Methodologies for analyzing future farming systems and climate change impacts in Flevoland as applied within the AgriAdapt project

Joost Wolf, Maryia Mandryk, Argyris Kanellopoulos, Pepijn van Oort, Ben Schaap, Pytrik Reidsma, Martin van Ittersum

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ABSTRACT

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A key objective of the AgriAdapt project is the development of methodologies to assess climatic change impacts on agriculture including adaptation at regional and farm type level in combination with market changes. More specifically, the methodologies should enable (a) the assessment of impacts, risks and resiliencies for agriculture under changes in climatic conditions including increasing climate variability but also under changes of other drivers (market, technology, policy, etc.) and (b) the evaluation of adaptation strategies at farm type and regional scale.

The methodologies are applied on arable farming in Flevoland, the Netherlands as the key case study to demonstrate the approach. The methodologies cover the following main areas: (a) Integrated sustainability analysis and linkage and integration of the different methodologies, (b) Development of scenarios of farm structural change towards 2050, (c) Calculation of crop yields for different scenarios in 2050 inclusive agro-climate calendars and analysis of the effects of extreme events, and (d) Partial and fully integrated analysis of farming systems with different methods (i.e. bio-economic farm modeling, Fixed cropping pattern method, and Data envelopment analysis) for both 2010 and 2050.

In Chapter 2 the integrated methodology for sustainability assessment within AgriAdapt is described to explain first how the different methodologies are applied in an integrated way and for which time horizons and scales they are applied. Then this report gives a description of the different methodologies (from Chapter 3 onwards) as they will be applied in the AgriAdapt project. Each section with a description per methodology covers the following: (a) Description of the methodology, (b) Short example of its application, and (c) Discussion of the methodology, its potential and limitations, and the first results. The report presents the different methodologies and their proposed integration, whereas the actual and consistent application of the proposed methods will be the subject of the second part of the project.

Keywords: AgriAdapt, agro-climate calendar, climatic change, data envelopment analysis, extreme event, farming system, farm structural change, Flevoland, FSSIM, optimization model, potential yield, scenarios, sustainability

Wageningen University, Groups Plant Production Systems & Centre for Crop Systems Analysis P.O. Box 430, 6700 AK, Wageningen, The Netherlands

or

Droevendaalse steeg 1, 6708 PB Wageningen Netherlands

Phone +31-(0)317-483078, Fax +31-(0)317-484892

E-mail: joost.wolf@wur.nl

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Summary

A key objective of the AgriAdapt project is the development of methodologies to assess climatic change impacts on agriculture including adaptation at regional and farm type level in combination with changes in other drivers (e.g. markets). More specifically, the methodologies should enable (a) the assessment of impacts, risks and resiliencies for agriculture under first, changes in climatic conditions including increasing climate variability and second, other changes (e.g. markets, technological development, policies, etc.), and (b) the evaluation of adaptation strategies at farm type and regional scale.

The methodologies are applied to arable farming in Flevoland, the Netherlands as the key case study to demonstrate the approach. The methodologies cover the following main areas, as described in the following: (a) Integrated sustainability assessment, (b) Development of scenarios of farm structural change towards 2050, (c) Calculation of crop yields for different scenarios in 2050 and analysis of the effects of extreme events, (d) Agro-climate calendars, (e) Partial and fully integrated analysis of farming systems with different methods (i.e. bio-economic farm modeling, Fixed cropping pattern method, and Data envelopment analysis) for both 2010 and 2050, and (f) Integration of methodologies at crop and farm level. The report presents the different methodologies and their proposed integration, whereas the actual and consistent application of the proposed methods will be the subject of the second part of the project.

Integrated sustainability assessment shows how the different methodologies, as described in the following, are linked and integrated. We use different methods for different questions, to assess the impacts of different drivers (e.g. climatic change, policies, market, technology), and the most effective adaptation strategies. Different methods complement each other, and together they can provide a detailed picture of pathways to a climate robust agriculture in the future. This is done at two levels, crop level and farm level, and for two time horizons, 2010 and 2050. Two SRES emission scenarios, A1F1 and B2 (IPCC, 2001), and related KNMI climate change scenarios, W (or W+) and G (or G+), for the Netherlands are used. Stakeholders are consulted to define specific questions that will be analysed with the different methods.

