Delft University of Technology

Master Thesis

M.Sc. Engineering & Policy Analysis

Financial performance of strip cropping in the Netherlands under high uncertainty: a Monte Carlo analysis.

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Contents

0 Summary

During the XXth century, technological breakthroughs in genetics, machinery, and improved inputs led to dramatic increases in crop yields (Pingali, 2012). This agricultural revolution was a remarkable success in food production, tripling yields while increasing the area devoted to production by only 30% (Pingali, 2012). This increase in crop yields was necessary to avoid famine, as the world population more than doubled during this period (Pingali, 2012).Unfortunately, this form of industrial agriculture, which relies on crop uniformity, heavy machinery and the intensive use of agrochemicals, leads to the loss of soil fertility, and an acceleration in soil degradation (Gomiero et al., 2011). The current system is reaching its limits, with yields either stagnating or growing much slower than needed to meet the projected demand (Hawkesford et al., 2013).

In response to this looming crisis, the Dutch Ministry of Agriculture aims to convert the Netherlands to circular agriculture by 2030. This shift requires the need to develop new ways of farming (Ministry of Agriculture & food quality, 2020). Strip cropping is proposed by researchers at Wageningen University and farmers as a potential solution. Strip cropping is a form of agriculture, which is less reliant on agrochemical inputs and promotes biodiversity by planting narrow rows (or strips) of different crops next to each other (Zhang, 2019). Researchers at Wageningen University and farmers in the Noordoostpolder want to investigate the future economic performance of this new type of agriculture compared to traditional intensive farming. This problem is formulated in the following research question: What are the economic opportunities and risks associated to the implementation of strip cropping in the Netherlands?

This research is relevant to the MSc Engineering and Policy Analysis as it can guide decisions related to horticulture. Given that agriculture is a complex socio-technical system and food security is a global challenge, this topic is an adequate fit for an EPA master thesis. The EPA master promotes the use of mathematical modeling to gain insight into societal challenges within a context of high uncertainty. The problem at hand is to determine the future economic performance of alternative farming methods, namely strip cropping, through a mathematical model with currently available information. The resulting document should enable farmers and policymakers to make informed economic decisions about the adoption of strip cropping.

The detected knowledge gap relates to a lack of understanding of the economics of the strip cropping farming method. Through a study of the literature, the ecological benefits and drawbacks of strip-cropping and monocropping are examined. By gathering information from agricultural specialists, the financial impact of strip cropping is examined. A mathematical model is then used to process and analyze this data. Microsoft Excel is the program of choice because farmers and researchers are familiar with it and it would enable farmers to input their unique parameters and simulate their future financial returns for both monocropping and strip-cropping configurations.

Initially, the information provided by the farmers is used to identify the pertinent financial variables. Revenue and Costs are the two groups into which these variables are divided. Yields, price per kilogram, and byproducts are all factors that affect revenue. Seeds, fertilization, crop protection, fuel price, fuel usage, labor cost, labor hours, and miscellaneous costs are variables in the Costs category. More specifically, a Monte Carlo analysis was chosen for the simulation since it has been shown to be effective for assessing the adaptability of various cropping systems to climatic uncertainty (Cary & Frey, 2020). This entails assigning probability distributions to the variables affected by high levels of uncertainty and executing an experiment several times to determine how the investigated farming systems would behave in various scenarios.

The distinctions between strip cropping and monocropping systems are incorporated into the model since it attempts to explore the various behaviors of these different cropping systems. In fact, only one theoretical crop (obtained by averaging the parameters of five crops) is modelled in monocropping, whereas five different crops are modelled independently and the final profit is the average of all five harvests in strip cropping. According to the parties contacted, historical data for monocropping and strip cropping systems in Noordoostpolder is not available, hence it is impossible to compare the model results to the historical outcomes. As a result, the

model's validation depends on professional knowledge from farmers with strip cropping experience.

The simulation, which takes into consideration the worst-case climatic situation, indicates that the average profit per hectare for monocropping, which is currently €3,865, could fall to €2,373. Profits would decrease by 39% as a result. In addition, there were losses 23% of the time rather than gains. Given that the profits from monocropping might be very high but the losses can also be very large and more frequent, it is likely that there will be an increase in variability for monocropping. For strip cropping, assuming a moderate increase in resilience compared to monocropping, the simulated profit per hectare for strip cropping is € 2.779. This represents a 28% decrease in profits compared to the current profits of € 3.870, as estimated by experts. This is 11 points lower than monocropping, which results in a 39 % loss in profits. Nonetheless, the returns from strip cropping are significantly more stable than those from monocropping. Indeed, the likelihood of having negative profits in a given year is only 6%, as it can be seen in table 1. Being financially performant, sustainable and allowing a 33% reduction in the use of fertilisers, strip cropping could be an attractive option for farmers. Moreover. considering the nitrogen crisis which is creating social tensions in dutch society. strip cropping could contribute to a reduction in nitrogen emissions if implemented on a large scale.

The simulation results appear to provide a solid business case for strip cropping. However, the simulation has several significant limitations that reduce the strength of the research's implications. Indeed, the mathematical model itself has numerous limitations. There are specific climatic events and pests for each crop that can reduce yields. However, this is also highly dependent on the farm's location. This was not taken into account in the model. A negative binomial distribution was used to account for yield loss, which acts as a black box in the model. Because of the nature of Excel, it is also difficult to create more complex simulations that may or may not provide a more accurate picture of reality. Furthermore, when it comes to strip cropping, farmers are encouraged to select crops that are as diverse as possible: the idea behind a good design is for some crops to perform exceptionally well while others perform poorly with the same climatic conditions. As a result, in a well-designed strip cropping setup, yield loss between species should be negatively correlated to balance risks. This was not taken into account in the model's strip cropping setup. Each crop's yield loss was calculated independently. This is due in part to the nature of the software used, which limits the model's complexity. Furthermore, quantifying the yield loss correlation between multiple crops would have been difficult. This would have also made the model more difficult to run if a user introduced new crops. Furthermore, the model was only run 434 times. More runs would be beneficial for a better Monte Carlo simulation. Unfortunately, Excel was also a significant limitation in this case.

Table 1: Simulation results

Cropping setup	Monocropping	Strip Cropping	Strip Cropping	Strip Cropping	Strip Cropping
Resilience coefficient	0%	0%	20%	40%	60%
Current average	€ 3.865,00	€ 3.870,40	€ 3.870,40	€ 3.870,40	€ 3.870,40
Predicted average	€ 2.373,43	€ 2.440,96	€ 2.778,77	€ 3.339,33	€ 3.784,30
Number of times losses	105	63	29	16	16
Percentage	23%	14%	6%	3%	3%
Reduction in yield	39%	37%	28%	14%	2%
Maximum profits	€ 11.541,85	€ 11.078,79	€ 8.397,66	€ 10.408,33	€ 9.461,35
Minimum profits	€ -4.017,10	€ -4.031,18	€ -3.702,57	€ -1.706,67	€ -2.645,60

To conclude, strip cropping provides numerous ecological benefits, including increased soil biodiversity, reduced pollution, and a better environment for rural fauna and flora. Monocropping, on the other hand, is harmful to the environment and contributes to the formation of ecological deserts. From a financial standpoint, strip cropping profits can be comparable to those of monocropping. This is however highly dependent on the crops studied, as strip cropping has been shown to be more profitable for onions, potatoes, and beans, but significantly less profitable for beetroots and barley. Furthermore, farming experts warn of a steep learning curve for new adopters. Strip cropping, on average, results in lower yields as well as significantly higher seed and labor costs.

Nonetheless, these increased costs are offset by cost savings in fertilizer and crop protection. Being 33% less reliant on fertilizer use, strip cropping could be part of the solution to solve the Dutch nitrogen crisis which has caused widespread farmer protests. Furtheremore, another advantage of strip cropping is that in a scenario with high climatic uncertainty, strip cropping is expected to outperform monocropping.

Additional pilot farms in multiple regions of the Netherlands are recommended for policymakers. Most soil and climate profiles in the Netherlands should be covered by these pilot farms. The government should assist them during the first few years to help them navigate the steep learning curve that comes with adopting strip cropping. The advantage of this approach is that data will be made available for farmers, which would allow them to make informed decisions about the impact of adopting strip cropping using this model or preferably an improved version of it. Furthermore, the knowledge gained in these pilot farms would spread to neighboring farmer communities, facilitating the adoption of strip cropping on a larger scale in case these pilot farms are successful.

1 Introduction

In the decades following the 1960s, technological breakthroughs in genetics, machinery, as well as improved inputs such as fertilizers and, to a certain extent, pesticides, have allowed an extraordinary increase in crop production (Pingali, 2012). A notable success of this agricultural revolution was witnessed in cereal production, where yields were tripled while the land used for their production only increased by 30% (Pingali, 2012). This increase in crop production was necessary to avert famines, since the global population more than doubled during that period (Pingali, 2012).

Unfortunately, this substantial achievement did not come without costs. This industrial form of agriculture which relies on the uniformity of crops, heavy machinery and the intensive use of agrochemicals is causing a loss in soil fertility, an acceleration of land degradation, as well as an increase in environmental pollution (Gomiero et al., 2011). The current system is indeed showing its limits, as it can be witnessed in cereal production, where yields have either stagnated or have grown at a much weaker rate than required to meet the projected demand (Hawkesford et al., 2013).

