Efficiency analysis of pesticide application in the Dutch agriculture: a case study in onion production

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Abstract

The aim of the study was to investigate the development of regulations on the use of pesticides in agriculture together with the current status of the environmental pollution by pesticides especially in the flower bulb crop production system. The intention was to combine this information with a data envelopment analysis based on flower bulb crop production. A DEA analysis would be conducted to investigate if it is feasible to reduce the amount of pesticides without a loss in current production output.

The literature review showed that pesticides of flower bulb production are resulting in higher concentrations of pesticides in the environment compared to limited level of concentrations which is determined by the Dutch government. Improvement in sustainable use of pesticides is needed in the upcoming years in order to reach the environmental targets before 2023.

Due to the lack of data on flower bulb production, the DEA analysis was conducted for onion crop production in the time period 2008 – 2012. The DEA analysis showed that in this production system the reduction in pesticide use can be maximized up to the range of 43% - 59%, assuming variable returns to scale. By constant returns to scale the maximum reduction is between 46% - 63%. There were no significant differences found in pesticide efficiency between different farm size categories. The change in measurement unit of the input variable pesticide use from “costs in euro`s per hectare” to “environmental impact points per hectare” did result in significant lower efficiency scores. The results of the efficiency scores showed that a reduction in pesticide use in onion crop production is possible. However, the role of production risk needs to be clarified because of the preventive use of pesticides. The uncertainty in time of infection, pest density, yield loss per pest and the effectiveness of pesticides generally results in an over use of pesticides as farmers can face high production risks if the pesticide application is limited. Management supporting tools are needed to reduce this uncertainty, resulting in a more efficient use of pesticides.

Keywords: Regulation, Data envelopment analysis, pesticide, flower bulbs, onions, technical efficiency

Preface

This master thesis is written in the context of the master program Management, Economics and Consumer Studies at Wageningen University. The subject about pesticide use in agriculture gained my attention because of my background in agriculture. I saw the opportunity to use my background together with my obtained knowledge about agricultural economics. I found it interesting to work on the subject pesticides because of the ongoing debate about the use of pesticides in agriculture.

The completion of this thesis would not be possible with the help of some people. First I would like to thank my supervisor Monique Mourits for the help and guidance during my thesis. It was not easy to start this thesis because of the lack of data and we discussed many times the possibilities of continuing the research. Her positive attitude really helped me to finish this thesis. I would also like to thank Alfons Oude Lansink for sharing his knowledge about the DEA analysis method. This thesis would not be completed with the help of the Agricultural Economic Research Institute (LEI). By using their database it was possible to conduct the data analysis.

Matthijs Gebbink

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1. Introduction

1.1 Pesticides in agriculture

The use of pesticides is essential for the Dutch agriculture in order to grow healthy crops in combination with high yields. There are, however, also disadvantages like the threat for environmental pollution and the negative effects on human health. Public concern about the pesticide application, especially near city areas, has increased over the years. Especially in flower bulb production systems high amounts of pesticides are applied. The amount of pesticides applied per hectare on flower bulbs is on average 42 kg in 2008. In comparison, the average pesticide application for all the arable crops grown in the Netherlands is around 7 kg ha^{-1} (CBS, 2010). The higher amount of pesticide use in flower bulb cultivation is the result of a longer growing season in combination with higher risks for plant disease infections.

In order to reduce the negative effects of pesticides, regulations on European and national level have been developed throughout the last decades. The reduction is attained by limiting the use of pesticides in combination with the prohibition of pesticide products which are not meeting the requirements anymore, described in newest directive EC 1107/2009 (Williams, 2011). The reduction in pesticide availability forces farmers to apply less pesticide in order to protect crops against pests and diseases, or to use pesticides which are less harmful for the environment. One of the key elements in the newest directive is the use of alternative, more sustainable techniques resulting in an integrated pest management (Matthews *et al,* 2014).

In general, the negative impacts of pesticides can be reduced by applying pesticides more efficient (Tillman, 1999). An evaluation on the efficiency of pesticide application can be done by using the Data Envelopment Analysis (DEA) method. Various studies have been focusing especially on the efficiency of pesticide use by using DEA (De Koeijer *et al,* 2002) (Skevas *et al,* 2012) (Skevas *et al,* 2014). The rate of efficiency indicates how much the use of an input can be maximal reduced without any loss in output, or to which extend the output can be maximized given the actual inputs (Färe *et al*, 1978). For pesticides the focus on reducing the amount of inputs is more obvious instead of focusing on maximizing the output.

The increase in efficiency of inputs can be interesting because of the economic benefits for farmers. Improvements in terms of environmental aspects will become even more important given the aim of the European and national government to improve the sustainability of agriculture (European Commission, 2012). Improvement in sustainability can be obtained by reducing environmental damaging inputs such as pesticides. “No loss of economic perspectives for farmers” is one of the restrictions set by the European Commission. The competitive position of farmers should not be harmed due to the new implementations. However, the limitation of availability of pesticides can harm intensive cropping systems in terms of quality and yield.

1.2 Research objectives

The first objective of this research is to conduct a literature study to research the development of future pesticide regulations. It involves a review on the development of directives and regulations over time in combination with an overview of the current status of pesticides. The focus is especially on the environmental pollution, expressed in the concentration of pesticides in the environment, of flower bulbs production. This actual pollution status is compared with the maximum values which are developed by the government.

The second objective is to conduct a DEA analysis on pesticide use. Until now, insight in the efficiency use of pesticides in Dutch agriculture is lacking. Therefore, no estimation can be made about the feasibility of a further reduction of pesticides in agriculture. It is important to identify this input efficiency because of the ongoing adaptation of pesticide regulations. Possible improvements in terms of input efficiency can help farmers to meet the requirements of new regulations in the future.

1.3 Reading guide

The initial intention of this research was to research the efficiency of pesticide use in the flower bulb cultivation in the Netherlands. The quality of flower bulbs is highly depended on the use of pesticides in order to have high standard products as a result. Therefore, it is interesting to investigate what the current situation of the flower bulb sector is in terms of environmental pollution and the availability of pesticide products. The literature review in combination with a DEA analysis could have provided an indication if improvement in pesticide use is necessary based on the current pollution status and if it is possible limit the use of pesticides based the efficiency scores from the DEA analysis. If farmers are forced to apply less pesticides, but the outcome of the DEA analysis indicates that this rate of reduction is probably infeasible, there can be argued that farmers will face problems in the future to maintain their output on the current level.

Unfortunately during the research it became clear that no DEA analysis could be conducted for the flower bulb sector because of the lack of data. More about this problem is elaborated in the final discussion. The literature study for the flower bulb sector was already performed and therefore included in the research. For the DEA analysis the switch was made to onion crop production systems. In onions more pesticides are used on average (22 kg ha^{-1} in 2008) compared to other arable crops.

1.4 Outline of the report

The report starts with a literature review in chapter two. It involves the development of regulations over time. The national regulation and development of amendments are discussed with the focus on pesticide use in flower bulbs production. Based on the literature findings, future prospects of pesticide application are discussed

In chapter three the material and methods for the DEA analysis are elaborated. It involves the explanation of the DEA method and the description of the DEA model which is used in this research. Chapter four includes the results of the DEA analysis. Chapter five includes the discussion of the results of this research and chapter six contains the general conclusions.

2. Literature review

The start of the literature study is a short overview of the flower bulb sector and the onion sector and why pesticides are important in the cultivation of these types of crops. Subsequently, in order to understand the pesticides regulation, a short overview of the different directives on the introduction of new pesticides is given in combination with a description of the decision making progress which is regulated on European and national level. After this, the focus is on the national regulations of pesticides with a short description of the laws for pesticides. The government has developed amendments in order to reduce the negative effects of pesticides. These amendments are used to research the ambitions of the government and to investigate the current status of the flower bulb sector. Following this, the role of integrated pest management in flower bulbs is discussed. At the end the future prospects of pesticide application are elaborated.

2.1 Dutch Flower bulb sector

The Netherlands has generated a dominant position in the cultivation and trade of flower bulbs worldwide. This position is obtained because of the favourable climate conditions, high knowledge level and the strong image of Netherlands in the flower bulb sector (Productschap Tuinbouw, 2010). The Netherlands is responsible for 50 percent of the global export value of flower bulbs and 60 percent in total amount of flowers and bulbs. The Dutch export value was responsible for 590 million euro in 2010 (Productschap Tuinbouw, 2010). France, Japan, United States, United Kingdom and Germany are five destination countries which are responsible for almost half of the export. The export towards upcoming countries is increasing. Especially the export towards China increased with 56 percent in 2010 (Productschap Tuinbouw, 2010). The total cultivated hectares in the Netherlands were 23.289 in 2010 (Table 2.1). Although the number of hectares is low compared to other crops, flower bulbs are responsible for a high export value. The average revenue of flower bulbs is around €20.000 per hectare in 2012 (LEI, 2012). There are different areas in which flower bulbs are cultivated on a large scale, mainly on sandy soils. Especially areas in provinces Noord-Holland, Flevoland and Limburg are covered by flower bulbs. Also some areas in the Eastern part of the Netherlands are used for the cultivation of lilies (CBS 2011). There are five crops which are majorly grown in open field cultivation (Table 2.1). Tulips are responsible for almost half of the total area in 2010.

The cultivation of flower bulbs is capital intensive and involves high risks. Land rent, labour and planted bulbs are inputs which are responsible for the high costs of production. Especially the planted bulbs are costly. Bulbs are multiplied vegetative (Sectorplan Gewasbescherming Bloembollenteelt 2010). This implies that the bulbs are genetic identical in the next generation(s). This involves a high risk because the spreading of diseases will affect also the small bulbs which are needed for the next growing season. In other words, if farmers are having bulbs which are infected by diseases, it remains present in the crops in the next season(s). Quality is an important factor in flower bulbs. Products which are free of pests and diseases are important for exporting flower bulbs. Different countries will only accept products which are completely free of diseases (Sectorspecial Bloembollen, 2011). Quality is directly linked with the price of the bulbs. If the rate of viruses is increasing in flower bulbs, it will directly cause high price differences. Therefore, preventive control of pests and diseases is essential. The presence of fungi and virus diseases is growing in flower bulb crops the Netherlands. The increase in mechanisation, lack of employees and increase in scale of farms are responsible for the increase of diseases in flower bulbs. Farmers are spending less time to remove all plants manually from the field which are infected by a pest or disease (Sectorplan Gewasbescherming Bloembollenteelt, 2010).

Table 2.1: Total hectares per flower bulb crop in the Netherlands in 2010. Source: CBS, 2014

Crop	Area (hectares)
Gladiolus	1.111
Narcissus	1.760
Tulip	11.349
Lilies	4.887
Hyacinthus	1.433
Other	2.749
Total	23.289

In order to protect the quality and quantity of the crops, different pesticides are used to minimize the effect of pests and diseases. Insecticides are used to avoid the spreading of viruses by aphids. Virus diseases in flower bulbs are one of the major plant health problems (Kreuk, 2006). Unfortunately insecticides are having a high impact on the environment. The total amount of insecticides applied in flower bulbs is low, but the high emission of pesticides products is causing high concentrations of pesticide residues in the surface water (Landelijk Milieuoverleg, 2011). These products are reported as problem products. Special attention is paid to these products in order to reduce the emission towards the surface water. Regular application of fungicides is needed to avoid the fungi infections. Fungicides are used in high amounts in flower bulbs (Landelijk Milieuoverleg, 2011). Soil disinfection is used in flower bulbs to remove nematodes in the soil which can harm crops. The use of products for soil disinfection involves almost 50% of the total pesticide use in flower bulbs by looking to the kg`s of active ingredients (Landelijk Milieuoverleg, 2011). As a result, these products are causing a high emission towards the surface water. The recent prohibition of soil disinfection in the Netherlands can have a high impact for flower bulb cultivation. Other alternatives must be researched in order to limit the nematode populations in the soil. The upcoming years will clarify the effect of this abolishment.

2.2 Dutch onion sector

The Netherlands is one of the leading countries in the export of onions worldwide (Rabobank, 2006). The majority of the onions are exported to Russia and some African counties. The combination of high yields, low costs for cultivation, transportation and processing are responsible for the high export volume of the Netherlands (ING, 2014). The area under onion crops is on average 6% of the total arable land in 2014 (ING, 2014). The onion crop can be seen as the fourth crop for arable farmers. There are different types of onions cultivated in the Netherlands. However, during this research are only the data of onions used which are sown as seeds and sold after one year. These types of onions represent the majority of the onion products (CBS, 2014a). The area of onions in the Netherlands increased from 1.400 ha in 2000 to more than 2.300 ha in 2014.

In the cultivation of onions some problems frequently emerge. In order to have high yields with high quality onions, different pesticides are used. The total amount of active ingredients of pesticides per ha is more or less stable over the years. In total around 23 kg of active ingredients per ha was used in 1998 compared to 22 kg per ha in 2008. In comparison, the average use for arable crops was around 7 kg of active ingredients per ha in 2008 (CBS, 2014b). Onions is the crop in this category with the highest amount of active ingredients per ha. The high amount of active ingredients in combination with the large scale cultivation in the Netherlands makes onions an interesting crop for investigating the efficiency of pesticide applications.

The cultivation of onions involves a high price risk. The price of 1 kg onions fluctuated between € 0.00 per kg and €0.40 per kg in the last 5 years (ING, 2014). The high volatility of revenues between years makes it for famers a high risk crop. The time of selling and the quality are determining the price. Next to the high price risk different production risks are present during and after the cultivation stage. Farmers are selling their onions directly after harvest or they will store the product. It is important that the stored onions are free of pests and diseases. The duration of the storage is highly depended on the quality of the onions. The export of onions to destinations far away will require quality assurance. Therefore, farmers are using different pesticides during the season to have onions that are suitable for storage. Different diseases can infect the onions which will result in a reduction in the quality of the product. More heavy rain periods due to climate change can contribute to a rate of fungal diseases. As a result, onions will have a lower quality and problems with exporting onions can occur (ING, 2014). Onions are not covering the soil completely during the season, especially in the beginning of the growth period. The slow development of leafs is resulting in a high emerging rate of weeds. Therefore, herbicides are repeatedly applied to supress different weeds. It is important to apply herbicides at the right moment in the growing season to avoid problems (Van den Broek, 2003). Insecticides are needed to supress the accumulation of Thrips (flying insect) and onion flies. These insects are reducing the yield by causing starvation of onion leafs. Control of these insects is crucial and multiple spraying applications are needed to avoid damage.