Development of scenarios of farm structural change towards 2050 has been done, using a farm typology for arable farms in Flevoland and considering the effects of different drivers on the different dimensions of the farm typology. The drivers have been derived from the A1F1 and B2 SRES emission scenarios. The possible farm structural changes are only indications and provide images of future farms; however, any precision as to structural changes for such a long time horizon cannot be provided.

Potential yields of the main crop types cultivated in Flevoland have been calculated with the WOFOST crop model. These yield calculations have been done for four different climatic change scenarios from KNMI (i.e. G, G+, W, W+) for 2050 and for two related atmospheric CO₂ concentrations, corresponding to the A1F1 and B2 emission scenarios. Changes in climate and increases in atmospheric CO₂ in year

2050 for the four scenarios result in yield increases for all crop types in Flevoland, except sometimes for the most extreme climatic change scenario W+. These simulated potential yields appear to be reliable.

Actual yields for 2050 are calculated as: simulated potential yields times (1 + GI) times (1 - GAP50), with GI being equal to the Genetic Improvement factor (e.g. 0.30; based on yield increase by plant breeding towards 2050) and GAP50 being the yield gap in 2050. GAP50 is equal to the minimum of either GAP50s (i.e. yield gap set for 2050) and GAPc being equal to the current (year 2000) yield gap as dependent on the crop management level. This method is straightforward, however, the calculated actual yields for 2050 depend on a number of assumptions. We can assume that the effects of climatic change and increase in atmospheric CO₂ on the actual yields are represented reasonably well by the simulated potential yields for 2050, but the changes in yield by genetic improvement and by yield gap reduction due to improved management are both uncertain, in particular when the method is applied to many regions over Europe. In Flevoland where the current crop management is almost optimal and hence, the yield gap is almost at its minimum, the uncertainty in the calculated actual yields for 2050 is mainly caused by the estimated yield change due to genetic improvement.

Agro-climate calendars have been applied to determine the climatic change sensitivity of the main cropping systems in the Netherlands. The climate sensitive periods of cropping systems have been determined on the basis of long-term (30 year) weather data, both for current conditions and for a time frame around 2050 (as based on KNMI climatic change scenarios). An example of the approach is given for winter wheat cultivation in the Northern part of the Netherlands. For the occurring management problems, adaptation measures have been proposed. As the climate sensitivity of the main cropping systems in the Netherlands have already been studied, we are mainly interested and will discuss here, how the information from this approach can be combined with and integrated in the modeling results from the other approaches applied within the AgriAdapt project.

Analysis of the effects of extreme events on crop yields from the historical field trials provides some insightful results, which also show limitations as to what can be quantified. It was possible to derive definitions of weather extremes. For example, preliminary results indicate that the largest losses of production in the past 50 years in ware potato were caused by a prolonged wet start of the growing season which delayed planting and by a prolonged end of the growing season which caused harvesting problems. On the other hand, limitations are that weather extremes and changing rainfall patterns in the future are very difficult to predict and that historical data on effects of weather extremes are available for only a few crops and events.

Exploration of farming systems has been done with the bio-economic farm model FSSIM for an average farm in Flevoland, maximizing the gross margin and applying the following constraints: available land and labour, obligatory set-aside constraint, sugar beet quota constraints and possibly also bounds on total N leaching and the change in soil organic matter content. This example study shows the advantage of a bio-economic farm model, being the capacity to generate and assess a large number of alternative activities on the farm in an explicit, transparent and reproducible way.

For the optimized farms under different constraints, outcomes are calculated with respect to the financial results, labour demand, N leaching, cropping pattern, etc. A limitation of the procedure when applied to future situations, is that it requires detailed information on the activities (i.e. input-output relationships) and on the prices of inputs and outputs in the future. Another limitation is that many binding constraints need to be identified (e.g. related to main crop rotations) or a calibration procedure should be employed to add non-linearities by recovering the un-observed parameters that are related to e.g. risk aversion, complementarity and substitution. Parameters that are recovered with calibration based on historical data are not always valid for long term forecasts and hence, such a calibration procedure is preferably used for short term predictions. For longer term predictions (e.g. 2050) a normative approach (analysing 'what-if' questions) is to be applied.