Monocropping, which is the practice of only cultivating a single species on a field, negatively impacts cultivated biodiversity and soil biodiversity (Kopittke et al., 2019). Unfortunately, this form of intensive farming, (which relies on the overuse of pesticides, fungicides, chemical fertilisers and heavy machinery) destroys soil ecosystems (Kopittke et al., 2019). However, soil microorganisms , which represent 25% of earth's biodiversity, are essential to maintain soil fertility (FAO, 2020). As a result, due to an increasing global population and decreasing soil fertility, the world's food security is at risk (Kopittke et al., 2019).

To counter this incoming crisis, the Dutch ministry of agriculture wants the Netherlands to switch to circular agriculture by 2030. This does not only entail a change of paradigm from intensive farming to a more ecologically friendly approach: it means new ways of farming must be developed (Ministry of Agriculture & food quality, 2020). To this end, Wageningen University has been investigating strip cropping in the farm of the future in Lelystad. Strip cropping is a form of farming promoting biodiversity by planting narrow rows (or strips) of different crops side by side (Zhang, 2019). Researchers in Wageningen and farmers in the Noordoostpolder want to investigate the future financial performance of this novel way of farming compared to conventional intensive farming. The chosen approach to fill this gap in knowledge is mathematical modelling.

1.0.1 Research Objectives

This research is related to the MSc Engineering and policy analysis because it would allow to guide decision making related to horticultural farming. Considering that farming is a complex socio-technical system, and that food security is a global challenge, this topic is in perfect alignment with the EPA masters. The EPA program specialised in mathematical modelling to derive insights in contexts of high uncertainty.

The problem resides in determining the future economic performance of the alternative farming method tested in the farm of the future by mathematically modelling it with the knowledge currently available. The resulting document should allow farmers and policy makers to make an informed economical choice regarding the available farming practices.

1.0.2 Research Questions

The problem outlined in the previous paragraph can be summarized with the following guiding research question:

1. What are the economic opportunities and risks associated to the implementation of strip cropping in the Netherlands?

The following research sub-questions were delineated. These guiding research questions are meant to divide the knowledge necessary to answer the main research question into a set of interrelated knowledge gaps which should be filled. The research approach is designed to yield a convincing result to the main research question by sequentially answering the sub-questions. The first sub-question is related to the knowledge gap which must be filled regarding the ecological aspects of both cropping systems. The method chosen to answer this question is a literature review. The second sub-question is concerned with discerning the differences in terms of finance of the two farming setups. The method chosen to answer this question is a data analysis complemented by information from the literature.

Sub-questions 3, 4 and 5 are concerned with the model formulation. They allow to understand which variables should be considered as exogenous, which abstract concepts the model should rely on and how they can be included in a Microsoft Excel Monte-Carlo analysis. Sub-questions 3 and 4 are answered by evaluating the capacities of Excel, incorporating the information collected in the previous steps and investigating the available literature to determine relevant probability distributions. Sub-question 5 is answered though an open communication with experts.

1. What are the ecological advantages and disadvantages particular to strip cropping and monocropping?
2. What are the financial advantages and disadvantages of strip cropping and monocropping?
3. What variables, formulas and abstract concepts can be used to financially model strip cropping and monocropping systems?
4. How can these respective variables, formulas and abstract concepts included in a Monte-Carlo simulation?
5. What are the conclusions which can be made from the simulation?

1.0.3 Thesis outline

In order to answer these questions, it was necessary to plan the adequate steps to reach conclusions. The first step was to determine the ecological impact of strip cropping and monocropping. This is done through a literature review which takes into consideration the ecological advantages and disadvantages of monocropping and strip cropping.The factors included here concern soil fertility, soil biodiversity, pollution, the impact of each cropping system of on-farm biodiversity such as birds and the overall ecosystem impact of each system. The second step consists of better understanding the financial implications of each cropping system. This is done by collecting financial data about each farming system for experts.This data is analysed and is further cross examined with the available literature to detect discrepancies if they exist. This step is also important in order to determine what are the determinant factors impacting the financial performance of each system since these variables are used for the model. The third step is the model conceptualisation. In this step, the information from the previous step is interpreted and translated into a functioning Excel model. The fourth step is to obtain and interpret results from the simulation. Finally, the results are discussed and validated in a last step. The thesis outline is summarised in figure1.

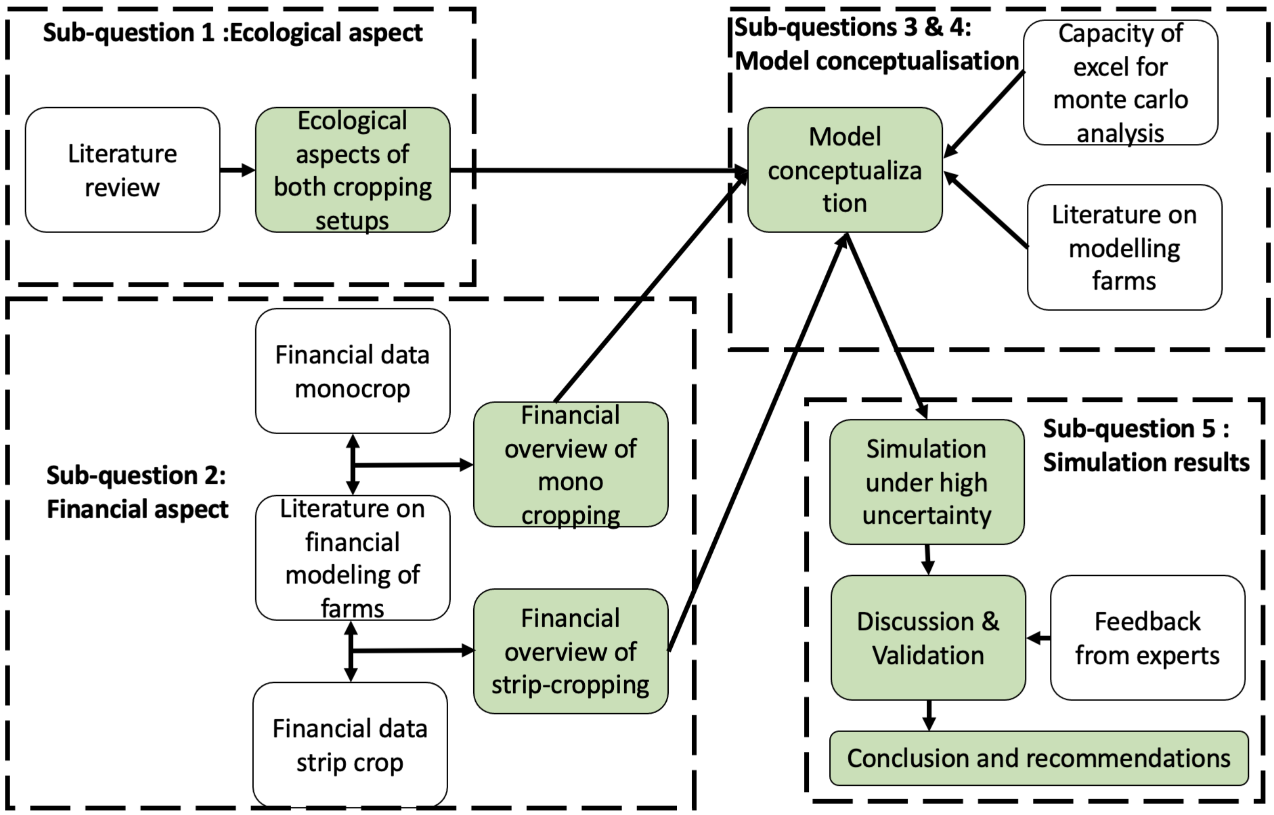

Figure 1: Research diagram

2 Literature Review and preliminary data analysis

2.0.1 Ecological impact of monocropping

Monocropping is the ubiquitous farming setup in intensive agriculture, where a field is planted with a sole crop (Higgs et al., 1990). This form of farming is reliant on agrochemical inputs and heavy machinery (Higgs et al., 1990).

Monocropping enables farmers to manage large fields efficiently through the use of large scale machinery. The disadvantage of this approach to farming is that it requires a reliance on external inputs such as synthetic fertilizers and crop protection products. This lack of genetic diversity in vast landscapes, combined with the use of agrochemicals has participated in the failure of ecosystems and the encroachment of the planet's boundaries (Ditzler et al., 2021). Monocropping and intensive agricultural production is negatively impacting the soil through erosion, salinization, acidifcation, contamination and compaction (Pennock et al., 2015).

Input intensive agricultural production reduces soil organic matter, which plays an important role in sustaining soil fertility. Indeed, soil organic matter is crucial to improve water infiltration and the capacity of the soil to retain water (Kopittke et al., 2017). The mineralization of the soil's organic matter also leads to the emission of green-house gases. Thus, this form of agricultural production contributes to accelerating climate change (Kopittke et al., 2019).

Although chemical fertilizers have a significant contribution in increasing and maintaining yields, it is important to limit their use. The negative impact of chemical fertilizer on the environment includes air pollution and the accumulation of chemicals in water bodies which leads to water eutrophication (Kumar et al., 2019).

Furthermore, the over reliance on chemical fertilizers contributes to the contamination of soils through the accumulation of heavy metals, inorganic acids and organic pollutants. This practice worsens the ecological environment and also contaminates agricultural produce with the above mentioned harmful components (Li & Wu, 2008).