2.3 Legislation procedure pesticides

Pesticide regulation is a slow and complex process and is continuously changing. Since 1980`s the European Union has developed regulations in order to prohibit the use of pesticides which were damaging human health and seriously affecting the environment. The European Commission developed several directives in order to minimize the negative effects of pesticides in the last decades. All the directives are described in the manual `EU Environmental Policy and the Netherlands` (Ministry of Infrastructure and Environment, 2014a). Directives are developed in order to set the criteria for the authorization of pesticides. Legislation for the authorization of new pesticides is majorly determined on European level.

The authorization of new active pesticide ingredients is controlled by the European Commission by means of Directive EC 1107/2009. The authorization of pesticides products based on these active ingredients is controlled by each member state individually. The authorization of new pesticide products is separated into two phases. First the active ingredient must be approved. In order to get permission for an active ingredient the producer must deliver information about the product regarding risks for humans, animals and the environment. This can be done in one of the member states in which the product will be available after authorization. In the Netherlands the authorization is done by the Ctgb (College voor de Toelating van Gewasbeschermingsmiddelen en Biociden). The criteria used by the Ctgb is harmonised in all the member states and the evaluation is done in cooperation with the European Food and Safety Authorization (ESFA). After a comprehensive research the new product must satisfy all the requirements as set in the directive 1107/2009. The most important criterion is that the product must be effective to reduce a pest of disease without harming the health of humans, animals or the environment (Gewasbescherming, tweede nota duurzame, 2012). The second phases consists of the authorization of pesticide products with contains the active ingredient. The EU is divided into three zones. If the authorization is approved by one country within this zone, all the other countries are also approving most of the time the product. A member state can reject the zonal authorization if the agricultural circumstances, phytosanitary and ecological circumstances are not comparable (European Commission, 2013).

In the authorization period is determined in which crop for which purposes and in which kind of regions in the EU the pesticide is allowed (Ministry of Infrastructure and Environment, 2014). It is also regulated how the pesticide must be used with a maximum dose and during which period of the growing season. The number of applications of one product is also regulated. The normal authorization period for a new product is 10 years but special conditions can change the time of authorization (Ministry of Infrastructure and Environment, 2014).

Active ingredients are divided into three categories based on the risk for human and environment. Low risk products receiving a longer authorization period up to 15 years. This will provide the producer and the user of the chemical more certainty that it will stay available for a longer period. High risk products will be controlled and evaluated within the authorization period. Research will be done to investigate if there are no other alternatives with a lower risk. In case there are other options the authorization of the high risk product will not be continued or terminated as soon as possible (Ministry of Infrastructure and Environment, 2014).

Member states can reconsider the authorization of existing pesticides. Pesticides are evaluated after the authorization period is expired or if there are specific reasons to evaluate. The authorization can be approved for another time period if it still meets the regulations. The authorization can be withdrawn or limited if there is an alternative pesticide available which is better and safer for the environment and human health. Another possibility is the availability of a non-pesticide method to minimize the effect of a pest or disease (Ministry of infrastructure and environment, 2014).

2.4 National regulation

The national regulation for the authorization and use of pesticides is described in `Wet Gewasbeschermingsmiddelen en Biociden (Ministry of Infrastructure and Environment, 2014). The law describes the authorization procedure, the conditions for the new requested pesticides products and the conditions how and when pesticides can be applied. The implementation of the Dutch law is elaborated in the resolution and regulation of pesticides. In the Netherlands the user must have a certificate to apply pesticides. The use of protection clothes is also required. The control for the proper use of pesticides is done by Dutch Food Safety Authority (NVWA) and water authorities (Ministry of Infrastructure and Environment, 2011).

In order to minimize the negative impacts of pesticides on human health and the environment and to achieve international standard regarding the environment, the Dutch government developed two plant protection policy amendments since 2003 (Dutch: Nota Duurzame Gewasbescherming).

The first amendment "Plant protection policy" (Gewasbescherming, Nota Duurzame (2004)) was developed in 2003 and lasted for a time period of seven years. The aim of the amendment was to reduce the negative impact of pesticides with maintenance of an economic perspective for the agricultural sector. The objectives regarding food safety and the protection of employees are not discussed in this research because of the focus on environmental pollution.

The overall aim of the policy was to reduce the negative environmental impact of pesticides with at least 95% in 2010 compared to 1998. One of the priorities was the improvement of the drinking water quality. The total number of measurements which were exceeding the maximum concentration of pesticides in water needed to be declined with at least 95% in 2010. The maximum acceptable concentration for each pesticide is expressed as the MTR value. The level of the MTR value is scientifically determined for each pesticide product (Wenneker *et al,* 2012). The average concentration level of a pesticide in a certain time period is expressed as the MIP value. MIP values >1 indicate an exceedance of the MTR value for this time period (Hendriks-Goossens *et al,* 2010).

According to the policy, the objectives could be reached by following the authorization procedure including environmental policies which were in line with the European regulations for pesticides. Another aspect was the improvement of integrated pesticide applications. This would stimulate the innovations for researching other options instead of using pesticide applications. Also sustainable and effective pesticide availability needed to be created. This could be obtained by developing products which were less harmful for the environment and which are more effective in pest and disease control. If there were bottlenecks regarding pesticides in crops, other effective alternatives needed to be researched to solve the problems. The main tasks of the government were to provide clear and adequate regulations regarding pesticides and strict control if the regulations were not exceeded. Another aspect was the development of knowledge about integrated pesticide application. The last objective was to have a proactive attitude in Europe to make the standards for pesticides stricter regarding the environment (Gewasbescherming, Nota Duurzame, 2004).

The government developed a second amendment "Plant protection policy" in 2012 (Gewasbescherming, tweede Nota Duurzame, 2012). This amendment was based on the evaluation and conclusions of the first amendment. Although since 2003 the agriculture had become more sustainable, not all the targets were reached. Especially the water quality was still a problem based on the concentrations of pesticides in surface water. The growing concern about the risks of pesticides for people who are living next to agricultural area`s required new research. The ambition of the government is to meet the international standards regarding environment, human health and working conditions before 2023. On the other hand, the economic prospective and competitiveness of the agricultural sector must be maintained. Authorization institutes, traders and users of pesticides are responsible for a sustainable use of pesticides. The government will provide support and will remove regulations if these are causing unnecessary barriers.

The main issue in the new amendment is the application of integrated pesticide application. The government will stimulate the innovation to apply integrated application. Every sector must develop a plan to apply integrated pesticide management. One of the major goals is the improvement of the water quality. In 2023 exceedance of the maximum concentrations in water (MTR) are not allowed anymore. This requires major efforts from the agricultural sector. Since 2014 the drift percentage must be declined with at least 75% instead of 50%. An increase in cultivation free area`s with 1-1.5 meter extra near water is also an option is the government concludes that the reduction of bottlenecks is not declining enough. Authorization holders must develop emission reduction plans for pesticides products which are exceeding the maximum environmental norms (Gewasbescherming, tweede Nota Duurzame, 2012). The flower bulb sector will need to adopt innovations in order to reach the objectives as subsequently described in section 2.6.1.

2.4.1 Evaluation plant protection policy

The first amendment was evaluated after 2010 in order to see if the objectives were reached as set in 2003. The main starting point was to reduce the environmental impact with at least 95%. The maintenance of an economic perspective was one of the essential prerequisites. In order to evaluate all the disciplines in more detail, the evaluation report (van Eerdt *et al,* 2012) was divided into reports about the impact on economics, environment, food safety, occupational safety, knowledge development, biologic pest control and phytosanitary policies. In this literature study are majorly the evaluations on the environmental and economic impact described because the main objectives (improvement of sustainability and availability of pesticide products) are related to these two disciplines.

2.4.2 Sub-report environment

Next to general measurements about the environmental impact, measurements were done for each sector individually. In this heading the measurements and findings of the flower bulbs are described. The sub-report environment as published by Van der Linden *et al,* 2012 is describing the change of environmental impact between 1998 –2010. In this report measurements were done to investigate the change in the rate of pollution and emission of pesticides in the surface water, ground water and air.

In open cultivation systems like flower bulbs, there are different routes for pesticides to reach the surface water. Emission via the drainage system is one of the major factors. Atmospheric decomposition of pesticides and drift from applying pesticides are also contributing to the emission but these factors are declining (Van der Linden *et al,* 2012). The only factor which increases is the disinfection of bulbs before planting. The flower bulb treatment is performed at farmyards and runoff towards surface water of pesticides is occurring. In literature referred as point-sources (Van der Linden *et al,* 2012). In order to reduce the emission by drainage systems and atmospheric decomposition, other measures are needed. Measures such as lowering the dosage of pesticides , prohibition of pesticides which are having unfavourable characteristics like a high volatilization rate, use of pesticides which are decomposing slowly or pesticides which are not binding to soil particles (Van der Linden *et al,* 2012).

The use of pesticides in kg`s is the highest in the flower bulb sector. On average 88 kg ha^{-1} of pesticides were applied in flower bulbs in 1998. This amount declined to 72 kg ha^{-1} in 2005. However, the amount did not decline anymore after 2005. In 2010 the amount was almost equal around 73 kg ha^{-1} (Van der Linden *et al,* 2012). Reasons for the decline in the time period 1998 -2005 were change of regulations. In 2000, the regulation `Lozingenbesluit Open Teelten` (Ministerie Verkeer en Waterstaat, 2000) was established to reduce the emission of pesticides in surface water. Cultivation free areas were implemented and pesticides with a high emission were restricted or even forbidden (van Eerdt *et al,* 2012). Measurements showed that the emission, expressed in gram pesticides/hectare, caused by the flower bulb production was declined with 54% from 223 gram ha^{-1} in 1999 to 101 gram ha^{-1} in 2008. The emission did not decline anymore after 2005, which is in line with the kg ha^{-1}use of pesticides. In 2005 a reduction of 47% in emission was reached compared to 1998.

The MIP value per year declined in flower bulbs from around 26 MIP ha^{-1} in 1998 to 8 MIP in 2010. This is a decline of almost 70% of environmental impact on surface water. The impact on ground water declined with 65%. The MIP value for emission to the air declined with 36%. Only a small amount of active ingredients are responsible for the major part of the MIP value (Van der Linden *et al,* 2012). Based on these measurements, the conclusion can be drawn that the flower bulb sector did not achieved the 95% reduction on the environmental impact in 2010 compared to 1998. Active ingredients which are having the largest impact on the environment are listed in the `top ten list`. The three active ingredients with the largest impact are all used in flower bulb crops. These are two insecticides and one fungicide which are used on large scale.

A pilot study showed that drift limitation measures especially in flower bulb crops can help to reduce the MIP effectively in comparison to integrated pesticide measures. The set-up of the pilot study is described by Spruit *et al,* 2009. Improving the cultivation free area and the use of new spraying techniques will lead to a reduction in drift. In the report cost efficiency in MIP/ euro is used as a reference to determine the rate of success. In the report the effect is calculated on MIP for different measures for different crops. The improvement of cultivation free area will have the largest resuction effect in flower bulbs but the costs are also high. The use of other spraying techniques to reduce the drift up to 90% is also an effective measure and the costs are relatively low but this implementation also involves some risks. The effectiveness to suppress the pest or disease will decline to a rate which can be insufficient. The study also shows that especially some pesticide products are having high MIP values. An improvement for the environment can be reached if for these products alternatives are developed. This will lead to a reduction in use of these products and high environmental improvements can be obtained (Spruit *et al,* 2009).

2.4.3 Sub-report economics

Reducing the negative impact of pesticides on the environment is the aim of the first plant protection amendment. One of the conditions is that the change in regulations will not affect the competitive position of the Dutch agriculture. In the sub-report Economics published by Schoorlemmer *et al,* 2011 the effect of the change in pesticide regulations on the farmers' income was calculated. The change in costs between 1998 and 2010 was determined. The crops tulips, lilies, hyacinth and narcissus were used in the analysis by investigating flower bulb crops. The average increase in total costs for an average farm was 2,6 %. An average farm was defined by the economic institute LEI based on the number of hectares. The differences in costs increase between crops were high. The change in costs for narcissus was around 9% and for lilies around 2 %. The report compared these values with other Western Europe countries, but for flower bulbs no comparison was made because of the limited area of flower bulbs in other countries.

The effects were majorly caused by limitations set by the emission reducing norms. Emission reducing norms were drift reducing techniques and the implementation of 1.5 meter cultivation free area. These regulations were causing 1,3% increase in total costs. The negative effects were also caused by the change in availability of pesticides. Some pesticides were prohibited in 2010 and were causing a negative economic impact. The change in pesticide availability resulted in a 0,7% total cost increase. Pesticides were replaced by more expensive alternatives.

Since 2009 the use of basins is compulsory. Water used by cleaning the bulbs needs to be stored in these basins. The use of basins is only required in the Netherlands, resulting in a total cost increase of 0,5% . The last minor issue were the administration costs by which the total costs increased by 0,1% (Schoorlemmer *et al,* 2011). Changing the regulation of soil disinfection also had a negative economic impact. The regulation of applying soil disinfection only one time every five year affects soil fertility in terms of nematodes and soil borne diseases. The recent (temporary) prohibition of soil disinfection will have a negative impact in the future but exact numbers are not calculated until now.

2.4.4 Monitoring pests, diseases and weeds

Monitoring of the development of pest and diseases will help to prevent problems which can occur. In order to monitor the development properly, the platform `Monitoring Pest, Diseases and Weeds` was started in 2005 (Schoorlemmer *et al,* 2011). The aim of the platform was to signal and study alarming developments of pests, diseases and weeds which can have a negative effect on reaching the objectives of the plant protection policy.

The plant protection service developed a report in 2009 (Plantenziektekundige Dienst, 2009) with the findings of developments of pests in different sectors. The findings were done by establishing groups which consisted of different experts with expertise in pesticide application, pests and diseases and integrated pesticide application. Findings in the report showed that problems in pest control in the production, which were present in both 2005 and 2009, were majorly influencing the economic position of the flower bulb sector. The problems were majorly caused by the lack of availability of an effective pesticide product. The expiring authorization of pesticides played a large role in this process. The amount of products that expired was higher than the development of new pesticides. Lack of adequate pesticides was causing problems in preventing virus problems, fungi infections and suppressing weeds. When the number of possible pesticides was reduced, the chance of resistance development by diseases was increasing. This led to a reduction in effectiveness of pesticides in the future. Change in regulations was also playing a role. For example, the regulation of soil disinfection was causing an accumulation in soil borne diseases. The change in climate was causing a higher pressure of pests and diseases which is in combination with the lack of effective pesticide products were resulting in possible alarming developments. (plantenziektekundige dienst, 2009).