Fixed cropping pattern calculations (showing the impacts of climatic change, technological development, policy and market changes on farmer's income and assuming that the cropping pattern is fixed and is not determined by an objective function and constraints as in FSSIM) have been done for arable farming in Flevoland. First, this was done for the four main arable farm types in Flevoland for current conditions (about 2010). Second, the calculations are repeated for these four farm types with the same cropping patterns and farm area but for 2050. Third, the calculations are done again for 2050 and the same farm types but assuming more specialized cropping patterns. Fourth, the calculations are done for 2050 and the same farm types and cropping patterns, but with a tripled farm area. Relative changes in yields, product prices, variable costs and additional labour costs, that have been set (as first estimates) at respectively about 1% (of which 0.3 % from climatic change and increased atmospheric CO₂ and 0.7% from genetic improvement), 1%, 2% and 2% per year, are strongly determining the economic farm results. Effects of climatic change and subsidies appear to be of minor importance compared to the other factors (e.g. farm size and specialization, changes in product prices and variable costs, and yield increases due to genetic improvement of crops) for the economic results in 2050.

Data envelopment analysis (DEA) is a method used in operational research to rank entities that convert multiple inputs into multiple outputs. Such entities are defined as decision making units (DMU), being for example firms and farms. The capacity of each DMU to convert inputs into outputs is evaluated and compared to the capacity of all other existing DMUs to convert inputs into outputs. A multi dimensional frontier is created by the superior decision making units, while all other inferior decision making units are enveloped (enclosed) in this frontier. Inputs can be seen as criteria to be minimized while outputs as criteria to be maximized. In the example we apply the DEA based approach to arable farming systems in Flevoland (the Netherlands) to show its approach and its potential in three steps. First, the basics of DEA for identifying a production frontier are revealed and an approach for including technological innovation and alternative agricultural activities is presented. Second, the proposed DEA based methodology is used to identify the current technology of Flevoland (the Netherlands) and based on this current technology to demonstrate how alternative activities or technological advances can be taken into account. Third, the results of the experiment in Flevoland are presented.

Integration of methodologies at crop level shows that changes in the effects of extreme events on crop yields towards 2050 cannot easily be included in the actual yield calculations for 2050. Part of the effects of extreme events on yields are already included in the yield gap. Changes in these effects towards 2050 might result in changes in the yield gap due to changed yield losses or in the simulated potential yields due to changed planting/sowing dates. However, both changes are difficult to quantify and probably remain within the range of uncertainty in the actual yield calculations. If so, the effects of extreme events should not be included in the actual yield calculations but should be presented separately.

Problematic with crop model results is that they mainly show the effects of gradual climatic changes on crop production and yields, and that they cannot assess all types of adaptation measures. In practice, climate extremes may have more impact than a gradual climatic change. Many adaptation measures for such extremes are available and for farmers these may be highly relevant. Impacts of climate extremes on crop production are determined for both current and future climate conditions, and based on the major climate risks, adaptation measures are identified. Together, these methods provide a good picture of the impacts of climatic change on crop production and the most relevant adaptation measures and their effects.

Integration of methodologies at farm level - The analyses and projections at crop level are used for the farm level analyses. Several complementary methods are used at farm level, as they provide answers to different research questions. Although climatic change is already apparent, impacts are mainly expected in the long term. However, in the long term other drivers such as technological development, markets and policies will change, too. Farm analyses have therefore been done for two time periods, 2010 and 2050.

The farm level assessment for 2010 is performed for current farms and their activities (2010), but assuming climatic conditions for 2050. This is done to explore which most effective adaptation strategies are available for current farms if a change in the climate occurs. Although it is likely that climatic change will occur in a gradual way, extreme years that represent 2050 conditions, can occur already now. Two farm level assessment methods are used for the 2010 assessment: i) DEA + FSSIM and ii) Expert knowledge + FSSIM. DEA + FSSIM uses data on 27 actual farms in Flevoland as a basis for the assessment, whereas Expert knowledge + FSSIM uses data for typical farms using the expert-based 'simple survey' data. Future climate change scenarios from KNMI (as related to the SRES emission scenarios A1 and B2) are used, whereas the other conditions are assumed to be as in 2010. These assessments give answers to questions such as: i) What is the impact of climatic change on cropping patterns and associated economic, environmental and social indicators, considering different farm objectives; ii) Which adaptation strategies are effective and therefore selected on different farm types, considering their objectives. The two methods are to some extent complementary, allowing to address different questions.