Monocropping has a highly detrimental effect on biodiversity, which leads to the creation of ecological deserts (Sukkel et al., 2019). This favorizes the occurence of pests and diseases, which experience a facilitated development in homogenous landscapes (Liu et al., 2015). These artificially uniform landscapes lead to biodiversity loss, notably for arthropods for example (Habel & Schmitt, 2018). This human induced biodiversity loss phenomenon is depriving farming systems from crucial ecosystem services such as pollination and biological pest control (Bommarco et al., 2013). Furthemore, it is important to consider a uniform crop leads to a uniform set of plant defense mechanisms to abiotic stress such as droughts or heat waves. Hence, this reduced diversity in fauna and flora is a source of fragility in agricultural systems.

2.0.2 Ecological impact of strip cropping

Intercropping systems such as strip cropping are proposed as a potential solution for promoting biodiversity and natural resilience in farming systems (Bybee-Finley & Ryan, 2018). These systems benefit from the natural interactions of plants and were found to be more resilient to damage from herbivorous pests than monocropping. In the Netherlands, strip cropping has the potential to promote biodiversity while maintaining yields (Juventia et al., 2019). This method of farming was also found to reduce the amount of fertilization needed (Ayisi et al., 1997). It also limits soil erosion (the drift of soil particles) (Ciobăniţă et al., 2019). Furthermore,this method of farming was found to reduce the propagation of diseases such as blight in potatoes. Additionally, strip cropping was found to support larger populations of natural enemies to pests and diseases than monocropping systems (Ditzler et al., 2021). This suggests that the implementation of strip cropping can reduce the reliance on crop protection products and thus reduce the impact of their undesirable side effects. Furthermore, it has also been known for a long time that strip cropping has a positive impact on bird populations due to the diversity of the plants cultivated(Dambach & Good, 1940). Hence, strip cropping has the potential to promote biodiversity in fields while reducing the use of agrochemicals and increasing the resilience of farming systems to pests and diseases.

2.0.3 Financial analysis of monocropping and strip cropping

Information from the literature Input intensive agriculture has achieved substantial increases in yields in the decades following the 1960s (Pingali, 2012). Yet, this increase has considerably stalled in the last few years (Gomiero et al., 2011). Furthermore, considering that this form of agriculture has a negative impact on biodiversity, and hence reduces ecosystem services which play an important role in maintaining yields such as pollination, the productivity of these systems is expected to reduce in the future (Isbell et al., 2017).

With the current state of the art, crop models cannot successfully anticipate all the effects of climate change and the loss of ecosystem services. Additionally, changes in technology, policy and prices are expected to have a large impact on farm profits (Reidsma et al., 2015). When considering the impact of climate change on economic losses in farmers of Flevoland, it is estimated that without an adaptation of farming methods, the losses due to extreme events and pests may reach a maximum of 85% in the years between the present and 2050 (Schaap et al., 2013). In the case of arable farming in the Netherlands, the yield potential is expected to slightly increase, however, the impact of discrete extreme events is expected to reduce that advantage (Schaap et al., 2013).

In the face of these uncertainties, it is important to adapt the farming systems to this novel and challenging context. One such adaptation could be strip cropping,which has been demonstrated to be feasible in the Netherlands (Songa, 2020).

In fact, in the Netherlands, strip cropping setups increase the resilience of potatoes against blight. Furthermore, strip cropping can offer a compromise between maintaining productivity and ecological values in horticultural systems (Ditzler et al., 2021). One drawback of strip cropping is that it needs a small additional labor input (Sukkel et al., 2019).

On an international level, similar results were found. For example, in Ghana, strip cropping was identified as one of the most financially rewarding on-farm strategy adaptations for climate change (Azumah et al., 2020). It is however unclear whether this conclusion can be applied to strip cropping in the Netherlands.

In the United States, a study evaluated the economical performance of strip cropping through mathematical modeling. In that study, it was found that strip cropping could have similar or even higher returns compared to monocropping but did not significantly mitigate risk (Cary & Frey, 2020). Furthermore, an importance is given to the knowledge and expertise of farmers, which affects farming design choices and the overall productivity of the farm (Cary & Frey, 2020).

Information from the preliminary data analysis In the context of this research, data was provided by an expert in arable farming with experience in strip cropping, it can be found in the appendix. The data is from a small-scale farm in Noordoostpolder which farms different horticultural crops in strips of 3m. The crops considered are potatoes, onions, sugar beets, beans and barley. These were the crops for which data was available for strip cropping.

The variation of financial parameters between monocropping and strip cropping can be seen in table A3, in the appendix. Strip cropping leads to a 14% decrease in yields on average, however, it leads to an increase in the price per kg of produce of 7%, which suggests a higher product quality. Strip cropping also has a reduced income due to the fact that farmers do not benefit from selling by-products of their main crop. As a result, strip cropping has on average 2% less revenues.

Regarding costs, strip cropping requires an additional spending on seeds (14%) and on fuel (4%). The additional costs in seeds are mainly driven by high seed costs for potatoes and onions. However, one of the advantages of strip cropping is a lesser cost in fertilizers (-33%) and on crop protection products (-69%). The additional labor necessary to adopt strip cropping is of 39%. Overall strip cropping can be as profitable as monocropping according to experts. However, it is important to mention that such good results for strip cropping are only possible with high expert knowledge. Furthermore, experts warn that new adopters of strip cropping may face a steep learning curve before obtaining such results.

A crop per crop breakdown is available in Table 1. In that figure,it is possible to conclude that one one hand, some crops are more suited to strip cropping, such as onions, potatoes and beans. On the other hand, barley and beetroots perform better in a monocropping setup.

Table 2: Change in variables of strip cropping compared to monocropping

Crop	Onions	Potatoes	Barley	Beetroot	Beans	Average
Revenue						
Kg yields	-30%	0%	-13%	-10%	-9%	-14%
Price/ kg	49%	0%	0%	0%	0%	7%
cash yield	4%	0%	-13%	-10%	-9%	-2%
By-product	-100%	0%	0%	0%	0%	-83%
Total money yield	3%	0%	-12%	-10%	-9%	-2%
Inputed costs						
Seed	58%	3%	0%	0%	0%	14%
Fertilization	-25%	-25%	-25%	-50%	-18%	-33%
Crop protection	-67%	-82%	-70%	-45%	-67%	-69%
Fuel price	0%	0%	0%	0%	0%	0%
Fuel liters	6%	1%	7%	3%	4%	4%
Fuel costs	6%	1%	7%	3%	4%	4%
labor price/h	0%	0%	0%	0%	0%	0%
labor hours	29%	6%	30%	143%	0%	39%
labor costs	29%	6%	30%	143%	0%	39%
Other costs	15%	0%	0%	0%	0%	1%
Total accrued costs	-3%	-13%	-11%	17%	-17%	-4%
Profit	7%	9%	-14%	-50%	11%	0%

3 Method

3.0.1 Literature Review

The literature was found through Web of Science and google scholar. The key words in English used were "strip cropping", "alley cropping", "strip farming", "alley farming", "financial overview", "financial performance", "financial", "biodiversity", "Netherlands", "mathematical modeling", "Noordoostpolder", "Monocropping" and "Wageningen". The literature review hence exlcludes grey literature published in Dutch. The literature review is divided in three sections: Ecological impact of strip cropping, ecological impact of monocropping and the financial analysis of monocropping and strip cropping. In the last paragraph, the information found in the literature is compared to the financial data obtained from farmers.

3.0.2 Conceptual model

The knowledge gap identified is related to a lack of knowledge when it comes to the finances of the strip cropping farming system. The ecological advantages and disadvantages of strip-cropping and monocropping are investigated through a literature review. The financial aspect of strip cropping is investigated by acquiring data provided by agriculture experts. More information regarding that data is available in the section below. This data is then processed and analysed through the scope of a mathematical model. The software chosen is Microsoft excel. This choice of software was imposed by researchers at Wageningen University because they are familiar with it, and it would allow farmers to input their individual parameters and estimate their future financial returns for both monocropping and strip-cropping setups.The reason why this research is relevant is that the Dutch Ministry of agriculture wants the Netherlands to switch towards circular agriculture by 2030 (Ministry of Agriculture & food quality, 2020). Within that optic, strip cropping can be considered as part of the solution since it reduces the reliance of horticultural farming on external inputs. However, it is important for farmers to be able to assess the economic impact of this farming method in order to evaluate its economic feasibility.

The reason why mathematical modelling was chosen is that it allows farmers to use the excel model by inputting the numerical values related to their farms and crops of interest. This allows different farmers with different situations to have an overview of how adopting strip cropping would affect their finances.

Since the model aims to investigate the different behaviours of strip cropping and monocropping systems, the differences between these systems are embedded in the model. Indeed, for monocropping, only one crop is considered while for strip cropping, 5 different crops are modelled separately and the final profit is the average of all 5 crops. Conceptually, financial returns from strip cropping should be more resilient to climatic events and the increase in prices of inputs. This is due to the diversity of crops planted in a strip cropping, which spreads out the risk. Furthermore, strip cropping promotes a higher soil health and biodiversity, which limits the impact of pests. Strip cropping is also less reliant on agrochemical inputs. Hence, the aforementioned characteristics make, in theory, strip cropping an attractive option to farmers in a scenario of high uncertainty.

Through the literature review, the ecological impacts of both farming methods are investigated, this answers sub-question 1.