2.4.5 Minor crops

In directive 1107/2009 is set that pesticides can only be approved if a risk assessment is performed. However, there are pesticides which are lacking this risk assessment because they are applied in "minor crops". The Dutch agriculture is characterized by a high number of minor crops (Dutch: kleine teelten). The definition of minor crops is based on the number of cultivated hectares. In 2012 the secretary of state for agriculture Bleker changed the definition for minor crops. Before 2012 crops less than 1.000 hectares were classified as minor crops. This was changed to 5.000 hectares in order to putt more crops under the label minor crops (Ctgb, 2012). Almost all different flower bulb crops can be assigned as minor crops. Only tulips are covering a higher amount of hectares (Table 2.1). Because of the high costs for authorization, producers do not have high interest in developing specific pesticides for minor crops. Crops which are covering a higher amount of hectares will generate higher profits for producers. In order to establish an efficient and effective pesticide availability for minor crops the government developed special regulations for these group of crops. The minor use fund (Fonds Kleine Toepassingen) is established to generate knowledge and finance for the authorization and research expenses of pesticides for minor crops. The funding is basically coming from the Ministry of Agriculture and the agricultural production industry (EU Monitor, 2014)

In the second amendment plant protection policy, the Dutch government pays special attention to minor crops. The government will take different actions in line with directive 1107/2009 to stimulate the authorization of basic and low risk pesticides for minor crops. This is done by raising an EU coordination centre. This centre is called Expert Centre Speciality Crops. The ECSC will stimulate the research for sustainable and effective pesticides in minor crops. The government, pesticide producers, farmers and researchers will provide the ECSC with expertise to obtain solutions. In directive 1107/2009 is also an article devoted to the expanding possibilities for minor crops. The Netherlands is having a leading role in the interpretation of regulations for minor crops because of the high importance for the Dutch agriculture (Gewasbescherming, tweede nota duurzame, 2012).

In the Netherlands a regulation for exception of pesticides is approved. The regulation (Dutch: regeling uitzonder gewasbescherming, RUB) is established for pesticides use in minor crops. This makes it possible to authorize pesticides directly instead of an elaborated authorization procedure. There is also partly (or no) risk assessment done about the effect of the pesticide. However, this is not in line with the directive 1107/2009. This will have a major impact on the availability of pesticides in minor crops if these products are forbidden. The Dutch government requested a delay for the abolishment of the RUB. It is unclear what the criteria will be for categorizing basic and low risk pesticides. Therefore, the RUB will stay intact until clear regulations are set how these categories are classified and authorization procedures can be requested. These categories are more or less in line with the pesticides in RUB and this will give producers enough time to authorize the pesticides in line with the directive (Ctgb, 2013). However, it stays uncertain how this process will develop in the future in terms of authorization of pesticides and availability of products for farmers.

2.5 Integrated pest management

Integrated pest management (IPM) is one of the possibilities for reducing the amount of pesticides in agriculture. IPM will force farmers to apply other methods to minimize the effect of a pest or disease instead of using pesticides. These alternatives can be applied if these are effective and therefore (hardly) no negative economic consequences will occur (de Haan *et al,* 2007). As mentioned in the second plant protection policy, the Dutch government stated that IPM is the key element in reducing the amount of pesticides which will result in a lower emission in the surface water. Flower bulbs are highly depends on pesticides, but what is already achieved in this sector in order to improve IPM. In this heading is researched what type of IPM are developed for the flower bulb sector and how effective these alternatives are for the environmental pollution reduction.

The clarification of `best practices` is one of the actions which will stimulate the innovation and quality of pesticide management (de Haan *et al,* 2007). The aim of implementing best practice measures is to reduce the negative environmental impact of pesticides by applying IPM. The research was done by PPO commissioned by the ministry of agriculture in 2003. Best practices are measures which are still in research regarding effectivity and feasibility or which are already implemented by a small amount of farmers.. The best practices are dynamic and every two years the list must be evaluated to investigate the feasibility of new measures (de Haan *et al,* 2007). Best practice can turn into good practices measures if it is effective and feasible for implementation and if it has an added value for farmers. More effort is needed to spread the knowledge about the measure by providing demonstrations and information. The good practices are successful if the majority of farmers have adopted the measure and no more research or effort is needed for implementation. Measures which are not useful for a large scale adoption in practice after evaluation are removed from the list.

In the evaluation of the first plant protection policy sub-report `knowledge development` (van der Wal *et al,* 2011) is researched how much IPM contributed in each sector. The most recent update about the status of best and good practices is done in 2009. The website www.gewasbeschermingsmaatregelen.nl provides an overview of all measures per sector. For this literature research the measures which are referred as good practices and which are adopted by >30% of the farmers are used. This will give an indication how much measures are developed until 2009.

In total 26 measures were reported. Table 2.2 provides an overview of the different type of measures which are developed. Prevention of an infection of pests and diseases is the largest category; in total 19 different preventive measures were adopted by > 30% of the farmers . An example of these measures is the change of planting date based on the soil temperature. A lower temperature will reduce the chance of infection of different diseases. Chemical pesticide refers to the more efficient use of pesticides. Pesticides are preventive applied. Here, the focus is on the best time of pesticide application in the growing season. A best practices measure is the reduction in applications of insecticides in lilies after august because of the lower chance of virus infections.

Table 2.2: Different type of measures referred as good practices and adopted by >30% of the farmers

Type of measure	>30% of farmers
Prevention	19
Cultivation method	1
Decision support systems	2
Non-chemical pesticide	-
Chemical pesticide	3
Emission reduction	1

The effect of these measures on the environmental impact is also determined (Table 2.3). The classification is a qualitative estimation (de Haan *et al,* 2007). The environmental impact is classified into high, moderate, small and none. The reductions in dependency of pesticides are measures which are preventing the use of pesticides. If the no effect on the reduction of the environmental impact, there is stated that there is a possibility that the measure will have a possible effect in the long term. Table 2.3 shows that six practices led to a high reduction and six in a moderate reduction in the environmental impact. For one practice there was hardly any improvement and five practices did not change the impact on the environment.

Reasons which are causing barriers for implementing the measures are divided into different categories. a) the measure is causing an increase in costs b) the measure is causing a reduction in yield c) the measure will take too much labour d) the risks of crop failure are increasing e) there are not enough pesticides to support the measure (de Haan *et al,* 2007). It was not indicated what the possible barriers for the indicated individual measures were.

Table 2.3: Effect of good practices measures on the environmental impact

Effect reduction environment impact	>30% of farmers
Reduction dependency pesticides	8
High	6
Moderate	6
Small	1
None	5

2.6 Future prospects

In this heading two subjects are discussed which are aiming at the future of pesticide application, i.e., 1) the feasibility of the second plant protection policy and 2) the increased concern about the risks of pesticides for local residents.

2.6.1 Feasibility plant protection policy

The improvement of the water quality is one of the major objectives in the second amendment plant protection policy. In 2012, the economic institute (LEI), RIVM and independent consultancy company CLM calculated the feasibility of different measures stated in the amendment for different sectors. The Dutch Ministry of Economics and the Ministry of Environment wanted to know which emission reductions are needed in order to reach the objectives of 50% reduction of standard exceedings in 2018 and with at least 90% in 2023. There is determined if the proposed measures for emission reductions stated in the amendment will reach the required emission reductions in 2018 and 2023. The economic effect of the required reduction is calculated for each sector (Buurma *et al,* 2013).

In the report of Buurma *et al,* 2013 the required emission reduction is calculated for the flower bulb sector. The calculation is based on the EQS/MTR value. The EQS value represents the environmental quality standards for water policy which is harmonised in the EU. In the report is the current EQS/MTR value calculated for 50% and 90% reduction. A complete description of the EQS value can be found in the report ` common implementation strategy for the water framework directive 2000/60/EC` (European Parlement, 2000).

In order to reach the reduction with 50% in 2018, the flower bulb sector must decrease the emissions with at least 83%. Condensation water from the storages is causing a high emission. Bulbs are treated with the insecticide product pirimifos-methyl. The product is causing a high emission if it will come in the surface water. Measures to reduce the emission of condensation water will significantly improve the quality of surface water. The 90% norm in 2023 will require a reduction in emission of 99,3%. (Buurma *et al,* 2013). The different routes of emissions needed to be more researched. The volatilization and leaching of pesticides are also responsible for emissions towards surface water. More research is needed to investigate what the possibilities are to reduce these emission routes.

The costs for implementation of different measures were calculated. This increase in costs was compared to the value which represented 1% revenue loss. In the second amendment was stated that 1% of revenue loss was acceptable to implement the measures for emission reduction. For flower bulbs one percent equalled 3.700 euro. The average size of farmers is increasing. As a result, measures will become cheaper for larger farms. The revenue loss for 66% of the largest farms were calculated. For this category is one percent revenue loss equal to 6.900 euro(Buurma *et al,* 2013).

The change of the spraying technique by using other type of spray caps will reduce the drift percentage with 75 or 90%. This will have a major impact on the emission reduction. Spray caps with 90% drift reduction will reduce the emission with 76%. This drift reduction in combination with the purification of the condensation water can reach the objective of 83% reduction in emission for 2018. Costs for spray caps are low and the investment for purification of condensation water will be probably lower than the reference value.

By the cultivation of flower bulbs is already a cultivation free area required of 1.5 meter. An increase in size of this area will not result in a reduction in emission. Buffer areas (Dutch: akkerranden) are useful for the reduction of drift but buffers are costly. The 90% reduction in 2023 will require more measures which can have a major impact. Here, drift reduction will provide a significant emission reduction, but this is insufficient to reach the target. The suggestion is done to reduce the emission of condensation water in combination with the reduction or even prohibition of pesticides which are responsible for high emissions. The annual costs if pesticides are forbidden are not quantified but it is obvious that it will involve high costs for farmers. In Buurma *et al,* 2012 the costs for the replacement of insecticides are calculated. The replacement will cost on average flower bulb farm 12.000 euro. The costs for the purification of condensation water were not calculated.

2.6.2 Risks of pesticides on the health of local residents

There is a growing concern about the risks of pesticide application on the health of local residents. In several areas in the Netherlands people are concerned when crops are cultivated closely to living areas. Therefore, different protest groups were founded to demonstrate against the intensive use of pesticides in flower bulbs. The Board of Health is informed in 2011 by the Government to do research about the possible risks of pesticides on local residents.

This Board published a report in 2014 about the risks of pesticide application close to area`s where people live or work (Gezondheidsraad, 2014). This holds especially for the intensive use of pesticides in flower bulbs and in orchards. The commission of the board stated that the current pesticides are more specified for one pest or disease and the pesticides are quicker decomposed in the environment. The cumulative amount in humans and animals is also lower. The authorization procedure of new pesticides has been improved continuously, but it is difficult to define risks like the risk for unborn children, the effect of different combinations of pesticides and the effect of pesticides when it is coming from different sources (environment, food or work).

Until now, little research has been done about this topic in the Netherlands. Literature research was done by the health authority (GGD) during the 90`s about the health risks of pesticides for residents. The conclusion was that people do not have a higher risk if they are exposed to a certain type of pesticide. However, the combination of different type of pesticides can be a possible threat. The state secretary of environment in the Netherlands concluded in 1998 that there are no negative effects on the public health and more research will not lead to other conclusions. This was also the conclusion of prof. Heederik in 2009 who investigated the risks of pesticide application on the health of residents. His conclusion was based on the spraying technique and scientific literature. There is some evidence from studies abroad that residents are exposed to pesticides can face health risks. The board of health concluded that it is useful to research the effect of pesticides on local residents. An exposure research among local residents will be the start of the research. The outcome of this research will determine how the research should be continued.

The authorization of pesticides has been changing continuously because of new research and insight about the risks of pesticides. Until now, the Dutch authorization of pesticides does not take the risks for local residents into account by evaluating the risks of pesticides. The EFSA is developing an EU harmonised procedure for evaluating pesticides including the risks for local residents. Around 10 percent of the amount of pesticides will end in the environment. The emission of pesticides to the air is much higher than the emission towards surface or ground water. Volatility of pesticide, application technique and the weather circumstances are determining the emission to the air. The concentration in the air reduces because of the large distance towards the source. The decomposition rate in the air is also fast, around two days. This does not mean that the concentration of pesticides close to the source of application also shows a low value. Especially under certain weather circumstances the concentration next to the fields can the significant higher.

Farmers can improve their own safety by diagnosing how and when they are exposed to pesticides. Discussion between local residents and farmers about the use of pesticides will also help to reduce the exposure rate. New innovations to reduce drift (diffusion of pesticides) will have a positive effect. Producers of pesticides can improve their products by also take the risks for residents into account and provide all stakeholders with information about the possible consequences of chemical application.

2.7 Summary literature study

Since 30 years the European Union has been developing directives in order to minimize the negative effects of pesticides. Governments of individual member states can decide which products are allowed based on the restrictions as set by the European commission. The authorization of new products is a complex and slow process because of the intensive testing regarding possible threats for the environment and human health. The authorization of new products or for extending already existing products involves a lot of costs. Therefore, producers of pesticides are considering which products are extended or not.

Especially in the Netherlands a lot of minor crops are cultivated. The abolishment of the pesticide products which are lacking a risk assessment will have a major impact for the flower bulb sector. The government developed a coordination centre for these crops, but until now it is uncertain how the process of these pesticides for minor crops will develop in the future.

The evaluation of the first amendment plant protection policy showed that the goals in reducing environmental impact, which were developed in 2003, were not achieved in 2010. Especially the goals with the aim to improve the water quality were not accomplished. The fact that the environmental impact did not decline between 2005 and 2010 is a reason for concern.

The ambition of the government to have no MTR exceedance anymore before 2023 will ask major effort from all the stakeholders. The feasibility report shows that emission reducing techniques can be implemented but these will not generate sufficient reduction in 2023. These techniques also involve high costs or a reduced effectiveness in pest control. Therefore, the emission route of the pesticides with the highest emissions need to be researched. Lowering the dosage of these products can help to reduce the effect, but limiting the emission by forcing farmers to apply the pesticides in the right way seems more effective.