The farm-level assessment for 2050 is done for images of future (2050) farms. The main method used is the 'Fixed cropping pattern method', but additional explorations are done using DEA+FSSIM. Towards 2050 many developments will

take place simultaneously, and technological development cannot easily be separated from adaptation. It is assumed that the technological development (i.e. crop genetic and management improvement) includes adoption of the most effective crop level adaptation measures. The A1 and B2 scenarios for 2050 are used to project changes, not only with respect to the climate, but also for e.g. farm structural change and technological development. For estimating future actual yields, estimates on potential yields are combined with estimated improvements in the crop's genetic characteristics and its management. Future prices are estimated by the agricultural market model CAPRI. These assessments give answers to questions such as: i) What is the relative importance of climatic change, technological development, markets and policy changes for the farmer's income on the main farm types in 2050; ii) What is the impact of farm size and specialization on the farmer's income in 2050; iii) What are the most effective farm level adaptation strategies in 2050.

1 Introduction

A key objective of the AgriAdapt project is the development of methodologies to assess climatic change impacts on agriculture including adaptation at regional and farm type level in combination with market changes. More specifically, the methodologies should enable (a) the assessment of impacts, risks and resiliencies for agriculture under first, changes in climatic conditions including increasing climate variability and second, other changes (e.g. market, technology, policy, etc.), and (b) the evaluation of adaptation strategies at farm type and regional scale.

The methodologies should provide answers to questions such as:

- What are the risks and opportunities for agriculture in the selected region under climate and market change?
- How important are climatic change effects on agriculture as compared to market changes?
- Are farming systems able to cope with increased frequencies of extreme climate events?
- Does adaptation to climatic change provide opportunities for agriculture?

The different methodologies developed and to be applied in the AgriAdapt project, are described in this report. Each methodology is described in a separate chapter which covers the following:

- Description of the methodology
- Short example of an application of the methodology
- Discussion of the methodology, its potential and limitations, and the first results

The methodologies are to be applied to arable farming in Flevoland, the Netherlands as the key case study to demonstrate the approach. The methodologies cover the following main areas:

- Integrated sustainability assessment (Chapter 2), and the linkage and integration of different methodologies
- Development of scenarios of farm structural change towards 2050 (Chapter 3)
- Calculation of crops yields for different scenarios in 2050 inclusive agroclimate calendars and analysis of the effects of extreme events (Chapters 4, 5, 6 and 7)
- Partial and fully integrated analysis of farming systems with different methods (i.e. FSSIM optimization modeling, Fixed cropping pattern method,

and Data envelopment analysis) for both 2010 and 2050 (Chapters 8, 9 and 10)

The report presents the different methodologies and their proposed integration, whereas the actual and consistent application of the proposed methods will be the subject of the second part of the project.

2 Integrated sustainability assessment

The study is set up along the steps of integrated sustainability assessment (ISA). ISA is a cyclical, participatory process of scoping, envisioning, experimenting and learning, through which a shared interpretation of sustainability for a specific context is developed and applied in an integrated manner in order to explore solutions to persistent problems of unsustainable development (Weaver and Rotmans, 2007; Bohunovsky et al., in press).

2.1 Scoping: the problem

Scoping includes a thorough definition of the problem and aims at developing a context-specific interpretation of sustainability. The main problem to be assessed in this study is the impact of climatic change on agriculture in Flevoland. The main aim of this research is to explore adaptation strategies that contribute to a viable, sustainable agricultural sector. A sustainable development of the agricultural sector does, however, not only depend on the impacts of climatic change, but also on changes in technology, policy and markets. Drivers act at multiple scale with climatic change impacting the farm level mainly through the crop level (assuming that sealevel rise can be controlled at higher hierarchical levels), while other drivers (such as markets and policies) act at regional to global level. Drivers also act at different temporal scales. Climatic change seems to be apparent already, but as impacts will increase towards the future, a longer time horizon (in this report 2050) is necessary. Furthermore, different stakeholders have different perceptions of what a sustainable agriculture implies. Many climatic change impact studies have focused on crop production (Easterling et al., 2007), but farmers are entrepreneurs that not necessarily pursue the maximum yield but rather maximize income, and moreover farmers may also obtain income from other sources. Over the last decades, the environmental and social impacts of agriculture (e.g. biodiversity, landscape) have become more important, and agriculture also needs to adapt to satisfy other demands besides food production. This study thus considers multiple drivers, multiple scales and multiple dimensions of sustainable development (economic, environmental, social). The main level of analysis is the farm level, but specific studies are done at lower and higher levels for an integrated assessment.