Then, to answer sub-question 2, the relevant financial variables are determined by utilizing the data provided by the farmers. These variables are separated in two categories: Revenue and Costs. Revenue variables include: Yields, Price per kg and by-products. Cost variables include Seeds, Fertilization, Crop protection,fuel price (L), fuel consumption, labour price, labour hours and miscellaneous costs. More precisely, a Monte Carlo analysis was chosen, since that method was proven to be adequate for evaluating the resilience of different cropping systems in the face of climatic uncertainty (Cary & Frey, 2020). This consists of attributing probability distributions to the variables impacted by high uncertainty and running an experiment multiple instances in order to derive the behaviour of the farming systems in multiple scenarios. The advantage of using a Monte-Carlo analysis is that it allows to obtain an overview of the performance of the system under the scenario of climatic uncertainties induced yield losses and supply chain induced increases in the price of inputs. Hence, using a Monte-Carlo analysis is an efficient approach to answer the knowledge gap vis-a-vis the future financial performance of strip cropping in the Netherlands under high uncertainty.

Then, to answer sub-question 3 and 4, in the model section, probability distributions are chosen for each variable in order to simulate the financial performance under a scenario of high uncertainty. Following that, the probability distributions and variables are included in formulas which form the backbone of the model. Then, the Monte Carlo simulation is run for 15 series of 30 years. Finally, the resulting data from the simulation is analyzed and conclusions are enunciated to answer sub-question 5.

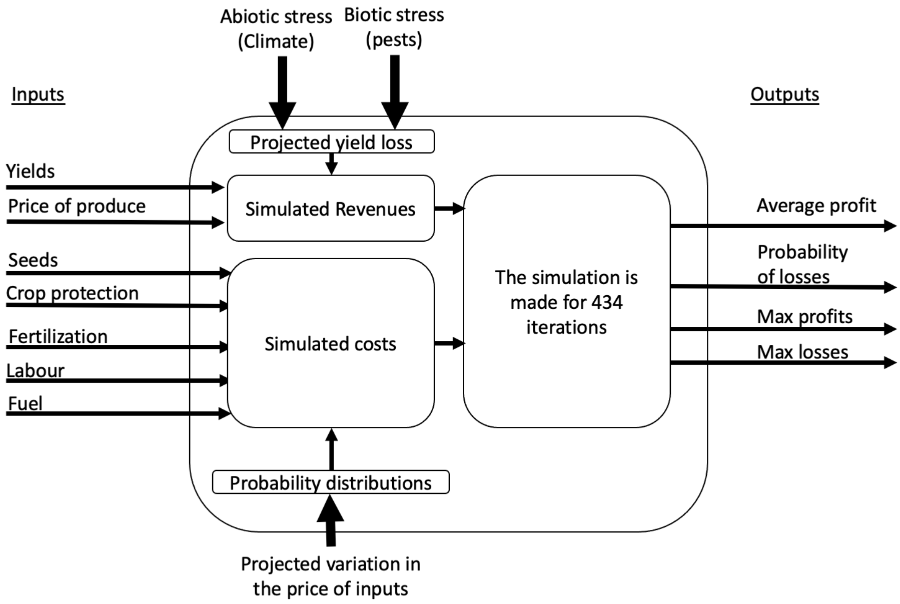

Figure 2: High level system diagram

3.0.3 Data used

The data for monoculture was collected from an accountancy firm and describes the finances of large scale farms in the Noordoostpolder region. The data for strip cropping was collected from farmers that adopted strip cropping in strips of 3m in the Noordoostpolder region. The data used concerns only the prognostic for the year of 2022, based on expert knowledge.

The data collected is of quantitative nature. It includes the costs related to both farming methods and as well as the yields and profits made. The data collected from the accountancy firm, is the financial data collected from many conventional farmers. It includes all their variable costs (mainly seeds,fuel, pesticides and fertilizers), and revenues. The data obtained from the experts in strip cropping is the aggregate financial accounts of farmers implementing strip cropping since 2018 on a small exploitation managed by a foundation in Noordoostpolder . It also includes all their costs and revenues. This financial data has been collected over the year by farmers and their accountants for financial accounting purposes.

The data was analysed and normalised to make it comparable to that of a large scale exploitation by a farming expert and prognostics for the year 2022 were made. These expert estimations were used as a basis data for the model. They can be found in the appendix.

The data obtained is only limited to potatoes, sugar beets, onions,beans,barley and potatoes. The reason for this choice of crops is that they are the only crops farmed in a strip cropping system in Noordoostpolder for which data was available.

3.0.4 Validation

Once the model is finalised and results are obtained, it is important to validate the model. This can be done in multiple ways. Due to the unavailability of historical data for both monocropping and strip cropping systems according to the parties contacted, comparing the model results to the historical results is not possible. Hence, the model relies on expert knowledge for validation. A farmer experienced in strip cropping and an expert in farmin from WUR were contacted via email. Their summarized comments can be found in the appendix.

4 Model

For the purpose of this research, Excel was imposed as a modelling tool by farmers and researchers at WUR. The reason behind that is that Excel is a software both researchers and farmers are familiar with, which means that the tool would be easily usable for them. Since this research aims to evaluate the performance of different cropping systems in a scenario of high climatic uncertainty, assumptions and scenarios must be chosen to model the expected behaviour of the studied systems. For the purpose of this research, to account for high climatic uncertainty, the scenario investigated is that of a 2 degree Celsius increase in temperature induced by climate change. This is consistent with the IPCC's 2021 report, which expects climate change to reach a minimum of 1.5 degrees Celsius if very proactive are taken within this decade(Levin et al., 2021). We do not take into account inflation: prices, wages and input costs follow real prices of 2022. Gaps between input and output prices are led by input prices, as it can be seen in figure 1 (fi compass, 2020).

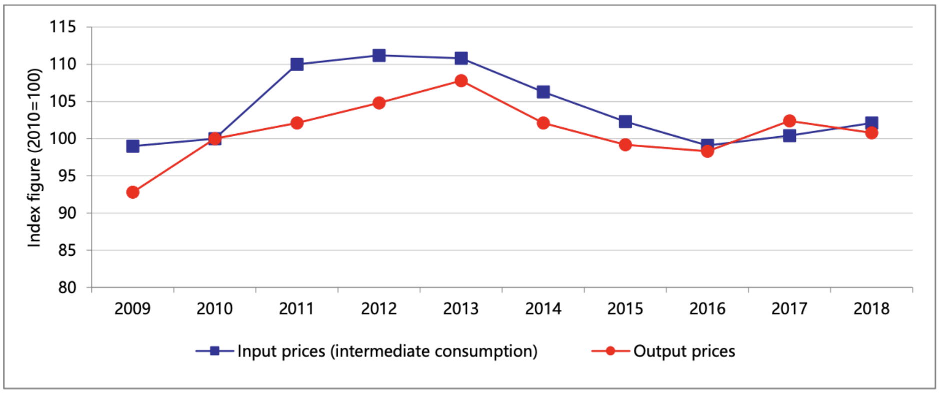

Figure 3: Evolution of agricultural input and output prices in the Netherlands, 2009-2018 (fi compass, 2020)

Climate change impact assessment is subject to a range of uncertainties due to both incomplete and unknowable knowledge. Assessing the impact of climate change is affected by many uncertainties due to incomplete knowledge. In order to address this uncertainty and unpredictability, a probabilistic approach is to define probability distributions for variables within the problem parameters within the framework of a Bayesian Monte Carlo simulation (New & Hulme, 2000). This approach was also shown to be useful to evaluate the performance of farming systems under different climate scenarios (Cary & Frey, 2020). As a result, a Monte Carlo analysis was chosen to evaluate the robustness and the resilience of both farming systems.

4.1 Main formulas

The main model formulas are the ones used by farmers in their accounting. This choice was made to make the model easily understandable to multiple stakeholders.

4.1.1 Revenue formula

The first formula is the one for the revenue:

$$Revenue(euros) = Yield(Kg) * price(euros/kg) + byproductrevenue(euros) \quad (1)$$

The Revenue is the total amount of money the farmers receives by selling his produce. The Yield is the mass of the main crop produced, the way it is modelled is explained further in the model. The price variable is the monetary value for one kg of the main crop. The byproduct revenue is the additional revenue obtained by the farmers by selling items other than the main crop.

4.1.2 Costs formula

The second formula is that of the costs:

$$\begin{aligned} Cost(euros) = {} & Seed(euros) + Fertilization(euros) \\ & + Cropprotection(euros) + Fuelprice(euros/L) * Fuelconsumption(L) \\ & + Labourprice(euros/h) * Labourneeded(h) + miscellaneouscosts(euros) \end{aligned} \quad (2)$$

Seven different costs are identified: purchasing seeds, fertilizers, crop protection products (pesticides), labour,fuel, and miscellaneous costs (which include unexpected expenses).

4.1.3 Profits formula

The last formula is the one for profit:

$$Profit(euros) = Revenue(euros) - Costs(euros) \quad (3)$$

It is the difference between the money received and the money paid by the farmer.

4.2 Modelling structural differences between monocropping and strip cropping

The structural difference between monocropping and strip cropping is the crop diversity cultivated at one time in the field. This structural difference plays a role in the resilience of each system with regard to yield losses.

4.2.1 Monocropping model structure

In order to compare monocropping to strip cropping, a theoretical crop is imagined, where each variable is the average of its respective value for onions,potatoes, beans,sugar beets and barley. The Monte Carlo simulation is then performed for that theoretical crop and results are then given, as it can be seen in figure 4.

4.2.2 Strip cropping model structure

In the case of strip cropping, the five different crops are modelled separately. According to simulations performed for the province of Flevoland, different crops such as potatoes,onions and sugar beets are sensitive to different climatic events and pests (Reidsma et al., 2015).Thus, for strip cropping, we assume no correlation regarding inter-crop yield loss. As it can be seen in figure 5, each crop is modelled separately and then the result of that simulation is averaged to give the final result.