Run-off of pesticides is one of the major emission routes. Developing new pesticides products which are causing less emission is also an option but this involves high costs. If the development of new pesticides is failing or if the emission is not declining sufficiently in the upcoming years, the prohibition of some pesticides which are causing high emissions is unavoidable. This can cause major problems for farmers because of the high dependency on these pesticides to protect flower bulb crops.

Problems in pest control which were occurring between 2004 and 2008 were majorly determined by the lack of pesticides which are able to reduce the disease effectively. No conclusion can be drawn about the competitive position of farmers with flower bulbs because of the lack of a reference with other Western Europe countries. However, flower bulb crops did not have on average a higher cost increase compared to other crops in the Netherlands. One of the options for reducing the amount of pesticides is the use of integrated pest management (IPM).

In this literature study IPM measures and their effect on the environment were researched. In general IPM focusing on preventing appears to be a successful approach. This will reduce the dependency of the use of pesticides and these also have an effect on the environmental impact. More research is needed to develop more IPM alternatives.

The Board of Health concluded that the authorization of pesticides needs to be more specific by the inclusion of the effect on local residents in the evaluation of risks for humans. Until now it is hard to determine what the exact effect is on humans.

To summarize, it is clear that the flower bulb sector is facing major issues with respect to the use of pesticides which need to be solved in the future. All stakeholders will need to contribute to this improvement in order to reach the goals in 2023. Bans on pesticide products can lead to serious problems to keep the quality and yield of flower bulbs at an acceptable level.

3. Material and methods

This chapter begins with a brief introduction about the DEA method. The second part consists of the DEA model and the bootstrapping model. The last part involves the description of the data which is used for this study.

3.1. Data envelopment analysis

The DEA method is a non-parametric mathematical programming method which is introduced by Charnes *et al,* 1978. The method enables to calculate the efficiency although the true production function is unknown (Coelli *et al,* 2005).

DEA uses the linear programming method to develop the production frontier based on the observations in the dataset, referred as decision making units (DMUs) which convert multiple inputs into multiple outputs. In this case, each farm is referred as a DMU. The production frontier is developed by determining a subset of farms which are set as the most efficient farms. The DEA method calculates the efficient frontier and the rate of efficiency, referred as technical efficiency, of each other farm is derived by the distance to this frontier (Coelli *et al,* 2005). Fully efficiency is obtained if the level of inputs can not be further reduced without affecting the output or outputs can not be further maximized without affecting the current level of inputs (Coelli *et al,* 2005).

Another advantage of using the DEA method is the possibility of adding multiple inputs and outputs in the model. It is possible to quantify the units of measurement for inputs and outputs differently. Another advantage is the possibility of decomposing the overall efficiency into technical efficiency and scale efficiency (Coelli *et al,* 2005). The technical efficiency can be calculated by assuming constant returns to scale, introduced by (Charnes *et al,* 1978), also referred as CCR model. Another possibility is the assumption of variable returns to scale which is introduced by (Banker *et al,* 1984), in general terms the BCC model.

DEA can be either input-oriented or output-oriented. Input-oriented means that the DEA analysis focuses on maximizing the possible reduction of inputs while keeping the output variables constant. Output-oriented analysis indicates the maximization of the output variables while keeping the inputs constant. In this research the input-oriented model is used because of the focus on the possible rate of pesticide reduction given the output produced.

3.2. DEA model

The input oriented model set up with variable returns to scale is used to explain the DEA model. In the model each farm is referred as a decision making unit (DMU). In total *n* DMUs are evaluated. Each DMU has multiple inputs and outputs. X indicates the input matrix and y represents output matrix for all *n* firms. Each DMU has various amounts of *m* different inputs which are producing *s* different outputs. DMU_j uses x_{ij} of the amount of input *i* for the production of y_{rj} amount of output *r*. The values of X_{ij} and y_{rj} are both ≥ 0. In the model is assumed that each DMU has at least one positive input and also one positive output value.

The actual technical efficiency of each DMU is calculated according to following CCR model based on Cooper *et al,* 2005.

The LP dual problem is:

$$\theta^* = \min \theta$$

subject to:

$$\sum_{j=1}^{n} \lambda j\ Xij \leq \theta\ Xi0 \quad i = 1,2,\ldots,m\ ;$$

$$\sum_{j=1}^{n} \lambda i\ Yrj \geq Yr0 \quad r = 1,2,\ldots,s\ ;$$

$$\lambda j\ \geq 0 \quad j = 1,2,\ldots,n. \quad (3.1)$$

The θ^* represents the optimal efficiency score for each DMU and $\theta^* \leq 1$. The LP problem is solved for each DMU to calculate θ^*. DMUs are fully efficient if $\theta^* = 1$ and ≤ 1 implies inefficiency. λj (j = 1,...,n) represents the vector of peer weights. The first two equations represent the restrictions based on inputs and outputs of DMU_j.

The BCC model which assumes variable returns to scale involves the first three equations from model (3.1) with the addition of the constraint $\sum_{j=1}^{n} \lambda j = 1$. λ_j (j = 1,...,n) as the fourth equation in the model. The addition of the constraint makes it possible to investigate the type of returns to scale (increasing, constant or decreasing).

The scale efficiency is calculated by dividing the CRS score by the VRS score for each DMU. The scale efficiency is focusing on the most productive scale size of each DMU. The scale efficiency can be divided into increasing returns to scale which indicates that the size of the farm is too large to take advantage of scale. Decreasing returns to scale means that the farm is too small for the scale of operations. Scale efficiency is obtained if the farms shows a constant returns to scale (SE=1) (Coelli *et al,* 2005). In this research scale efficiencies are calculated but the identification of type of returns to scale is not performed.

Within this study the software package *FEAR (*Frontier Efficiency Analysis in R) package version 2.0.1. in R version 3.1.2. is used to conduct the DEA analysis.

3.2.1. Bootstrapping method

Efficiency scores of DMUs generally are measured relative to an estimated unobserved frontier (Simar *et al,* 1998). The statistical estimators of the frontier are obtained from finite samples and this is resulting in corresponding measures of efficiency which are sensitive to the sampling variations of the obtained frontier (Simar *et al*, 1998). The bootstrapping method, introduced by (Efron, 1979), is an useful tool to analyse the sensitivity of the obtained efficiency scores to the sampling variations. It is possible that the sampling variation will result in relative distance to the frontier which is underestimated, referred as bias. The use of bootstrapping makes it possible to calculate the bias corrected estimators and the corresponding confidence intervals for the efficiency scores for each DMU (Simar *et al,* 1998).

The principle is to take a bootstrap sample which implies a random sample taken with replacement from the original data and with the same size *n* as the original sample size. The process is illustrated in figure 3.1. Bootstrapping uses the principle of providing an infinite simulation of true sampling distribution. This is done by repeating observations from a population which is not known and using the obtained data sample. Bootstrapping method makes use of the repeatedly simulating the data generating process (known as DGP) by resampling the data (Simar *et al,* 1998). This is resulting in a large number of pseudo estimators. The difference between average of the pseudo estimators and the single original estimator from the real data is referred as the bias. The bias value is calculated for each DMU and the original efficiency scores are corrected.

The 95% confidence interval for each bias corrected estimator are calculated by ;

$$\hat{\theta}_{conf} = \hat{\theta} \pm z_{\alpha/2} * (\widehat{se}_{boot}(\hat{\theta})) \quad (3.2)$$

The $\hat{\theta}$ refers to the efficiency score for each DMU obtained from the bootstrapping method. The $\widehat{se}_{boot}$ is the corresponding standard error of $\hat{\theta}$. $z_{\alpha/2}$ is the confidence coefficient which is 1.96 for two sided confidence interval for α=0.05.

In *Fear 2.0.1.* the command *boot.sw98* is used to conduct the bootstrapping statistics.

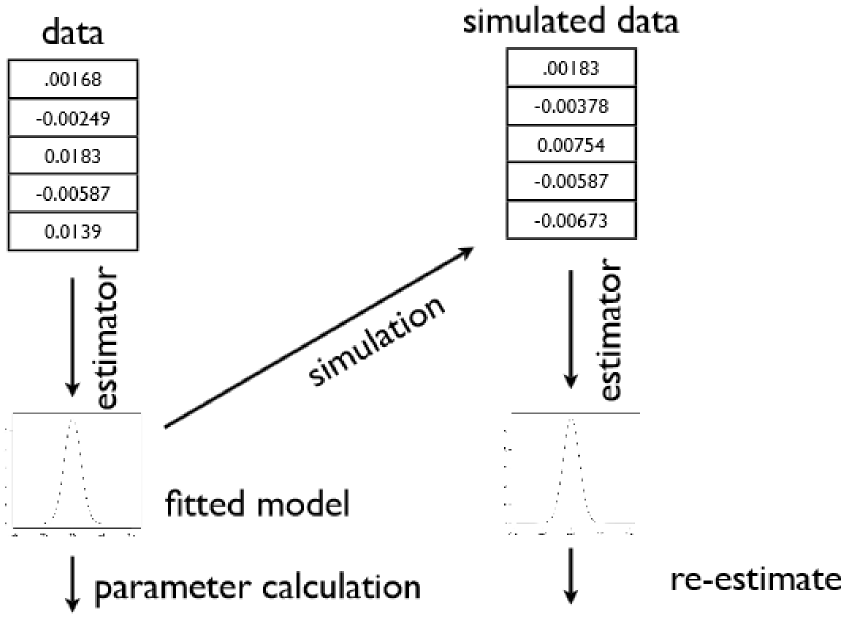

Figure 3.1: Principle of bootstrapping procedure

3.2.2 Outlier identification

The data are checked for outliers after conducting the DEA analysis and the bootstrapping method. Outliers are atypical observations in the dataset (Wilson, 1993). Outliers are not by definition removed from the dataset. It is justified to remove an outlier in the dataset if it contains invalid or missing data (Cooper *et al,* 2005). Invalid data show extreme high or extreme low values compared to the other values of the dataset. However, the consideration to quantify data as invalid is different per research. Wilson uses the statistic method which identifies outliers based on ordinary least squares residuals (OLS) designed by (Andrews *et al,* 1978) and makes it suitable for multiple outputs DEA models. OLS is a statistical method which estimates the linear function which is minimizing the differences between the observed values and the regression line. It is a method to fit a model to the observed data.

In *FEAR* the commands *ap* is used to detect the outliers for non-parametric frontier models which is based on Wilson, 1993. The function *ap.plot* in *FEAR* is used to produce log-ratios plots from the data returned from the command *ap.* The process of identification of outliers is illustrated with an example from Wood, 1973. In figure 3.2 shows all the observations which were identified as outliers. In figure 3.3 the smallest values of the log ratios computed for the subset. The line connects the second smallest values for each *i* to show the distinction between the smallest ratios of *i*. The separation for *i* =1, 2, 3 is relative large. The values for *i* 3 to 6 becomes smaller. This indicates *i*=3 as an outlier which corresponds to the observations 75, 76, 77. The value for *i* increases again for 7 and 8. After this, the value becomes smaller again. This identifies also *i*=8 as an outlier group which is adding observations 44 and 71-74 next to the values of 75-77 as outliers. After *i*=8 the separation is negligible and no more outliers are in the dataset.

i	Observations	$R^{(i)}_{min}$
1	75	.6297
2	75, 76	.3743
3	75, 76, 77	.2239
4	75, 76, 77, 73	.1551
5	75, 76, 77, 73, 44	.1123
6	75, 76, 77, 73, 71, 72	.07987
7	75, 76, 77, 73, 71, 72, 74	.05221
8	75, 76, 77, 73, 71, 72, 74, 44	.03683
9	75, 76, 77, 73, 71, 72, 74, 44, 82	.02961
10	75, 76, 77, 73, 71, 72, 74, 44, 66, 67	.02380
11	75, 76, 77, 73, 71, 72, 74, 44, 66, 67, 82	.01873
12	75, 76, 77, 73, 71, 72, 74, 44, 66, 67, 82, 58	.01521

Figure 3.2: List of observations which are detected as outliers in Wood, 1973. Source: Wilson, 1993.

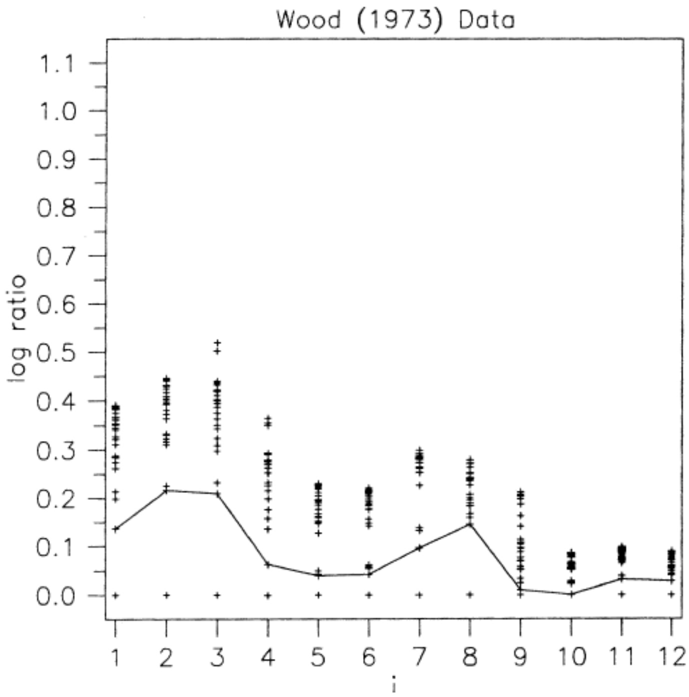

Figure 3.3: Log-plot ratio to identify outliers. Source: Wilson, 1993

3.3 Description of the data

The database Binternet from the agricultural economic research institute (LEI) is used to sample the data. Binternet is a database with data which is obtained from a panel of 1.500 farms, reflecting a representative sample of the agricultural sector. The data used for this research consists of unbalanced panel data of conventional arable farms which are using a part of their land for the cultivation of onions during the time period 2008-2012. As a result, the number of farms entries differ per year. Because of this difference, the data are specified for each year instead of using an average mean value for the time period of research (Table 3.1).

