the same products when the adoption rate gets higher, and why (not)?
…

3.1.8 Results from a big study on economic feasibility of microbials in the INBIOSOIL project show that a switch to using microbials can be beneficial for revenue per hectare in maize production, but in potato production, it would decrease the revenue per hectare. What are in your opinion crops for which the biggest increase in value can be reached?

…

3.1.9 It also resulted from the study that a switch to the use of microbials in conventional potato production is not beneficial, but it could be very beneficial in organic potato production, if the crops can still be sold as organic after the application of microbials. Do you think crops produced with the application of microbials can be sold as organic crops on the short term, and why (not)?

…

And on the long term?

…

3.2 Current adoption

3.2.1 How many of the crop farmers in Europe are according to you currently using microbials?

□ 0-5% □ 5-10%□ 10-20% □ 20-50% □ more than 50%

3.2.2 How many of the crop farmers in Europe are according to you currently using <u>only</u> microbials?

□ 0-5% □ 5-10%□ 10-20% □ 20-50% □ more than 50%

3.2.3 Do you think the adoption of microbials by farmers in Europe is currently high?

□ Yes □ No

b) If yes/no why?
…

3.2.4 Are the switching costs (for example learning costs or costs of no harvest in switching period) considered as a barrier for adoption?

□ Yes □ No

3.2.5 Do you think the adoption by farmers in Europe has the potential to grow?

□ Yes □ No

b) Why?
…

A how big percentage of all the farmers in the EU do you estimate as adoption ceiling of microbials?

…%

3.2.6 A study by Benjamin et al. from 2018 suggests that increasing the adoption ceiling would have a lot more positive influence on the market potential than increasing the adoption speed. So, increasing the volume of the target group would be on the longer term more beneficial than increasing the speed of adoption by the current target group. Do you agree on this, why (not)?

…

4. Market forecast

4.1 Expectation on development of EU regulation

4.1.1 Which factor do you think is currently mostly holding the industry in Europe back?

□ High costs □ Regulations □ Too little investment □ Other…

4.1.2 Do you think the regulation of implementation of new microbial products in the EU is currently holding the development of the microbials industry back?

□ Yes □ No

4.1.3 Do you think EU regulations on implementation of new microbial products will change in the upcoming five years?

□ Yes □ No

b) If yes, how will it change according to you?

…

c) Do you think these changes will influence the production costs of the microbial products?

…

d) If yes, in what way?

…

4.2 Probability of different scenarios

4.2.1 How big do you estimate the chance that microbials will gain, lose or not gain nor lose market share in the pesticide industry in the EU in the upcoming five years?

Gain: …%

Not gain nor lose: …%

Lose: …%

4.2.2 How big will according to you the market share of microbials in the EU be in five years?

…%

5. Price development

5.1 Expected price decrease

5.1.1 Do you think upscaling of the production and sales would be the solution for the products to become cost-competitive, or do you think most of the upscaling of the industry has already happened and not much cost-advantage is left to be gained this way?

…

5.1.2 Do you think the cost price of current microbial products will decrease if the production will upscale?

□ Yes □ No

5.1.3 How much cheaper do you think the products can get with upscaling of the production?

□ Not cheaper □ 3/4 of the current price □ 1/2 of the current price
□ 1/4 of the current price □ Less than 1/4 of the current price

5.1.4 Do you think the cost price of future microbial products will be lower if the production will upscale?

□ Yes □ No

5.1.5 Do you think microbials can eventually match the price of their synthetic alternatives?

□ Yes □ No

5.2 Expectation on benefits such as price premiums and their margins

5.2.1 Can farmers currently ask a higher price if they only use microbials or other biological products?

□ Yes □ No □ I don't know

5.2.2 Do you think price premiums linked to quality marks for crops produced with the use of microbials can boost the sales in the industry in Europe?

□ Yes □ No □ I don't know

b) Why?
…

Additional comments:

…

6. Revenue increase

6.1 Expected yield increase with microbials use

6.1.1 In literature it is often stated that microbials can be economically feasible because they can increase yield. From the INBIOSOIL study it indeed turned out that for grain maize the yield level can be increased by 2.6 tons per hectare, ceteris paribus. Do you think a yield increase of 26% is an assumption that can be made when assessing the benefits of microbials? Why (not)?

…

6.1.2 For which crops do you expect the yield to increase the most when switching to the use of microbials?

1) …
2) …
3) …

6.1.3 For which crops do you expect production risks in case of extreme weather conditions can be decreased the most when switching to the use of microbials?

1) …
2) …
3) …

Additional comments and recommendations for further research:

…

Would you like to receive a summary of our report when we are finished writing our theses?

□ Yes □ No