With this model structure, the resiliency of strip cropping is mathematically embedded in the system. Since there are five separate simulations which are then averaged, this means that the variability is expected to be lower in the strip cropping model. Furthermore, the resilience of strip cropping through the increased presence is

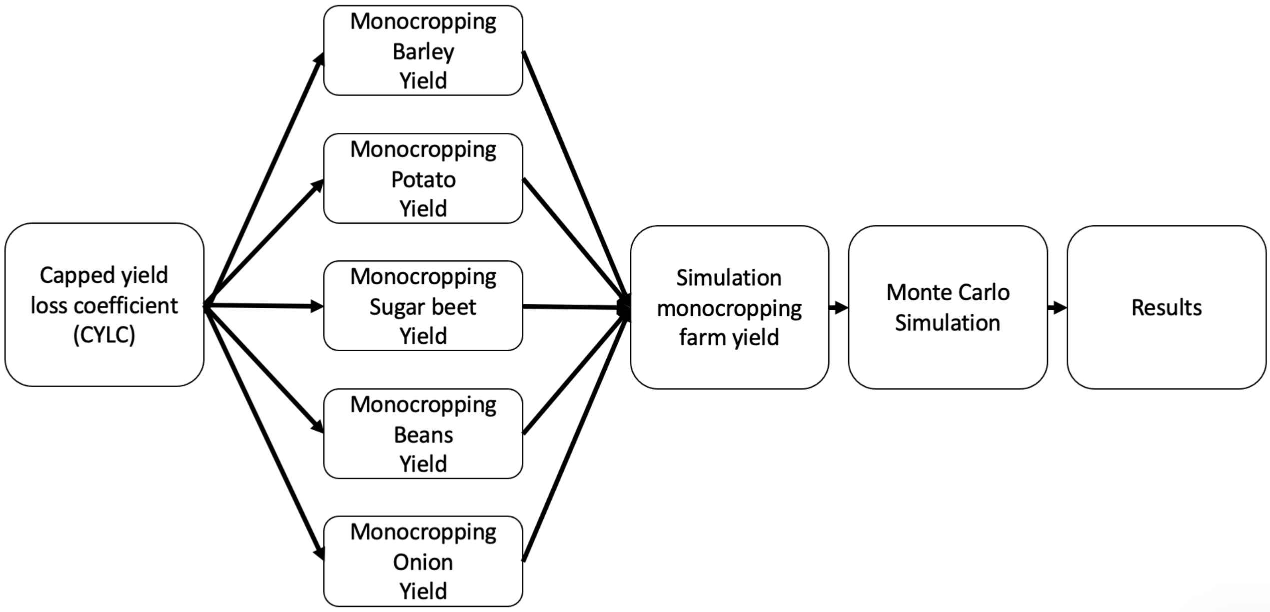

Figure 4: Monocropping simulation diagram: yield losses

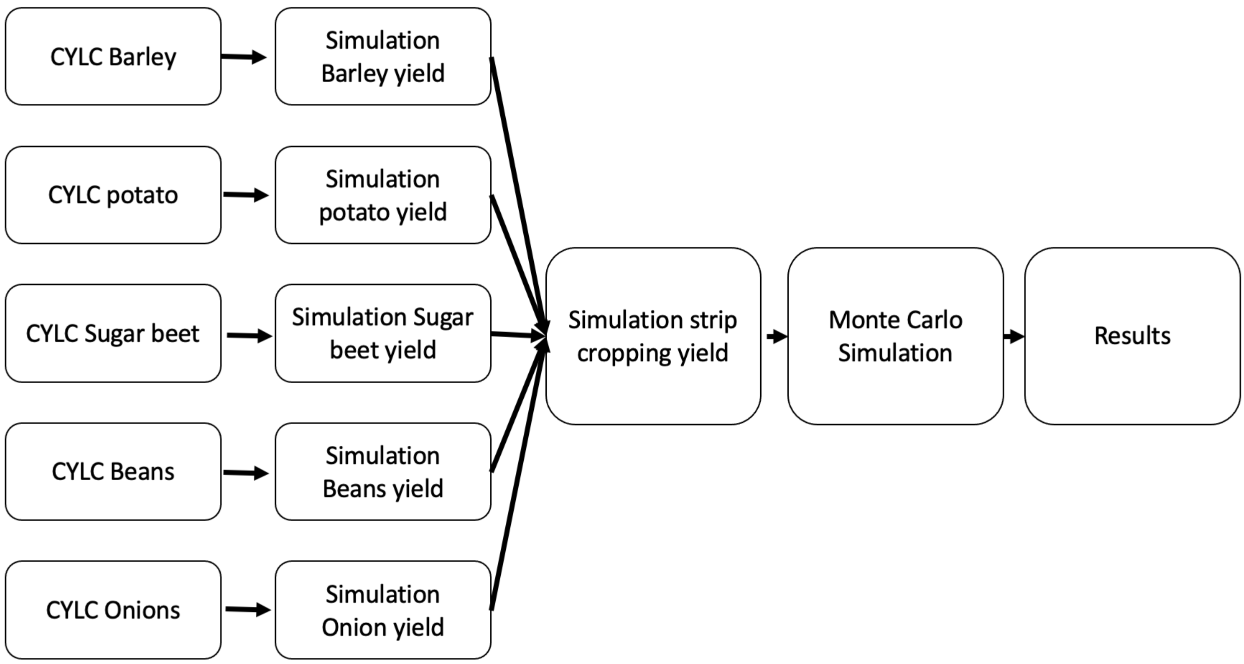

Figure 5: Strip cropping simulation diagram: yield losses

accounting for through the use of a resilience coefficient which limits the impact of yield losses on strip cropping systems. This is explained in more detail in section 4.3.1.

4.3 Input equations and probability distributions

For the purpose of running the Monte Carlo simulation, adequate probability distributions must be determined for every input variable.

4.3.1 Yield

Yield potential is expected to rise due to climate change (Schaap et al., 2013). Hence, we assume a 10% increase in potential Yield. Yield losses is mostly driven by extreme events and pests and can reach up to 85% (Schaap et al., 2013). Since yield loss is driven by extreme events and pests, it is assumed to follow a negative binomial distribution. For monocropping, the following formula is hence used:

$$Ysm = Y(euros) * ((1,1 - CYLC) \quad (4)$$

Ysm is the simulated yield. Y is the average yield for the theoretical crop. CYLC is the capped yield loss coefficient. The reason behind this is that the maximum projected yield loss is of 85% (Schaap et al., 2013). The value of the Negative binomial distribution is capped to 0,85 by using an if function: if the value is above 0,85, then we replace it whith 0,85 as it can be seen in the formula below.

$$CYLC = IF(YLC > 0,85; 0,85; YLC) \quad (5)$$

Discrete extreme events and pests, are the main drivers of yield losses. Their frequency is expected to increase due to climate change (Schaap et al., 2013). Hence, yield loss is assumed to follow a negative binomial distribution.The Yield loss coefficient formula is therefore based on a negative binomial distribution as it can be seen below:

$$YLC = NEGBINOM.DIST(0; 2; RAND(); FALSE) \quad (6)$$

For strip cropping, a coefficient is included to account for the additional resilience of strip cropping to pathogens due to an increased biodiversity and presence of natural enemies. We assume a resilience coefficient of 20%.

$$Yss = Y(euros)(1,1 - CYLC * (1 - RC)) \quad (7)$$

Yss is the simulated yield for strip cropping. Y is yield of the crop simulated. RC is the resillience coefficient related to strip cropping. Each crop is simulated separately with the formula above and then the results are averaged to give the simulated profit of the whole strip cropping system.

The price of the produce is assumed to be constant.

4.3.2 Seeds

Seed prices in Europe do not exhibit a clear trend. They appear to follow the prices of agricultural outputs with minor variations (OECD, 2019). As a result, we assume a normal distribution for the cost of seeds.

$$SCs(euros) = NORM.INV(RAND(); SC(euros); 50) \quad (8)$$

Where SCs is the simulated seed cost and SC is the seed cost.

4.3.3 Fertilization and crop protection

Fertilizer prices are influenced by supply chain shocks, transportation costs and gas prices (Smith, 2022). On the short term, gas prices are also affected by discrete events such as temperature and supply shocks (Nick & Thoenes, 2014).Evidence from academic literature suggests that climate-related risks have already caused substantial disruptions to shipping systems. These risks are expected to increase in the years to come (Becker et al., 2018).

As a result, we assume a negative binomial distribution for the increase in price of fertilizer and crop protection prices. The model also accounts for a maxmimum 10% decrease in costs related to fertilizer and crop protection prices.

$$FEs(euros) = FE(euros) * (0,9 + NEGBINOM.DIST(0;2;RAND();FALSE)) \quad (9)$$

FEs is the simulated fertilization expenses. FE is the current fertilization expenses.

The same is used for crop protection:

$$CPPs(euros) = CPP(euros) * (0,9 + NEGBINOM.DIST(0;2;RAND();FALSE)) \quad (10)$$

4.3.4 Fuel

Oil prices have historically shown to be sensitive to large shocks, such as the OPEP oil embargo in 1973, the Iranian revolution in 1978, the Iraqi invasion of Kuwait in 1990 and the 1999 oil shock (Cuñado & de Gracia, 2003). As a result, in order to model fuel prices in a scenario of high uncertainty, a binomial distribution is chosen to account for these disruptive events.

$$FCs(euros) = FL(litre) * FPs(euros/litre) \quad (11)$$

FCs is the simulated fuel costs. FL is the fuel consumption. FPs is the simulated fuel price. We assume the fuel consumption to be constant over the years.