Four categories based on farm size are made in order to specify the type of farms which are in the sampled data. The starting point was to have at least 10 farms in each category. The differences per year in the number farms is caused by the entrance or removal of farms in the database.

Over the studied years the farm size of the sampled farms averaged between 104 and 113 ha. More than 50% of the farms had a farm size between 60-140 ha. The area of onions was around 11 ha and the share of onions in the total area of the farm around 11 to 12 percent. Farms below 60 ha had the highest share of onions. However, the other categories do not show a clear link between farm size and the share of onions on the farm.

3.3.1 Variables DEA model

The mean values and the standard deviation for the different inputs and outputs used in the DEA model are described in Table 3.2. In total two outputs and six inputs were used in the model. The variables for the output are;

(1) Revenue of onion crops (€). The revenue is determined by the yield of the onions multiplied by the price which is the market price at the moment of selling.
(2) Revenue other farm crops and farm activities (€). The revenues from other crops and other possible income sources like income support.

The six Input variables are;

(1) Land (ha). Total area of the farm which is used for the cultivation of crops.
(2) Capital (€/ha). Replacement value of machines, equipment and buildings at the beginning of each year. The total replacement value is divided by the total area of land.
(3) Labour (AWU). One AWU represents one person which is full-time working at the farm, which equals 2000 labour hours. Labour involves both hired and own unpaid labour.
(4) Pesticides onions (€/ha). Total amount of pesticides applied on onion crops expressed in euro`s per hectare in one growing season.
(5) Pesticides other crops (€/ha). Pesticides expressed in euro`s per hectare which are applied on other farm crops in one growing season.
(6) Other variable costs (€/ha). Other variable costs next to pesticides applied on both onion crops and other farm crops expressed in euro`s per hectare. It includes costs for fertilizer, seed, energy and other crop specific costs.

3.3.2 Data analysis

The overall technical efficiency is calculated by using the two outputs and six inputs in the model. The overall efficiency is calculated for data including and excluding outliers to identify the impact of the removal of outliers. The input specific efficiency is determined for onions by one input, pesticides onions, and six outputs. Here, the other 5 inputs are used as negative values output values. The input specific efficiency is also determined for the input pesticides other crops, other variable costs and quasi fixed costs (labour, capital and land). The same procedure is followed in which the other inputs are transformed to negative output values. The differences in efficiency between farm sizes are investigated by using the general outcome of the input specific efficiency of pesticides in onion crops. These values are separated according to the four farm size categories mentioned in Table 3.1. The confidence intervals are used to determine if there is a significant difference between the different categories within one year of research.

In the last part of the DEA analysis research is done to investigate if changing the measurement units of outputs and inputs will result in significant different results. In this part, four scenarios are compared.

(1) Original input specific efficiency score for onion crops
(2) Output variable “onion revenue (€)” replaced by “onion yield”(kg). Output is now only determined by the yield factor and not by the price factor anymore
(3) Input variables “pesticide onions” and “pesticide other farm crops” are replaced by environmental impact point per hectare (EIP/ha) instead of the value of pesticides per hectare (€/ha).
(4) The second and the third options are combined. The output variable onion is allocated in yield (kg) and the inputs are allocated based on the environmental impact points (EIP/ha).

The descriptive statistics are in Table 3.2. The corrected mean values and the 95% confidence intervals are obtained by using the bootstrapping method. The mean values and the confidence intervals of the four scenarios are compared to investigate significant differences.

Table 3.1: Characteristics of farms in the database in the time period 2008-2012

Characteristics of farms										
year	2008		2009		2010		2011		2012	
Farm size (ha)	freq.	mean	freq.	mean	freq.	mean	freq.	mean	freq.	mean
0-60	11	43.3	14	39.1	18	37.7	15	40.1	18	41.5
60-90	25	76.6	23	77.0	24	76.5	25	77.5	22	73.4
90-140	19	107.1	25	112.2	19	110.0	18	111.6	25	113.8
>140	18	181.8	16	214.6	21	214.6	19	219.6	15	236.3
Total (N) + *average mean*	73	105.4	78	104.5	82	111.1	77	113.2	80	109.5
Area under onion crop on different farm size categories										
0-60	11	5.1	14	5.6	18	4.9	15	5.2	18	5.5
60-90	25	8.9	23	8.1	24	9.7	25	10.2	22	9.6
90-140	19	10.1	25	11.7	19	12.3	18	10.7	25	12.1
>140	18	18.9	16	17.3	21	18.9	19	20.3	15	20.9
Total (N)+ *average mean*	73	11.1	78	10.7	82	11.6	77	11.8	80	11.6
Share of onion crop on different farm size categories										
0-60	11	12.6	14	16.0	18	14.5	15	14.2	18	13.9
60-90	25	11.9	23	10.7	24	12.8	25	13.2	22	13.2
90-140	19	9.4	25	10.2	19	11.0	18	9.6	25	10.8
>140	18	10.1	16	8.8	21	9.9	19	10.4	15	10.3
Total (N) +*average mean*	73	10.9	78	11.1	82	12.0	77	11.9	80	12.0

Table 3.2: Basic statistics of different input and output variables used in the DEA analysis

Input/output variables	2008		2009		2010		2011		2012	
Output	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
Onion yield (kg/ha)	62213	14452	59364	14460	61061	11870	55163	13939	57197	14328
Onion revenue (euro/ha)	3337	2310	10188	4121	8188	4036	2025	2613	7301	2614
Farm level revenue (euro/ha)	7675	2776	5971	3389	5539	2801	7562	2759	5805	3134
Input										
Farm level										
Land (hectares)	105.4	56.8	104.5	62.0	111.1	90.7	113.2	89.3	109.5	88.5
Labour (AWU)[1]	2.27	1.14	2.2	1.22	2.23	1.27	2.52	1.99	2.34	1.77
Capital (euro/ha/year)	43432	21426	45075	24967	31625	17100	39402	20694	27537	14736
Onion crop										
Pesticides(euro`s / ha)	749.0	190.2	848.0	248.8	646.6	227.5	611.7	215.7	621.6	223.6
Pesticides(EIP[2] / ha)	-	-	-	-	2437.8	2066.9	1708.9	1204.1	1133.6	865.5
Other crops										
Pesticides(euro`s / ha)	455.2	170.0	438.6	159.0	450.3	158.3	464.9	167.7	482.7	171.5
Pesticides (EIP / ha)	-	-	-	-	489.4	399.7	606.5	739.2	556.3	773.9
Other variable inputs (euro`s)	2306.0	749.7	2464.6	948.2	2533.9	1514.9	2688.3	1462.6	2759.6	1693.4

[1] AWU = Annual working units = 2000 hours/year

[2] EIP = Environmental impacts points of pesticides on soil life and ground water; only present after 2009

4. Results

In this chapter the results of the DEA analysis are presented. The start is the identification of outliers in order to investigate if the data will be used with or without outliers in the remaining part of the analysis. The overall efficiency scores are calculated to see how much input reduction can be obtained on average level of inputs. The next step is the input specific efficiency scores. The distribution of efficiency scores of pesticides on onion crop production is researched by categorizing the data. This provides an overview in which efficiency scores the farms are allocated. The last part consists of the research if the use of different measurement units for the output value onion and the input value pesticides will result in significant differences in efficiency scores.

4.1. Overall efficiency

The start of the analysis was the outlier identification of the dataset. For each year the outliers are determined based on the statistical approach of Wilson, 1993(Appendix I). Table 4.1 describes the number of farms per year with and without outliers in the analysis. The result in the table shows that between 7 and 11 outliers were identified.

Table 4.1: Number of farms in the analysis with and without outliers

	number of farms	
year	incl. outliers	excl. outliers
2008	73	66
2009	78	73
2010	82	72
2011	77	67
2012	80	69

The average overall technical and scale efficiency are described in Table 4.2. The analysis is conducted per year and the model considers variable returns to scale (VRS) constant returns to scale (CRS) and the scale efficiency (SE). For each type of scale the corresponding mean value, 95% confidence interval, minimum value and maximum value are calculated. The mean values are bias corrected by using the bootstrapping method. The corresponding 95% confidence intervals are mentioned to investigate if there is a significant difference between the years within one type of returns to scale. The table is divided into results based on data which includes outliers and on data in which the outliers are removed.

4.1.1 Results outliers included

The variable returns to scale ranges between 0.83 – 0.91 in the time period 2008-2012 were outliers are included. This indicates that a maximum reduction between 0.09 – 0.17 in the average level of inputs would be possible. In other words, a reduction between 9% and 17% in the average level of inputs can be achieved without affecting the level of output. There is no significant difference between the years because all the ranges of confidence levels do overlap.

The range of possible input reduction varies between 0.19 – 0.34 assuming constant returns to scale. The scale efficiency is the ratio between the CRS and VRS efficiency scores. As indicated in Table 4.2 there is a significant difference between the mean values of the years 2009 and 2011. The scale efficiency ranges from 0.80 to 0.88. As indicated in Table 4.2, there is a significant difference in SE scores between the years. The years 2008 and 2011 are different from the years 2009 and 2012..

Table 4.2: Mean values overall technical and scale efficiencies and 95% CI per year of research

	Overall efficiency (incl. outliers)				Overall efficiency (excl. outliers)			
items	year	Mean	95% CI	Min	year	Mean	95% CI	Min
VRS	2008	0.87	0.80-0.92	0.52	2008	0.91	0.84-0.95	0.70
	2009	0.92	0.86-0.96	0.62	2009	0.94	0.87-0.97	0.64
	2010	0.84	0.76-0.90	0.58	2010	0.84	0.76-0.90	0.59
	2011	0.83	0.76-0.89	0.57	2011	0.87	0.79-0.92	0.59
	2012	0.83	0.76-0.89	0.61	2012	0.86	0.78-0.91	0.62
CRS	2008	0.71ab	0.65-0.78	0.24	2008	0.78	0.71-0.85	0.46
	2009	0.81b	0.74-0.84	0.52	2009	0.84	0.77-0.89	0.52
	2010	0.70ab	0.63-0.78	0.35	2010	0.72	0.65-0.80	0.35
	2011	0.66a	0.60-0.73	0.30	2011	0.76	0.70-0.83	0.50
	2012	0.73ab	0.67-0.80	0.42	2012	0.77	0.71-0.84	0.45
SE	2008	0.81a	0.77-0.84	0.38	2008	0.86a	0.83-0.88	0.49
	2009	0.88b	0.86-0.90	0.54	2009	0.90b	0.88-0.92	0.54
	2010	0.83ab	0.80-0.86	0.39	2010	0.86ab	0.83-0.89	0.39
	2011	0.80a	0.77-0.83	0.42	2011	0.87ab	0.85-0.90	0.57
	2012	0.87b	0.84-0.90	0.64	2012	0.90b	0.88-0.92	0.65

Notes: VRS = variable returns to scale, CRS = constant returns to scale, SE = scale efficiency (CRS/VRS). Significant difference at α=0.05 if 95% confidence intervals do not overlap. Significant difference indicated by symbols a, b, ab. Symbols a and b indicates significant difference between the mean values but symbol ab indicates no significant difference from the years indicated by the symbol a or symbol b.

4.1.2 Results outliers excluded

The mean values of the data without outliers show a VRS efficiency between 0.86-0.94. This indicates an average input reduction of 0.06 to 0.14 on average on all inputs. The mean values between years do not differ significantly. The CRS efficiency range varies between 0.72-0.84 The scale efficiency shows a variation between 0.86-0.90. The year 2008 is significant different from the years 2009 and 2012. The other two years, 2010 and 2011, do not show a significant difference in SE scores compared to the other three years.

4.1.3 Comparison results with/without outliers

The mean values and the corresponding confidence intervals of data with and without outliers do not show significant differences. The observations which are marked as outliers are checked. The data of these observations are compared with the data of the other observations. There are no values found which are out of range or could identified as unrealistic values. Based on these two arguments, the data with outliers are used in the remaining part of the analysis.

4.2. Input specific efficiency scores

Table 4.3 presents the efficiency scores divided for specific inputs. The analysis focuses now on one particular input. The first category is the efficiency score for the input pesticides allocated to the onion crop (POTE).The setup of the table is equal to Table 4.2. For each year the VRS, CRS and SE corrected mean values are calculated with the corresponding 95% confidence intervals.

Pesticide onion technical efficiency

The VRS shows an efficiency score between 0.41-0.57 but no significant difference between the years (α=0.05). This is indicating a maximum pesticide reduction in onion crop production in the range of 43%-59%. The CRS shows values between 0.37-0.54 referring to a pesticide reduction in the range between 46% - 63% with no significant difference between the years 2008, 2011 and 2012. The years 2009 and 2010 are significant different from the other three years of research. The SE has a mean value between 0.79-0.95, with significant different values for the years 2011 and 2012.

Pesticide other crops technical efficiency

The efficiency scores of pesticides of other farm crops is calculated under item (PFTE). The variation in the type of other farm crops is high between the farms. However, it was not possible to identify the type of crops. The range is 0.35-0.57 for VRS implying a maximum reduction of 43%-65% on average level of pesticides used in the cultivation of other farm crops. The CRS shows a range between 0.09-0.24. There is a significant difference between the years. Only 2008 and 2009 do not differ significantly. The mean value for 2011 is below zero after subtracting the bias estimator from the original value and therefore NA value is added. The SE also shows a high variation between 0.26 -0.91. All the years are significant different.

Other variable costs and quasi fixed costs technical efficiency

The other variable costs do not show significant differences for both VRS and CRS. The mean values are in the range between 0.72-0.78 by VRS and 0.68-0.72 by CRS. The SE shows a range between 0.91-0.98 and there are significant differences between the years. Only the last year is not significantly different from the other four years of research. The quasi fixed efficiency scores have a range of 0.47-0.63 by VRS and 0.42-0.57 for CRS with significant differences between 2008 and 2012. The SE is between 0.85-0.93with the years 2009 and 2011 significantly different.

Table 4.3: Technical and scale efficiency scores of specific inputs

Items	Year	VRS Mean	VRS 95% CI	CRS Mean	CRS 95% CI	SE Mean	SE 95% CI
POTE	2008	0.41	0.35-0.51	0.37a	0.33-0.42	0.92c	0.89-0.96
	2009	0.57	0.50-0.65	0.54b	0.50-0.59	0.95c	0.93-0.97
	2010	0.53	0.46-0.62	0.49b	0.45-0.54	0.93c	0.90-0.96
	2011	0.51	0.44-0.60	0.39a	0.35-0.44	0.78a	0.74-0.81
	2012	0.49	0.42-0.57	0.39a	0.35-0.44	0.81b	0.84-0.87
PFTE	2008	0.57b	0.49-0.67	0.20b	0.16-0.25	0.36b	0.33-0.39
	2009	0.47ab	0.39-0.58	0.24b	0.20-0.28	0.54c	0.51-0.57
	2010	0.35a	0.29-0.42	0.09a	0.07-0.11	0.26a	0.24-0.29
	2011	0.44ab	0.37-0.53	NA	NA	NA	NA
	2012	0.47ab	0.40-0.56	0.42c	0.37-0.49	0.91d	0.88-0.94
OVTE	2008	0.72	0.65-0.79	0.71	0.67-0.76	0.98b	0.96-1.00
	2009	0.73	0.66-0.81	0.68	0.64-0.73	0.92a	0.90-0.94
	2010	0.75	0.66-0.83	0.69	0.64-0.74	0.91a	0.89-0.94
	2011	0.78	0.69-0.84	0.72	0.68-0.77	0.93a	0.88-0.95
	2012	0.73	0.67-0.80	0.70	0.66-0.75	0.96ab	0.93-0.98
QFTE	2008	0.64	0.55-0.74	0.57b	0.52-0.65	0.89ab	0.86-0.92
	2009	0.63	0.55-0.72	0.54ab	0.48-0.61	0.85a	0.82-0.89
	2010	0.51	0.44-0.62	0.46ab	0.42-0.53	0.90ab	0.86-0.93
	2011	0.52	0.46-0.63	0.49ab	0.44-0.56	0.93b	0.91-0.95
	2012	0.47	0.41-0.57	0.42a	0.38-0.50	0.91ab	0.88-0.94

Notes: VRS = variable returns to scale. CRS = constant returns to scale. SE = scale efficiency (CRS/VRS). POTE = pesticide onion technical efficiency. PFTE = pesticide other crops technical efficiency. OVTE = other variable inputs technical efficiency. QFTE = quasi-fixed technical efficiency (land, labour and capital). NA= bias corrected estimator is negative. Different symbols (a. b. c. d) at mean values indicate significant differences (95% CI do not overlap). Combination of symbols (ab) indicate no significant differences with symbol a and symbol b.

Table 4.4: Distribution of farms based on efficiency scores of pesticide onion technical efficiency.

Year *Total (N)*	Efficiency score	VRS	%	CRS	%	SE	%
y=2008	<0.25	12	16.4	13	17.8	-	-
N=73	0.25-0.50	40	54.8	49	67.1	2	2.7
	0.50-0.75	21	28.8	8	11.0	5	6.8
	>0.75	-	-	3	4.1	66	90.4
y=2009	<0.25	2	2.6	1	1.3	-	-
N=77	0.25-0.50	28	35.9	33	42.3	-	-
	0.50-0.75	38	48.7	34	43.6	2	2.6
	>0.75	10	12.8	10	12.8	76	97.4
y=2010	<0.25	2	2.4	3	3.7	-	-
N=82	0.25-0.50	41	50.0	45	54.9	2	2.4
	0.50-0.75	30	36.6	25	30.5	6	7.3
	>0.75	9	11.0	9	11.0	74	90.2
y=2011	<0.25	6	7.7	6	7.7	-	-
N=77	0.25-0.50	34	43.6	57	73.1	3	3.8
	0.50-0.75	35	44.9	13	16.7	21	26.9
	>0.75	3	3.8	2	2.6	54	69.2
y=2012	<0.25	3	3.8	10	12.5	-	-
N=80	0.25-0.50	44	55.0	51	63.8	1	1.3
	0.50-0.75	32	40.0	18	22.5	26	32.5
	>0.75	1	1.3	1	1.3	53	66.3

Notes: VRS = variable returns to scale. CRS = constant returns to scale. SE = Scale efficiency (CRS/VRS).

The distribution of the efficiency scores from the category POTE from Table 4.3 is described in Table 4.4. In the table the number of farms and the corresponding percentage per efficiency score category are mentioned. Because of the bias corrected estimator, no farms were scored with an efficiency score of 1, indicating 100% efficiency. For VRS the number of farms in the category 0.25-0.50 is between 36% and 55%. For the category 0.50-0.75 this is between 29% and 49%. In 2008 16.4% of the farms showed an efficiency score lower than 25%. In other years the value is 7.7% or lower. The value above 75% is between 1.3% and 12.8%. For CRS most of the farms are allocated in the category 0.25-0.50. The range is between 42.3% and 73.1%. Only in 2009 the distribution is equal between the second and third category. The percentage of farms above 75% is between 1.3% and 12.8%. Most of the farms are in the category above 75% for the SE in the range between 66.3% and 97.4% indicating high scale efficiency.

Table 4.5: Pesticide onion technical efficiency for different farm size categories

Items *farm size (ha)*	*year*	**mean VRS**	**95% CI**	**mean CRS**	**95% CI**	**mean SE**	**95% CI**
	2008						
0-60		0.43	0.36-0.54	0.37ab	0.33-0.45	0.90	0.83-0.97
60-90		0.37	0.32-0.46	0.31a	0.28-0.36	0.89	0.82-0.95
90-140		0.41	0.36-0.52	0.40ab	0.35-0.46	0.97	0.91-1.00
>140		0.47	0.40-0.62	0.43b	0.38-0.51	0.93	0.87-0.99
	2009						
0-60		0.62	0.54-0.74	0.56	0.50-0.62	0.90	0.84-0.96
60-90		0.57	0.50-0.66	0.55	0.50-0.59	0.96	0.94-0.99
90-140		0.54	0.48-0.62	0.52	0.48-0.56	0.98	0.94-1.00
>140		0.56	0.48-0.66	0.53	0.48-0.61	0.95	0.91-0.99
	2010						
0-60		0.50	0.43-0.61	0.44ab	0.40-0.51	0.88	0.80-0.96
60-90		0.50	0.44-0.59	0.43a	0.40-0.47	0.89	0.82-0.96
90-140		0.53	0.47-0.61	0.52b	0.49-0.57	0.97	0.94-1.00
>140		0.61	0.52-0.74	0.57bc	0.51-0.64	0.95	0.90-1.00
	2011						
0-60		0.51	0.43-0.64	0.35	0.31-0.40	0.73ab	0.62-0.83
60-90		0.48	0.42-0.57	0.40	0.36-0.45	0.85b	0.81-0.89
90-140		0.50	0.44-0.57	0.40	0.35-0.44	0.80ab	0.76-0.84
>140		0.56	0.48-0.68	0.41	0.36-0.46	0.73a	0.69-0.77
	2012						
0-60		0.46	0.40-0.56	0.32ab	0.29-0.39	0.70a	0.63-0.77
60-90		0.43	0.38-0.53	0.33a	0.29-0.37	0.79ab	0.72-0.85
90-140		0.50	0.44-0.57	0.42b	0.38-0.47	0.87b	0.82-0.91
>140		0.58	0.52-0.64	0.52bc	0.46-0.59	0.89bc	0.85-0.93

Notes: VRS = variable returns to scale. CRS = constant returns to scale. SE = Scale efficiency (CRS/VRS). Different symbols (a. b. c) at mean values indicate significant differences (95% CI do not overlap). Combination of symbols (ab) indicate no significant differences with symbol a and symbol b.

The outcome of the pesticides efficiency on onion crops (POTE) from Table 4.3 is used to calculate the efficiency scores per farm size category. The data is divided in order to investigate if farm size will result in significant differences in efficiency scores. This is based on the hypothesis that larger farms will not postpone the moment of spraying because of the possible change in weather conditions and the large area they need to cover with pesticides. Postponing the spraying activity might lead to problems in terms of diseases because they are not able to spray all the fields properly within a certain period of time. Smaller farms might be able to wait with the moment of spraying because of the small area they need to cover. If necessary, they are able to spray the pesticides in a shorter time compared to larger farms.

The results in Table 4.5 do not show a significant difference between the farm sizes in all years of research assuming VRS. The results of assuming CRS shows some differences. In 2008, farms with more than 140 hectare of land have a significant higher efficiency score compared with farms between 60 – 90 hectares. The other two categories are not significant different from farms >140 hectare and farms between 60-90 hectare. In 2010 and 2012 the significant differences between the groups is equal. Farms in the category 60-90 hectares have the lowest efficiency score and these are significant different than the efficiency scores from farms in the category 90-140 hectare and >140 hectare

The scale efficiency shows that farms >140 hectare have the lowest efficiency score and these are significant different from farms between 60-90 hectare in 2011. Farms between 0-60 show the lowest efficiency score and these are significant different from farms between 90-140 hectare in 2012.

4.3 Changing measurement units in model

The impact of the measurement units of the output variable and input variable is illustrated in Table 4.6. The change in output unit is done to investigate if efficiency scores based on the actual onion yield will differ from efficiency scores based on onion revenues. The price of onions is fluctuating tremendously within one growing season and this can cause high differences in revenues.. By using the definition of onion yield instead of onion revenue the price fluctuation is not involved anymore. The input unit change is based on the fact that the efficiency of input is now scored based on the damage towards the environment. Within the data, environmental impacts points were only available for the last three years of research.

In the table, first, the original values of efficiency scores for pesticides on onion crops are mentioned, as obtained from Table 4.3. The change of the output unit is mentioned with item POYTE. The change is not causing significant differences for all years assuming VRS and CRS. The mean values for efficiency scores are now between 0.51 – 0.58 by VRS and 0.39 – 0.51 by CRS. The change of the measurement unit of the input variables for pesticides on both onion crops and other farm crops (POMTE) is resulting in significant lower mean values in 2010 and 2011 for both VRS and CRS. The mean values are lowered to 0.33 and 0.34 by VRS. CRS shows values of 0.24 and 0.27. In 2012 no significant difference is calculated between all the four items for both VRS and CRS. The combination of replacing the units of the indicated output and input variables (POMYTE) is resulting in a significant lower efficiency score in 2010 and 2011 compared with the original efficiency cores and the scores from replacing only the output variable. The combination has mean values which are more or less comparable with the mean values of POMTE.

Table 4.6: Replacement of units of inputs and output variables and the corresponding mean and 95% CI

items	Year	VRS		CRS		SE	
		Mean	95% CI	Mean	95% CI	Mean	95% CI
POTE	2008	0.41	0.35-0.51	0.37	0.33-0.42	0.92b	0.89-0.96
POYTE		0.57	0.49-0.67	0.41	0.37-0.46	0.73a	0.70-0.77
POMTE		-	-	-	-	-	-
POTE	2009	0.57	0.50-0.65	0.54	0.50-0.59	0.95	0.93-0.97
POYTE		0.58	0.50-0.66	0.53	0.48-0.58	0.92	0.90-0.95
POMTE		-	-	-	-	-	-
POTE	2010	0.53b	0.46-0.62	0.49b	0.45-0.54	0.93b	0.90-0.96
POYTE		0.56b	0.48-0.66	0.51b	0.46-0.56	0.92b	0.89-0.95
POMTE		0.34a	0.26-0.44	0.24a	0.20-0.28	0.75a	0.70-0.80
POMYTE		0.34a	0.25-0.44	0.24a	0.20-0.29	0.75a	0.69-0.80
POTE	2011	0.51b	0.44-0.60	0.39b	0.35-0.44	0.78b	0.74-0.81
POYTE		0.53b	0.45-0.62	0.40b	0.35-0.44	0.76b	0.73-0.79
POMTE		0.33a	0.28-0.41	0.27a	0.23-0.32	0.85a	0.81-0.90
POMYTE		0.34a	0.26-0.43	0.29a	0.24-0.35	0.89a	0.84-0.94
POTE	2012	0.49	0.42-0.57	0.39	0.35-0.44	0.81b	0.84-0.87
POYTE		0.51	0.43-0.60	0.39	0.34-0.44	0.79a	0.76-0.83
POMTE		0.41	0.34-0.50	0.38	0.33-0.43	0.93c	0.89-0.96
POMYTE		0.40	0.33-0.48	0.35	0.31-0.40	0.91c	0.88-0.94

Notes: VRS = variable returns to scale. CRS = constant returns to scale. SE = Scale efficiency (CRS/VRS). POTE = Original efficiency scores equal to Table 4.3. POYTE = output value onion revenue replaced by onion yield. POMTE = pesticides costs in euro`s/hectare for onion and other farm crops replaced by environmental impacts points per hectare. POMYTE = combination of replacing output value and replacing pesticide value. Significant difference if 95% CI do not overlap. Different symbols (a. b. c) indicate significant difference. Significant differences are calculated per group of items within one year of research.

5. Discussion

The main objectives of this study were to evaluate the development of the regulations of pesticides in particular the Dutch flower bulbs sector by doing a literature review and the use of the DEA analysis method to investigate the efficiency by which pesticides are used in the flower bulb cultivation.

Due to limitations in the data availability required to perform a DEA analysis in flower bulbs, a DEA analysis was conducted in onion crop production system. Efficiency results based on this analysis will be discussed in light of the expected future development in pesticide regulations.

Flower bulbs

The literature review shows that the needs for improvements in pesticide use in flower bulbs are necessary to meet the requirements as set by the Dutch government in terms of water quality in the future. The amount of pesticides applied in flower bulbs, especially in lilies, are high. Pesticides are important inputs in the cultivation of flower bulbs in order to reach high quality standards. The goals regarding environmental improvements which were developed by the Dutch government have not been achieved yet. The literature review shows that especially flower bulbs will need to improve in the upcoming years in order to meet the requirements. The number of exceedings, based on maximum concentrations of pesticides in the surface water, must decline with at least 50% in 2018 compared to 2010. This decline must continue until 90% in 2023. The debate on how to achieve these goals is still ongoing, while insight in the efficiency by which pesticides are used in practise is lacking. An efficiency analysis by means of DEA could provide an indication of the extent to which pesticide reduction would be feasible without affecting the output. Low efficiency scores would imply that stricter regulations are possible in theory.