The fuel price is modelled with the following formula, which takes into account a potential decrease of up to 10% in fuel prices:

$$FCs(euros) = FP(euros) * (0,9 + NEGBINOM.DIST(0;2;RAND();FALSE)) \quad (12)$$

FP is the fuel price from the data.

4.3.5 Labour

The price of labour is calculated with the following formula:

$$LC(euros) = LH(hours) * LP(euros/hour) \quad (13)$$

LC is labour cost, LH is the number of labour hours, which is assumed to be constant over the years and LP is the price of one hour of labour which is assumed be constant at 25 euros per hour.

4.3.6 Miscellaneous costs

Miscellaneous costs include administrative costs and contingencies for unexpected events. A normal distribution is assumed:

$$MCs(euros) = NORM.INV(RAND(); MC(euros); 50) \quad (14)$$

4.4 Simulation parameters

Due to the use of Excel, the number of simulations was limited to 15. We simulated 15 years from 2022 to 2052. Overall, this cumulatively amounts to 434 simulated years for each system. As mentioned earlier in this section, the resilience coefficient of strip cropping used is 20%. A sensitivity analysis is made in the following section to establish the impact of this coefficient on the results.

Users of the models can input the variables of their crop in the model and choose a resilience coefficient that suits them. This design parameter makes the model accessible for a large audience.

5 Results

5.1 Monocropping results

While the current average profit per hectare (as calculated in 4.1.3) for monocropping is € 3,865, it is expected to drop to € 2,373 according to the simulation, which accounts for a worst case climatic scenario. This is a reduction in profits of 39%. Furthermore, 23% of the times, there were losses instead of profits. This suggests that there will be an increased variability for monocropping, as the profits can be very high, however the losses can also be high and also increase in frequency.

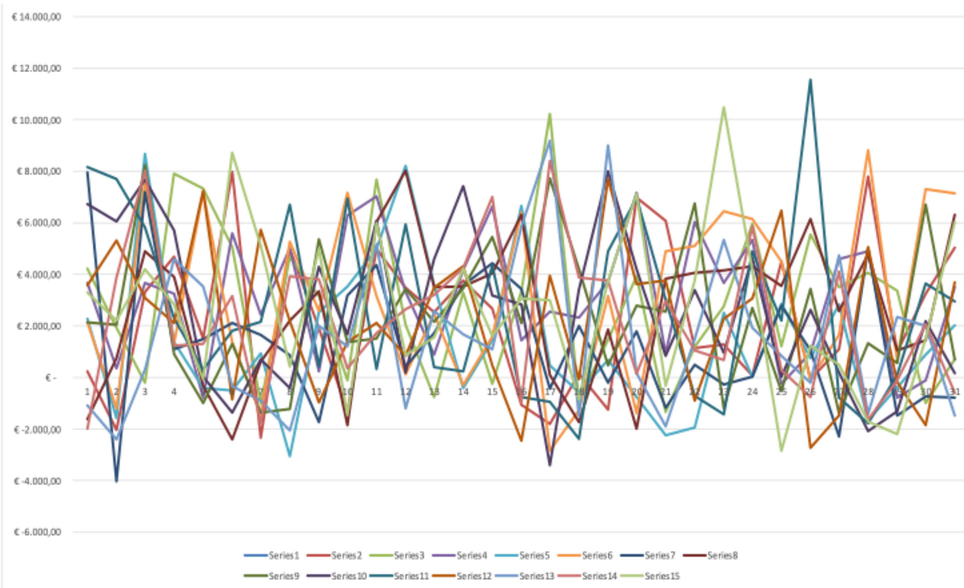

Figure 6: Monocropping simulation graph

This high variability in the profits related to monocropping can be seen in figure 6.This volatility in profits is due to the lack of diversity of crops in the field on one hand. Furthermore, monocropping does not promote the resilience of the soil ecosystems, which promote natural enemies of pests. As a results, monocropping has a higher exposure in terms of yield losses.

5.2 Strip cropping results

The initial resilience coefficient parameter for strip cropping was chosen to be 20%. Under that assumption, the simulated profit per hectare for strip cropping is of € 2.779 This is a 28% reduction in profits compared to the current profits of € 3.870, as estimated by experts.This is 11 points lower than compared to monocropping which experiences a loss in profits of 39%.

Furthermore, it is important to note that returns in strip cropping are much more stable than in monocropping. Indeed, the probability of having negative profits for a given year is of only 6%.

As is it can be seen in figure 7, profits in strip cropping are much more stable compared to monocropping. The resilience coefficient acts as a dampening factor for uncertainty in profits.

5.2.1 Sensitivity analysis for the resilience coefficient

The resilience coefficient is a large source of uncertainty in the model. Indeed, since every farm is different and soil microbiology is complex, it is difficult to precisely estimate the positive impact of strip cropping on a

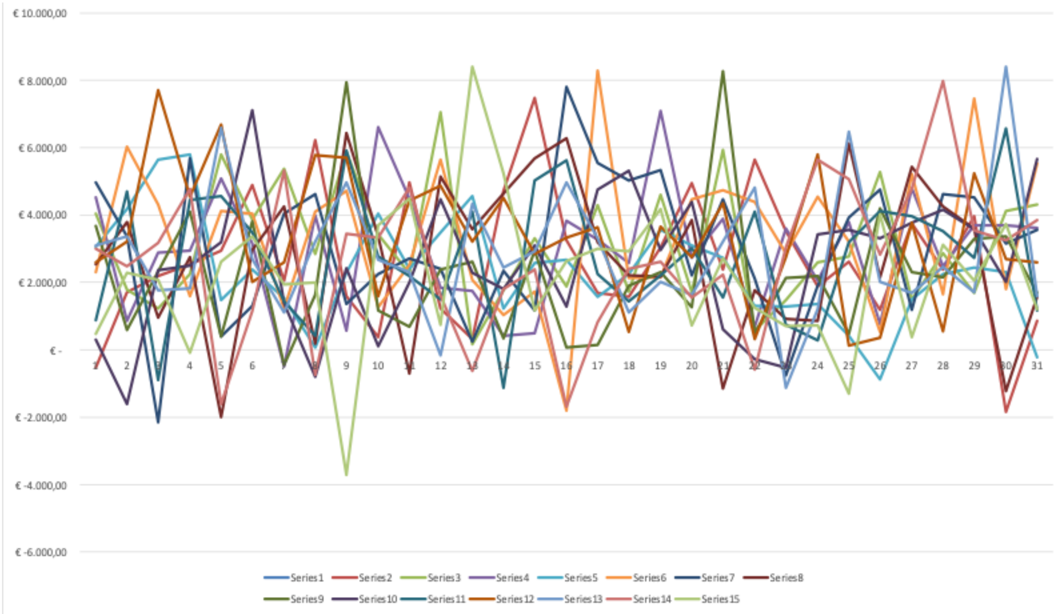

Figure 7: Strip cropping with a 20% resilience coefficient simulation graph

farm's resilience. As result, a sensitivity analysis was performed on the resilience coefficient. The simulation was run for the following values of that parameter: 0%, 20%, 40% and 60%. This also allowed to estimate the role played by the diversification of crops as a structural change in the system and the effect of the resilience . The results were compiled in table 3.

Table 3: Simulation results

Cropping setup	Monocropping	Strip Cropping	Strip Cropping	Strip Cropping	Strip Cropping
Resilience coefficient	0%	0%	20%	40%	60%
Current average	€ 3.865,00	€ 3.870,40	€ 3.870,40	€ 3.870,40	€ 3.870,40
Predicted average	€ 2.373,43	€ 2.440,96	€ 2.778,77	€ 3.339,33	€ 3.784,30
Number of times losses	105	63	29	16	16
Percentage	23%	14%	6%	3%	3%
Reduction in yield	39%	37%	28%	14%	2%
Maximum profits	€ 11.541,85	€ 11.078,79	€ 8.397,66	€ 10.408,33	€ 9.461,35
Minimum profits	€ -4.017,10	€ -4.031,18	€ -3.702,57	€ -1.706,67	€ -2.645,60

As it can be seen in the table 3, even with a resilience coefficient of 0, the profits of strip cropping remain more stable. Indeed, the probability of having negative profits for a given year are of 14% compared to 23 % for monocropping. However, the structural change in risk exposure does not affect the reduction in yield losses to a large extent: the yield loss in that scenario is of 37% compared to 39% for monocropping. This suggests that planting multiple different crops reduces the variability in profits, however, does not significantly affect the average profits.

On the other hand, as it can be seen in table 3, the increase in the resilience coefficient significantly increases average profits. Indeed, the reduction in profits is of 23%, 14% and 2% for resilience coefficients of 20%, 40% and 60% respectively.

These results are aligned with the existing literature, which claims that returns from alley cropping can meet or exceed monocropping returns in scenarios where projected yield losses are high (Cary & Frey, 2020).