The disadvantage of the DEA method is the need for data which involves information about all the inputs used in combination with a certain output. However, the high level of diversification in flower bulb crops resulted in a failure to find data representative for one particular type of flower bulb crop and therefore suitable for a DEA analysis. The large variation in classifications of the quality of flower bulbs and the variation in market possibilities (e.g. export, tulip hatchery, plant material next season) made a DEA analysis infeasible. The diversification of the output factor resulted in a failure to find a homogenous output which was useful in the DEA analysis. Another consequence of the high diversification is reduction the in the number of available observations. The number of farms with a homogeneous output was unsufficient to do a representative analysis.

Moreover, given the accounted data on pesticide application, it was not possible to allocate the applied amounts of pesticides to one particular type of flower bulb crop, as most of the farms registered pesticide use only on farm level.

This in contrast to the onion crop because of the single output possibility. In onions, no distinction is made in terms of quality.

DEA analysis method
The main advantage of the DEA method is the non-parametric approach. This makes it possible to calculate efficiency scores without specifying the production function. However, the general disadvantage of the DEA method is the lack of calculating measurement errors and other sources of statistical methods (Coelli *et al,* 2005). Non-parametric DEA analysis can be sensitive to the number of inputs and outputs in the analysis. Therefore, only the most relevant factors must be used. Aggregations of inputs and outputs can be considered in order to limit the number of variables.

In this research all the inputs are aggregated in order to limit the number of input variables. Only the input variable pesticide is separated for onion crops and for other crops. The output variable is also split into onion revenue and revenue of other farm crops. The number of observations should exceed the number of inputs and outputs several times (Change *et al,* 2010) (Sarkis, 2002). The number of observations must be at least three times the sum of the number of inputs and inputs (Karaduman, 2006). For this research the sum of variables is six inputs and two outputs. Following this rule of thumb, the number of observations must be at least 24. In this research the lowest number of observations is 73 which is much higher than the required minimum.

Another limitation is the fact that the DEA method is deterministic which implies that there are no random factors affecting the location of the frontier. The use of the bootstrapping method will prevent that this limitation is influencing the results (Simar *et al,* 2011).

The assumptions behind the DEA method are also debatable. The DEA method assumes homogeneity in environmental conditions and the ability to use the same technology for all the farms (Hartwich *et al,* 1999). If one DMU is able to produce a certain output given the amount of inputs, other DMU should be able to produce the same output if the inputs are equal. The data used in this research represents arable farms in the Netherlands. It seems more realistic that the environmental conditions within this population of farms are heterogeneous. By dividing the data into different regions (e.g. geography or soil type) more homogeneity can be achieved. The number of observations in this research is too low to divide the data into different regions. The currently obtained efficiency scores of farms in regions in which the environmental conditions are less suitable to achieve higher yield might, therefore, be underestimated.

The efficiency scores per region will provide a more accurate result about the actual efficiency in onion crop production. This information is useful in discussing the regulation of pesticides in relation to the DEA analysis. It is possible that some regions will face earlier problems with stricter regulations because of the higher efficiency scores. Given the restriction of the Dutch government that the competitive strength must be maintained when regulations are changed for pesticides, this can help to sharpen the regulation of pesticides until the level that (hardly) no farms are facing problems to maintain the current level of output. Another option is that will indicate that alternatives must be developed to overcome the problems of possible output reduction.

Efficiency scores

CRS can be assumed if full proportionality between the input and output can be guaranteed (Atici, 2012). This indicates that the rate of change of the input will also result in the same rate of change in the output. If this can not be proven VRS is assumed because the VRS is based on convexity assumptions instead of proportionality assumptions (Atici, 2012). In this research full proportionality can not be assumed between pesticides as input variable and onion revenue as output variable. Therefore, it is more likely that the VRS will provide the most reliable efficiency scores.

The efficiency scores for pesticide onion technical efficiency assuming variable returns to scale are between 0.41 and 0.57 in the time period 2008-2012. This is indicating a maximum input reduction in the range of 43% - 59% without affecting the output. This would lead to 100% efficient use of pesticides, but it is questionable if this is feasible. Farmers are perceiving production risks due to unpredictable factors such as weather circumstances and crop diseases. Pesticides are majorly used to prevent the infection of diseases in crops. The time of infection and the variation in pesticide productivity are changing over time (Pannell, 1991). Serious problems can arise if pesticides are not applied at the right moment but the most suitable time of application is hard to predict. The uncertainty in terms of time of infection, pest density, yield loss per pest and the effectiveness of pesticides is influencing the decision making process of farmers (Pannell, 1991). The change in weather conditions is affecting the effectiveness of pesticides (Skevas *et al,* 2014). The uncertainty is resulting in an over use of pesticides because farmers are trying to reduce the production risks (Skevas *et al,* 2014). Therefore, it can be argued that the possible pesticide reduction rate is overestimated. Farmers will perceive higher production risks which will not outweigh the benefits from reducing the pesticides use.

The possible reduction in pesticides in the other crops is shown in Table 4.3. The lower efficiency scores are caused by the high variation between the farms. The only similarity between the farms in the analysis is the cultivation of onions. Assuming VRS, the efficiency scores are not lower than the pesticide efficiency scores of onions. The other crops can be pesticide intensive like flower bulbs or pesticide extensive like cereals. This high difference causing a high variation in the data which is resulting in low efficiency scores. Remarkable is the higher efficiency scores of the other specific variables (OVTE). The OVTE is aggregated on farm level. Based on these data there can be argued that the high variation in crops between farms does not result in a high variation in other variable costs. On average the efficiency is between 0.72-0.78 assuming VRS and 0.68 – 0.72 assuming CRS. The quasi fixed factors (labour, land, capital) show an efficiency of 0.47 – 0.64 assuming VRS and 0.42 – 0.57 assuming CRS. This would indicate that the quasi fixed inputs can be reduced with a maximum percentage around 30%. However, these inputs are fixed in the short run and there can be argued if it is really necessary to reduce the amount of fixed inputs.

In literature several studies are performed on different kind farm types which are stating that farm size is affecting the technical efficiency. In this research no differences were found between the different farm categories illustrated in Table 4.5. The hypothesis that farms with a smaller area can postpone the moment of spraying is not supported by the outcome of the results. The differences in area of onions between the farm sizes are probably not large enough. The larger area of onions is not causing any problems for farmers in managing the spraying activities of pesticides. It is possible that larger farms have the availability over spraying techniques which makes it possible to spray larger areas in a shorter time period.

The change of the measurement unit of the variable pesticides is causing differences in efficiency scores as shown in Table 4.6. By changing the unit to environmental impacts points, the efficiency score changes in the time period 2010 – 2012 from the range 0.49-0.53 to 0.33-0.41. This implies a reduction of 59% - 67% in environmental impact points of pesticides in onions. The efficiency scores by using environmental impact points is increasing in 2012 but the difference is not significant. Other type of pesticides can be used which are less damaging for the environment without affecting the output of onions. In this assumption only the improvement in environmental conditions is taken as a restriction. More research is needed to identify the causes of this inefficiency. It is possible that the low efficiency is caused because of the different problems which are present in the onion cultivation. These problems can differ per farm. This is requiring different type of pesticides in order to prevent or to reduce the problems. The efficiency in pesticides expressed in euro`s per hectare show a higher efficiency rate. The use of pesticides which are more damaging for the environment are not necessary also more expensive pesticides. This pattern is also shown in the descriptive data in Table 3.2. The mean values for environmental impact points (EIP) for onion crops are declining every year from 2437 EIP in 2010 to 1133 EIP in 2012. The costs for the pesticides in onion crops stay more or less stable.

Scale efficiency

Scale efficiency rate indicates how close farms are operating to the optimal farm size. In this research in each table the scale efficiency is calculated. The scale efficiency is for the overall efficiency in Table 4.2 in the range 0.80-0.87. This value indicates that overall inputs a reduction between 13% - 20% can be obtained if the size of the farm operation is adjusted to an optimal scale (Oude Lansink *et al,* 2004).

Table 4.3 shows a scale efficiency for pesticides technical efficiency in the range of 0.78-0.95. This implies a reduction of 5% - 22% in the use of pesticides is the farm is operating at the optimal scale. The scale efficiency for pesticide other crops technical efficiency is low. This is caused by the diversification in crops which are marked as other crops. As a result, large differences between farms are present which are resulting in low efficiency scores. The scale efficiency of other variable inputs and quasi fixed inputs are high, respectively 0.91-0.98 and 0.85-0.93, indicating that the farms are operating close to the optimal size.

The differentiation of farms based on farms sizes in Table 4.5 does not show a clear pattern in scale efficiencies. In the first three years of research, no significant differences are calculated between the different farm size categories. In 2011 and 2012 significant differences for scale efficiencies are calculated. The smallest farm size category in 2012 and the biggest farm size category in 2011 show the lowest scale efficiency.

The scale efficiency can be divided into increasing returns to scale, indicating that the farm need to expand the size in order to reach the optimal scale for production, or decreasing returns to scale which implies that the farm needs to reduce the size of the farm to reach the optimal scale. Given the fact that farm sizes in general are increasing, it can be interesting to investigate if farms are operating under increasing returns to scale. This would imply that the efficiency of the pesticide use will increase in the future based on the assumption that farms are expanding.

Implications for flower bulb sector

The results of the DEA analysis in onion crop production show that a reduction in efficiency is possible. This suggests that a reduction in pesticide use is also feasible in flower bulbs. Pesticides are preventive applied to control diseases in both types of production. The level of preventive application of pesticides is expected to be higher in flower bulb production because of the importance of maintaining a current level of quality. Reducing the number of pesticide applications in flower bulbs can have major negative consequences on the current level of output. The role of production risk needs to be integrated in the debate about reducing the pesticides in flower bulb production.

Future implications

Although in this research the DEA analysis was conducted on Dutch onion crops, the need for data for a DEA analysis in flower bulbs is still present. This will ask major efforts to come up with possibilities of obtaining data. Next to this, the aggregation of the flower bulb output will stay a challenging subject. Tulip crop is based on the total area the largest category. There is a large diversification in output but if sufficient data can be obtained, a DEA analysis can be possible.

As such the results indicates the possibility for a more efficient use of pesticides and therefore for a reduction in pesticide use without affecting the output level. If farmers will use less pesticides, the increase in production risks will need to be clarified. The research for management tools will be necessary which will provide supportive information in the decision making process. These tools will help to deal with the heterogeneity in environmental conditions which are affecting the disease pressure during the growing season.

At stated in the discussion, the role of scale efficiency in the efficiency scores of pesticides can be researched. The upscaling of farms can possible result in higher efficiency rates. The rate of upscaling combined with the scale efficiency can provide information about the improvement in efficiency scores.

6. Conclusions

In this study, a literature review was conducted to investigate the development of regulations for pesticides over time. Special attention was paid to the pesticide use in flower bulb crops in relation to the environmental pollution. Next to the literature review, a DEA analysis was conducted to examine the performance of Dutch onion farms with special attention to the pesticide use in the time period 2008-2012. The main findings are:

- The evaluation of the plant protection policy showed that environmental goals set for 2010 were not reached. The number of exceedings, which are expressed in maximum concentrations of pesticides in the surface water, did not decline after 2005. According to the plant protection amendment as developed by the Dutch government in 2010 ,no exceedance of maximum concentrations in the surface water are allowed after 2023.
- The reduction in the emission of pesticides towards the surface will require large efforts. The development of new spraying techniques will help to reduce the emission but this is probably unsufficient. Improvement in cultivation free area`s is an option but this will involve high costs. The development of new pesticides must also contribute to a reduction.
- The prohibition of existing pesticides is an option if the emission will not decline sufficiently. However, this prohibition will affect the quality and yield of flower bulbs if no alternatives are developed. These types of pesticides are essential in the cultivation of flower bulbs in order to maintain the current quality and yield.
- Crops which are covering less than 5.000 hectares in the Netherlands are referred as minor crops. Pesticides used in minor crops are lacking a risk assessment (producers do not want to invest in an assessment). These pesticides are currently tolerated but it is the intention that these groups of pesticides will be forbidden in the future. Different pesticides which are essential for flower bulbs are in this category. The possible abundance of these pesticides will negatively affect the quality and yield of flower bulbs. Alternative pesticides or techniques needs to be developed in the future to replace these pesticides.
- The overall technical efficiency of pesticides in onion crop production is between 0.83 – 0.92. This indicates the possibility of a reduction of 8% - 17% of in the average level of inputs, without influencing the level of output.
- Pesticides can be applied more efficient in onion crop production. The maximum pesticide reduction in onions without affecting the level of output is between 43% - 59% assuming variable returns to scale. The years of research do not show significant differences between the years.
- The uncertainty in terms of time of infection, pest density, yield loss per pest and the effectiveness of pesticides generally results in an over use of pesticides as indicated by the efficiency scores. Management supporting tools are needed to reduce this uncertainty, resulting in a more efficient use of pesticides.

- The differences in farm size (hectares) do not result in significant differences in the efficiency scores of pesticides in onion crops. Differences between the years 2008-2012 were not significant.
- Changing the unit of the output variable onion revenue (€) to onion yield (kg) did not result in significant differences in efficiency scores. The efficiency scores were primarily caused by the yield; differences in price between farms did not have any effect.
- Changing the variable unit on input pesticide from euro`s per hectare to environmental impact points per hectare did result in significant differences in efficiency scores. The scores changed from 0.49 – 0.53 to 0.33 – 0.41 in the time period 2010 – 2012. By taking only the improvement in environmental standards as a restriction, a maximum improvement of 59% - 67% can be reached. The rate of efficiency increased in 2012, but there was no significant difference between the efficiency scores between 2010 – 2012. Based on the comparison between pesticides expressed in euro`s and in environmental impact points there can be stated that more expensive pesticides are not necessary more damaging towards the environment.

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Appendix I: Outliers

Table 4: Outliers in data from year 2008. 73 observations

i	Observations (y=2008)												$R^{(i)}_{min}$
1	69												0.3618
2	21	69											0.1424
3	24	21	69										0.0800
4	68	24	21	69									0.04753
5	64	68	24	21	69								0.02728
6	59	64	68	24	21	69							0.01693
7	64	22	68	62	24	21	69						0.009450
8	59	64	22	68	62	24	21	69					0.005360
9	59	64	34	22	68	62	24	21	69				0.003655
10	51	59	64	34	22	68	62	24	21	69			0.002391
11	51	59	50	64	34	22	68	62	24	21	69		0.001632
12	20	51	59	50	64	34	22	68	62	24	21	69	0.001134

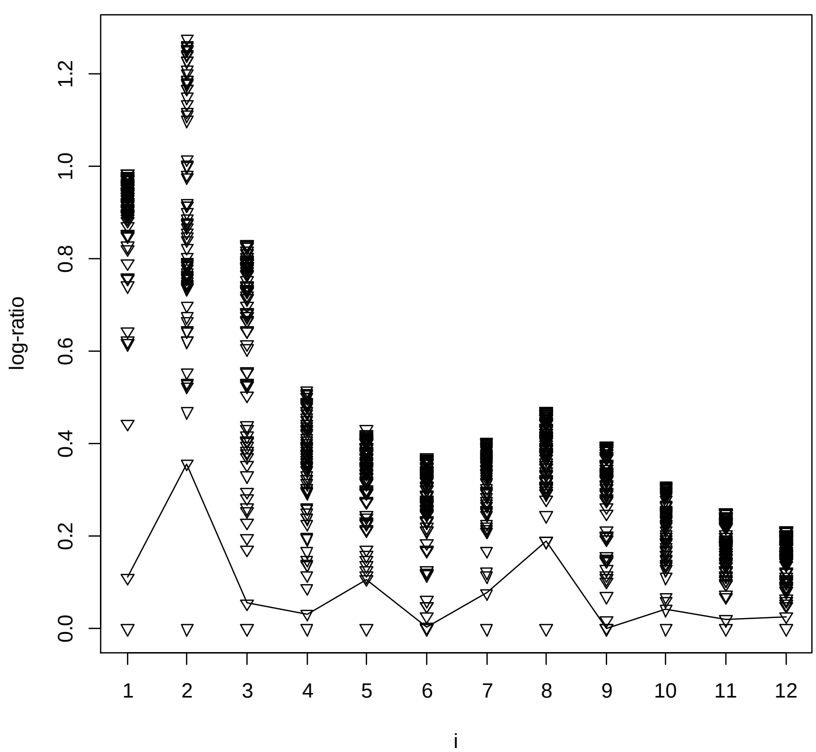

Figure 4: Log-ratio plot for data y=2008

Table 5: Outliers in data from year 2009. 78 observations

i	Observations (y=2009)												$R^{(i)}_{min}$
1	78												0.4941
2	56	78											0.2796
3	52	56	78										0.1634
4	21	56	63	78									0.09778
5	52	21	56	63	78								0.05548
6	55	52	21	56	63	78							0.03653
7	19	55	52	21	56	63	78						0.02491
8	19	33	55	52	21	56	63	78					0.01796
9	19	70	33	55	52	21	56	63	78				0.01302
10	19	61	70	33	55	52	21	56	63	78			0.009394
11	19	61	51	66	70	55	52	21	56	63	78		0.006339
12	19	61	51	66	70	33	55	52	21	56	63	78	0.004346

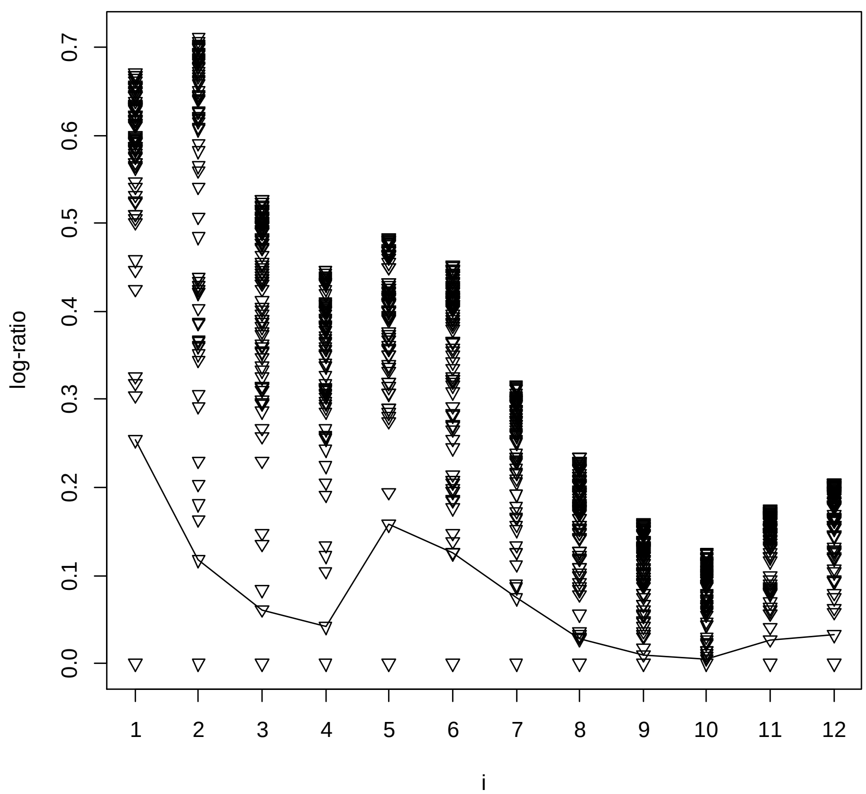

Figure 5: log-ratio plot year for data y=2009

Table 6:Outliers in data from year 2010. 82 observations

i	Observations (y=2010)											$R^{(i)}_{min}$
1	69											0.2567
2	5	69										0.1315
3	68	5	69									0.07047
4	68	3	5	69								0.04068
5	68	64	3	5	69							0.02598
6	68	4	64	3	5	69						0.016922
7	52	61	68	4	3	5	69					0.01054
8	52	61	68	4	64	3	5	69				0.006609
9	52	61	57	68	4	64	3	5	69			0.004126
10	67	52	61	57	68	4	64	3	5	69		0.00271
11	67	52	76	61	57	68	4	64	3	5	69	0.001895
12	67	74	52	76	61	57	68	4	64	3	5	69 0.001298

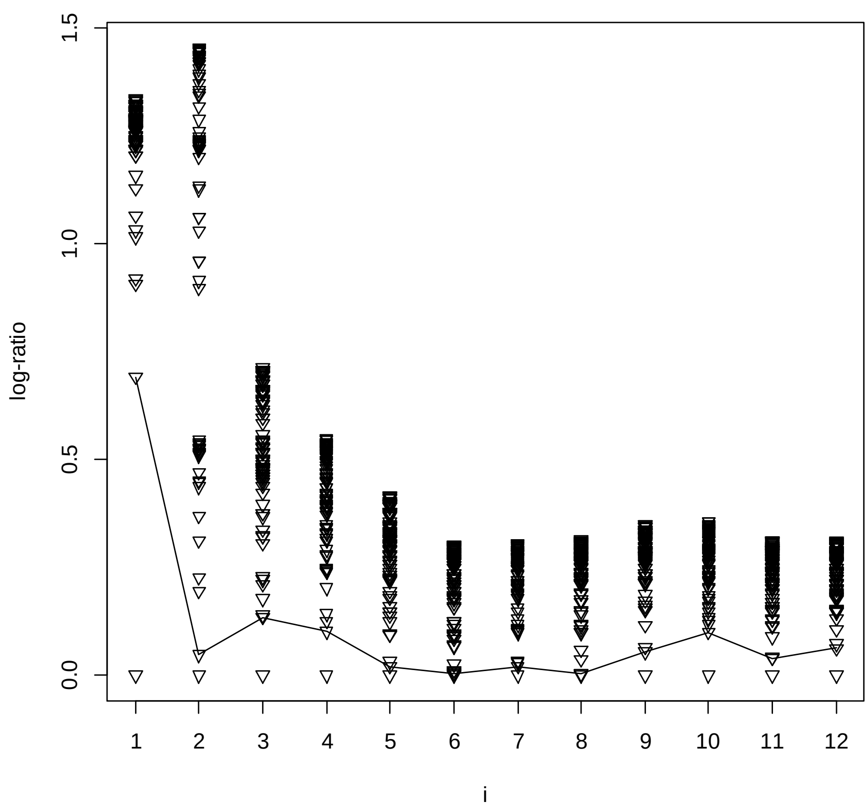

Figure 6: Log-ratio plot for data y=2010

Table 7: Outliers in data from year 2011. 77 observations

i	Observations (y=2011)												$R^{(i)}_{min}$
1	65												0.1855
2	3	65											0.08245
3	6	3	65										0.04203
4	55	6	3	65									0.02219
5	55	5	6	3	65								0.01178
6	64	55	36	6	3	65							0.005955
7	64	55	5	36	6	3	65						0.002952
8	64	46	55	5	36	6	3	65					0.001593
9	58	64	46	55	5	36	6	3	65				0.0009369
10	51	58	64	46	55	5	36	6	3	65			0.0005177
11	70	51	58	64	46	55	5	36	6	3	65		0.0003326
12	70	32	51	58	64	46	55	5	36	6	3	65	0.0002316

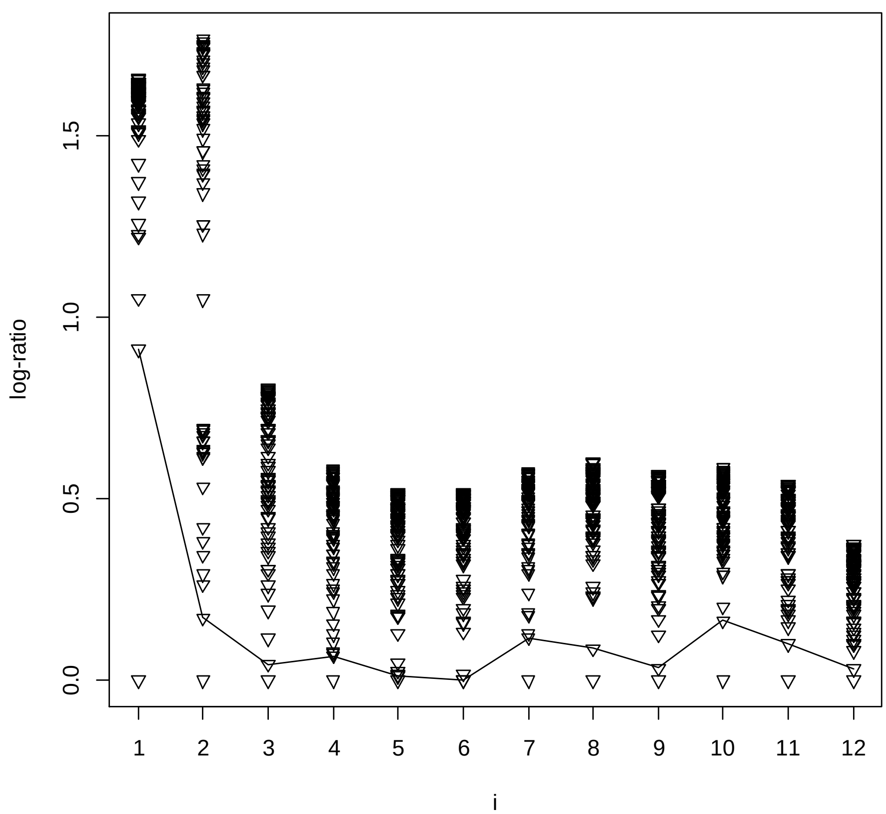

Figure 7: Log-ratio plot for data y=2011

Table 8: Outliers in data from year 2012. 80 observations

i	Observations (y=2012)												
1	66												0.1517
2	57	66											0.06774
3	5	57	66										0.02996
4	4	5	57	66									0.01735
5	59	4	5	57	66								0.01021
6	52	59	4	5	57	66							0.005587
7	65	52	59	4	5	57	66						0.003584
8	65	52	59	62	4	5	57	66					0.002295
9	65	52	59	62	74	4	5	57	66				0.001531
10	70	65	15	52	59	62	4	5	57	66			0.001013
11	70	65	15	52	59	62	74	4	5	57	66		0.0006481
12	70	60	65	15	52	59	62	74	4	5	57	66	0.0004759

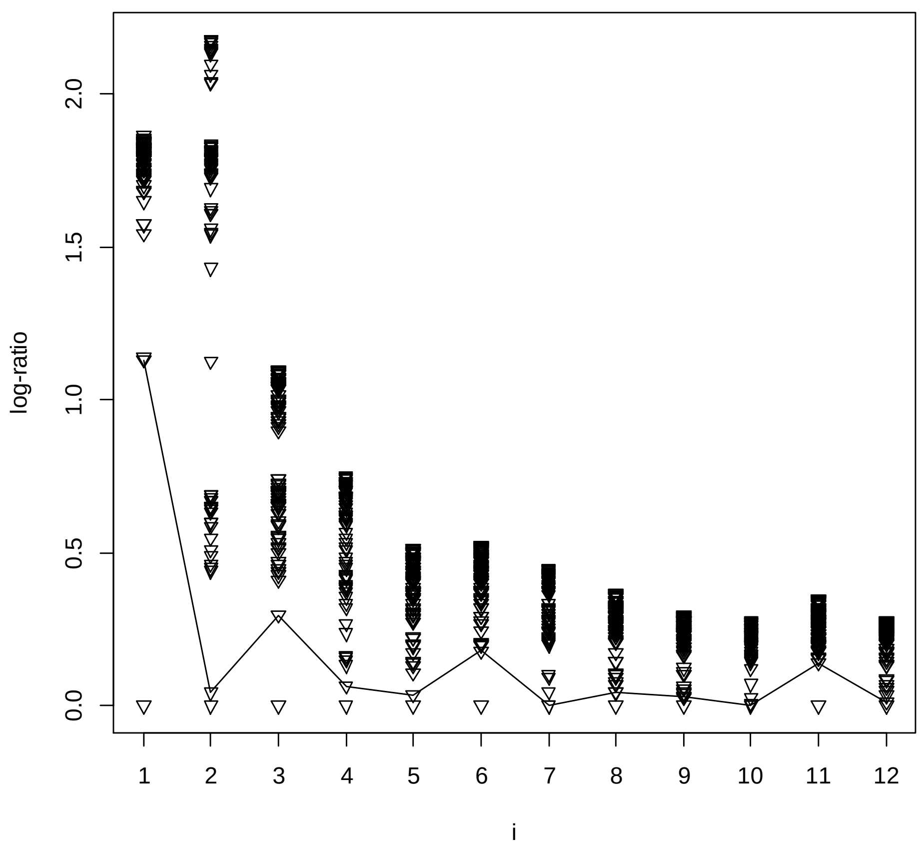

Figure 8: Log-ratio plot for data y=2012