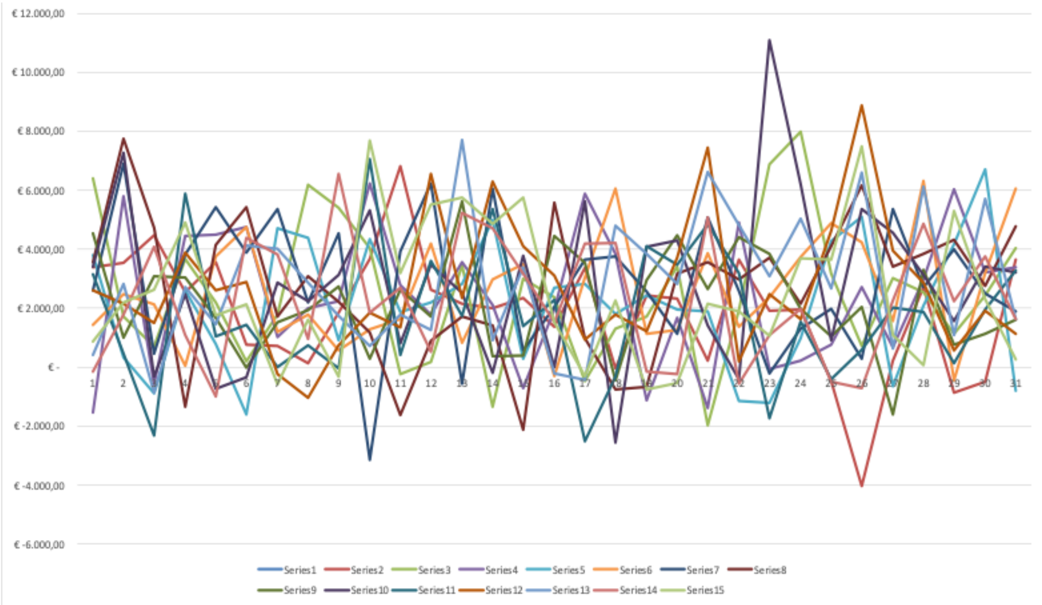

Figure 8: Strip cropping with a 0% resilience coefficient simulation graph

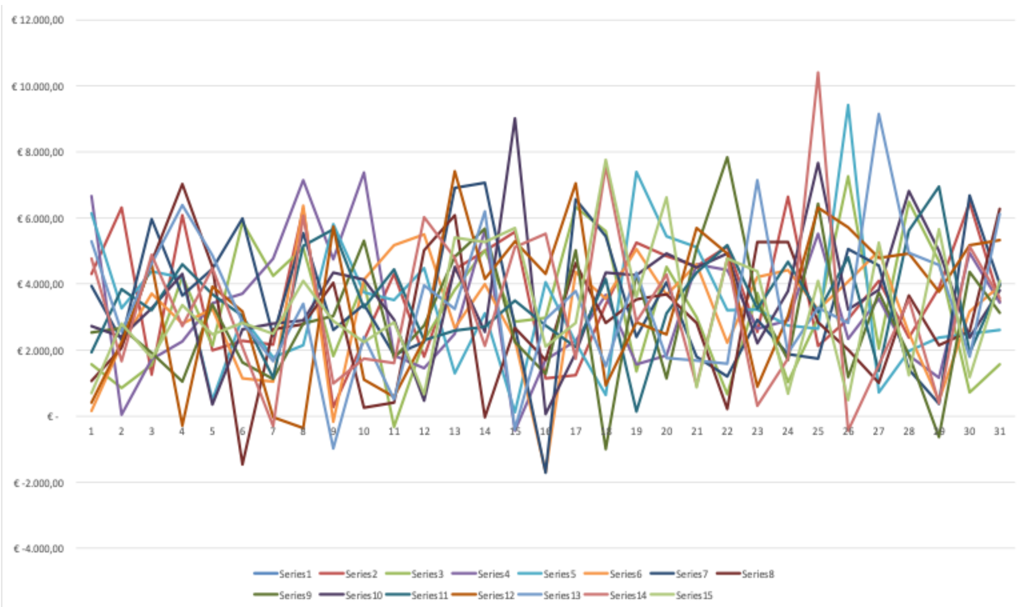

Figure 9: Strip cropping with a 40% resilience coefficient simulation graph

6 Validation

In order to validate the results, the thesis was sent by email to a farmer experienced with strip cropping and an agricultural scientist in order to collect their feedback and assess the limitations of the thesis. Overall, the farming experts agree with the main assumptions of the model, the simulation results and the projected behaviour of both farming systems. This is in part also validated by the lesser dependency of strip cropping to crop protection products as it can be seen in table 2.

Furthermore, farming experts were surprised to see a higher price for onions cultivated through strip cropping. Additionally, according to them the difference in yield loss between strip cropping should be less than 30%. They place it at around 15% instead on average. The reason for this discrepancy is that the data was collected from strip cropping farmers which experienced problems with fungi in their 2021 onion crops. As a result, their prognostic for 2022 had a pessimistic outlook regarding onion yields in a strip cropping setup. According to the experts validating the model, the average onion yield per hectare for strip cropping should be of 55,000 kg instead of 45,000kg as it is currently imputed in the model. Moreover, according to farming experts, by-products can be ignored since their impact is insignificant.

A criticism of the model voiced by farming experts is its simplicity: there are many factors that affect the yields which were not considered. Indeed, the model does not take into account the implementation of measures to mitigate the impact of climate change. Such measures include the use of new plant varieties which are more resistant to biotic and abiotic stress and the implementation of water saving systems such as drip irrigation. This is indeed consistent with information found in the literature which states that adaptations can include sowing dates but also harder to simulate measures such as drip irrigation to reduce water usage and planting in wider ridges to limit the damage of heat waves in potato production (Reidsma et al., 2015). The role of technology and innovation, which is not included in the model, is expected to significantly contribute to reducing yield losses in Flevoland by 2050(Reidsma et al., 2015).

It is important to note that the data used for the model was collected at the end of 2021. As a result, the fuel price was of € 1,1 per liter and fertilizer expenses were also indexed on 2021 prices. However, due to the war in Ukraine, a shock is anticipated in agricultural markets Pörtner et al. (2022). Indeed, while Ukraine and Russia are major exporters of fertilizers and fuel, exports are likely to be severely disrupted, which may affect prices(Pörtner et al., 2022). Hence, this force majeur event validates the use of a negative binomial distributions for fuel and fertilizer prices to account for disruptive events and supply shocks.

Moreover, according to experts, switching to strip cropping often requires purchasing different lighter machinery. This cost is not included in this study.This is clearly a limitation, since according to experts, depreciation of machinery is an important factor to compare different setups, unless it is assumed that the depreciation of machinery in strip cropping and monocropping setups is equivalent.

Taking into consideration the feedback of experts, it is possible to claim that the resulting model is a interesting tool for prospective adopters of strip cropping. The findings of this research can also be utilized by policy makers to better evaluate the impact of a large scale implementation of strip cropping. Nonetheless, the model was proven to have multiple limitations which are related in part to the limited capabilities of the modeling software used, but also to the limited availability of information such as precise figures for the increased resilience of strip cropping. As a result, while the overall behaviour of both cropping systems can be derived from the model, it is not recommended to use the model to accurately predict the profits of each cropping system. Furthermore, since the model does not take into account the impact of new technologies, it is likely to be outdated within a few years.

7 Discussion

The results obtained through the simulation appear to give a solid business case for strip cropping. However, there are several important limitations to the simulation, which reduces the implications of the research.

The available data for strip cropping is based on farms managed by experts which experienced a steep learning curve while adopting strip cropping. This makes strip cropping more attractive than it really would be, at least in the first few years, if it were to be adopted in reality. Indeed, experts have mentioned that in the past, due to some errors in judgement, yields were sometimes much lower than as shown in these projected yields. Since the data collected is the base on which the model is built, this has a significant impact on the results obtained.

Moreover, the mathematical model has many limitations. For each crop, there are specific climatic events and pests which may reduce yields. However, this is also highly dependent on the location of the farm. In the model, this was not taken into consideration. Yield loss was accounted for with a negative binomial distribution, which in fact acts as a black box in the model. Due to the nature of Excel, it is also difficult to make more complex simulations which may or may not offer a closer picture of reality.Furthermore, when it comes to strip cropping, farmers are encouraged to choose crops that are as different as possible: the idea for a good design is for some crops to perform very well when others perform badly. Hence, in a well designed strip cropping setup, in principle, the yield loss between species should be negatively correlated. In the model, this was not taken into account in the strip cropping setup. The yield loss for each crop was modelled independently. This is in part due to the nature of the software used, which limits the complexity of the model. Furthermore, it would have been difficult to quantify the yield loss correlation between multiple crops. This would also have made the model more difficult to run if new crops are introduced by a user.

Additionally, the model was only run for 434 instances. For a better Monte Carlo simulation, more runs would be beneficial. Unfortunately, here also, Excel was a severe limitation to the amount of simulations made.

Furthermore, the model is not able to accurately predict the performance of strip cropping for new species combinations. Since the interactions between different crop species can be very complex, the model did not take them into consideration explicitly. The way these interactions were accounted for was by obtaining real world data from strip cropping. As a result, the model is highly dependent on real world data of strip cropping to be of any use. The average variation in input variables between strip cropping and monocropping found in table 2 could be used to generate synthetic strip cropping data for new crops from available monocropping data for the new crops of interest.This synthetic strip cropping data can then be used to obtain a broad overview of the financial implication of adopting strip cropping.

An important point to consider was the impact of the resilience coefficient on the simulation results. As mentioned in the literature review, the adoption of strip cropping increases the resilience of a farm. However, it is difficult to quantify that accurately since it may vary from farm to farm. One clear finding of is that, for farmers interested in strip cropping, taking care of soil biodiversity and increasing the populations of natural enemies of pests is crucial to obtain good results.

Finally, the model is unable to quantify the ecological services given by the farms using strip cropping. There are initiatives for promoting environmentally friendly farming practices. Indeed, the idea of carbon farming, which consists of financially rewarding farmers for the carbon they store in their soil when practicing regenerative farming, is gaining traction. Unfortunately, there is currently no efficient and scalable method for measuring the soil carbon storage with enough statistical confidence (Gruijter et al., 2018). This highlights the need to find an accurate, affordable and scalable technique for determining the ecological services of a given farm. This includes carbon storage and soil biodiversity, which, if financially rewarded, would further incentivise farmers to adopt more environmentally friendly farming practices.

8 Conclusion

In a scenario of high uncertainty consisting of high input prices induced by supply chain shocks and climatic events induced yield losses, the financial performance of strip cropping appears to be significantly more resilient than traditional monocropping.

Within the context of a high nitrogen pollution caused by animal waste from dairy, pig and poultry farming as well as crop fertilisation, the Dutch government is attempting to curb nitrogen emissions by limiting the size of animal farms and the use of fertilizers (Stokstad, 2019). This has caused widespread farmer protests with a paralyzing effect on the Dutch economy (Stokstad, 2019). Being an alternative way of farming which allows a 33% reduction in fertilizer use, strip cropping appears to be a sustainable alternative to conventional horticulture. The wide scale implementation of strip cropping could hence be part of the solution of the nitrogen crisis, ensuring healthy returns while reducing nitrogen leakage in the environment.

The financial variables investigated are Yields, Price per kg and by-products, Seed costs , Fertilization costs , Crop protection costs,fuel price (L), fuel consumption, labour price, labour hours and miscellaneous costs. In the present, the profits of strip cropping are on average comparable to those of monocropping. This is highly dependent on the crops examined since strip cropping was shown to be more lucrative for onions, potatoes and beans, but significantly less lucrative than monocropping for beetroots and barley. On average, strip cropping entails lower yields as well as significantly higher seed and labour costs. Nonetheless, these increased expenses are compensated by savings in fertilizer and crop protection costs.

Under a scenario of high climatic uncertainty, strip cropping outperforms monocropping due to a higher resistance to yield loss caused by discrete climate related events causing abiotic and biotic pressures. Furthermore, in such a scenario, labour costs are projected to be stable compared to fertilizer and crop protection prices which are expected to significantly increase in the scenario of supply chain disruptions. As a result, returns from strip cropping are projected to be much more stable than the returns from monocropping: according to the simulation, farms practicing monocropping are expected to suffer financial losses in 23% of harvests compared to 6% for strip cropping.

The different ecological impacts of strip cropping and monocropping were also investigated through a literature review. Strip cropping confers many ecological advantages which include a healthier soil biodiversity, less pollution and a better environment for rural fauna and flora. On the opposite, monocropping is destructive of the environment and creates ecological deserts.

The model was found to have significant limitations due to the bounded capacities of Microscoft excel and the unavailability of information on key topics such as a precise quantification of the impact of strip cropping on yield loss resilience in Flevoland. Nonetheless, the model and the resulting simulations give a good overview of the challenges and opportunities related to strip cropping.

9 Recommendations

Strip cropping appears to be a feasible and attractive alternative for risk averse farmers which are willing to bear additional labour hours. Additionally, this improved farming setup in terms of sustainability enables a 33 % reduction in fertiliser use in a context where the nitrogen crisis is creating tensions in Dutch society. Hence, the large scale implementation of strip cropping could lead to a more sustainable and resilient horticultural sector without harming the livelihoods of farmers.

In order to improve the model and its conclusions, more research is necessary. It is recommended to create a table linking the correlation of yield losses among multiple different crops. This information would be not only useful to create and develop new strip cropping setups, but also to improve the accuracy of the model. Furthermore, it is necessary to further evaluate and quantify the impact of strip cropping adoption on yield loss resilience. This would also increase the pertinence and accuracy of the model.

For policy makers, it is recommended to setup additional pilot farms in multiple regions in the Netherlands. These pilot farms should cover most soil and climate profiles in the Netherlands. They should be assisted by the government during the first few years in order to help them through the steep learning curve involved with adopting strip cropping. The benefit of this approach is that data would then be made available for farmers to make an informed decision on the impact of adopting strip cropping by using this model. Additionally, the knowledge accumulated in these pilot farms would permeate through the neighbouring farmer communities, which would facilitate the adoption of strip cropping on a larger scale.

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Appendix A

Table 4: Monocropping data

Crop	Onions	Potatoes	Barley	Beetroot	Beans	Average
Revenue						
Yields (Kg)	64594	45000	8000	100000	6800	44878,80
Price/ kg	€ 0,15	€ 0,35	€ 0,20	€ 0,06	€ 0,30	€ 0,21
cash yield	€ 9.559,91	€ 15.750,00	€ 1.600,00	€ 6.000,00	€ 2.040,00	€ 6989,98
By-product	€ 20,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 5,00
Total money yield	€ 9.579,91	€ 15.751,00	€ 1.601,00	€ 6.001,00	€ 2.041,00	€ 6994,78
Imputed costs						
Seed	€ 760,00	€ 1.550,00	€ 100,00	€ 800,00	€ 280,00	€ 698,00
Fertilization	€ 600,00	€ 450,00	€ 200,00	€ 800,00	€ 170,00	€ 444,00
Crop protection	€ 1.001,00	€ 1.100,00	€ 200,00	€ 550,00	€ 330,00	€ 636,20
Fuel price	€ 1,10	€ 1,10	€ 1,10	€ 1,10	€ 1,10	€ 1,10
Fuel liters	170,00	255,00	124,00	175,00	125,00	169,80
Fuel costs	187,00	280,50	136,40	192,50	137,50	€ 186,78
Labour price/h	€ 25,00	€ 25,00	€ 25,00	€ 25,00	€ 25,00	€ 25,00
Labour hours	35,00	80,00	10,00	35,00	15,00	35,00
Labour costs	€ 875,00	€ 2.000,00	€ 250,00	€ 875,00	€ 375,00	€ 875,00
Other costs	€ 52,00	€ 850,00	€ 45,00	€ 352,00	€ 150,00	€ 289,80
Total accrued costs	€ 3.475,00	€ 6.230,50	€ 931,40	€ 3.569,50	€ 1.442,50	€ 3129,78
Profit	€ 6.104,91	€ 9.520,50	€ 669,60	€ 2.431,50	€ 598,50	€ 3865,00

Table 5: Strip cropping data

Crop	Onions	Potatoes	Barley	Beetroot	Beans	Average
Revenue						
Yields (Kg)	45000	45000	7000	90000	6200	38640
Price/ kg	€ 0,22	€ 0,35	€ 0,20	€ 0,06	€ 0,30	€ 0,226
Cash yield	€ 9.900,00	€ 15.750,00	€ 1.400,00	€ 5.400,00	€ 1.860,00	€ 6862
By-product	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 0,00
Total money yield	€ 9.900,00	€ 15.751,00	€ 1.401,00	€ 5.401,00	€ 1.861,00	€6862,8
Inputed costs						
Seed	€ 1.200,00	€ 1.600,00	€ 100,00	€ 800,00	€ 280,00	€ 796
Fertilization	€ 450,00	€ 338,00	€ 150,00	€ 400,00	€ 140,00	€ 295,6
Crop protection	€ 330,00	€ 200,00	€ 60,00	€ 300,00	€ 110,00	€ 200
Fuel price	€ 1,10	€ 1,10	€ 1,10	€ 1,10	€ 1,10	€ 1,1
Fuel liters	180,00	257,00	133,00	180,00	130,00	176
Fuel costs	€ 198,00	€ 282,70	€ 146,30	€ 198,00	€ 143,00	€ 193,6
Labour price/h	€ 25,00	€ 25,00	€ 25,00	€ 25,00	€ 25,00	€ 25
Labour hours	45	85	13	85	15	48,6
Labour costs	€ 1.125,00	€ 2.125,00	€ 325,00	€ 2.125,00	€ 375,00	€ 1215
Other costs	€ 60,00	€ 850,00	€ 45,00	€ 352,00	€ 150,00	€ 291,4
Total accrued costs	€ 3.363,00	€ 5.395,70	€ 826,30	€ 4.175,00	€ 1.198,00	€ 2991,6
Profit	€ 6.537,00	€ 10.355,30	€ 574,70	€ 1.226,00	€ 663,00	€ 3871,2

Appendix B

9.1 Feedback from a farmer experienced in strip cropping

In general: There are more actions regarding farm management that impact the results in yields and costs, such as the different manners crops can be fertilized.

The data for strip cropping was collected from farmers that adopted strip cropping in strips of 3m in the Noordoostpolder region. The data used concerns only the prognostic for the year of 2022, based on expert knowledge.

Comments on Table 1: Yield depression of onions should be less then -30% for strip cropping compared to monocropping; I estimate it to be of -15%. The farm the data was collected in did not perform well in the last two years, which might explain some pessimism in the data, but I do not see a real argument why it should be more than 15% in general. I also do not see a reason why the price of onions would be higher unless you go into short chain activities.

Comments on Table 3: I estimate the yield in onions for strip cropping should be at least 55 ton and a better estimate of the labour in Onions to be of 55 hours/ha. I think by-products can be ignored in the analysis.

9.2 Feedback from an agricultural scientist at WUR

More information on strip cropping can be found in grey literature written in Dutch.

Organic monocropping was not considered, however, it has a lower ecological impact than conventional farming and has benefits for soil health and soil biodiversity.

Depreciation of machinery is a significant cost to be considered unless it is assumed that they are the same for monocropping and strip cropping.

In general you delivered an interesting thesis and I hope in the coming years we gather more detailed information about this specific subject.