In the next chapters examples of questions to be addressed are provided to indicate and illustrate the scope of the work. In the project these questions will be further specified through stakeholder consultations and interactions, which are part of the overall approach and which are scheduled for the second part of the project.

2.2 Envisioning: scenarios and visions

In the envisioning phase, visions (i.e. desirable futures) are developed with stakeholders. For this study, two contrasting global scenarios are downscaled to the regional level. The A1 scenario reflects a globalized economy, while the B2 scenario reflects regional communities (IPCC 2000, Riedijk et al., 2007).

The envisioning phase, i.e. the development of regional and farm level visions, is done in the context of higher and lower level scenarios for specific drivers (Chapter 3). For projecting changes in climate, KNMI'06 scenarios are used (Van der Hurk, 2006). The European agricultural market model CAPRI (Heckelei and Britz, 2005; van Ittersum et al., 2008) projects changes in input and output prices, considering changes in crop yields in other European regions (Angulo et al., 2010). Policy developments are reviewed and impacts on agriculture (e.g. subsidies) are considered in assessments.

Considering these scenarios and considering that the effects of climatic change are expected to be more prominent in the long-term, images of future farms in 2050 are developed (Chapter 3). This method allows addressing the following questions:

- How may farms look like in 2050?
- What is the relative impact of climatic change in relation to technological development, policies and markets on farm structural change?
- What do stakeholders envisage for farming in the future, and what does this imply for adaptation strategies?

First, a farm typology of current farms was developed based on size, intensity, specialization and objectives of farms. Based on a historical trend analysis and the expected changes in climate, technological development, markets and policies, possible changes in farm structure were projected. These changes in farm types and their distribution in the region were discussed with stakeholders to obtain visions of where farmers and other stakeholders expect to be moving to, and to provide a context for the identification of effective adaptation strategies. The images may not be desirable for all stakeholders, but indicate what may happen and is considered feasible within the A1 and B2 scenarios. Note that the visions of future farms are of an explorative nature – they cannot be considered as predictions. They give a context for future farm level analysis and an indication of the context in which adaptation will take place, including technological development influencing crop production (Chapter 5).

2.3 Experimenting: multiple scales

In the experimenting phase, the scenarios and visions (i.e. images of future farms) are explored in further detail. We use different methods for different questions, to assess the impacts of different drivers, and the most effective adaptation strategies. Different methods complement each other, and together they can provide a detailed picture of the various pathways to a climate robust, sustainable agriculture in 2050.

This experimenting will be done at two levels, crop level and farm level, and for two time horizons, i.e. 2010 and 2050. For the time horizon 2010, the climatic change scenarios for 2050 are projected on the current farming systems, their impacts are assessed and options for adaptation are explored. This is a traditional way of assessing climatic change impacts and identifying adaptation measures. The time horizon 2050 is taken to put climatic change impacts and adaptation measures in the context of other drivers that affect farming, i.e. markets, policies, technological development and structural change. The main research questions are:

- What are climatic change (time horizon 2050) impacts and adaptation strategies projected on the current (2010) arable farming systems in Flevoland? – 2010 analysis
- What is the relative importance of climatic change (time horizon 2050) impacts and the effect of adaptation strategies for future (2050) arable farming systems in Flevoland vis à vis other major driving factors for agricultural development (markets, policies, farm structure, technology)? 2050 analysis.

2.4 Experimenting: crop level

As crop growth is directly dependent on temperature, radiation, precipitation and CO₂ concentrations, climatic change impacts mainly manifest at the crop level. The yield changes that are due to climatic change, can be calculated with crop growth simulation models (such as here, the WOFOST model). Questions that can be addressed in such climatic change impact studies (for 2050), are described in Chapter 4:

- What is the impact of climatic change (incl. changes in atmospheric CO₂ concentration) on potential and water-limited crop yields?
- What is the difference in impacts among different crop types?
- What is the difference in impacts between different climatic change scenarios?
- To what extent can generic adaptation strategies such as 'changing sowing date' and 'changing cultivar' (i.e. cultivars adapted to more southern climates) reduce the impacts or increase the benefits of climatic change?

In practice, potential or water-limited yields are not achieved due to other limitations or reducing factors causing a yield gap. Furthermore, climatic change is not the only factor that results in changes in crop yields. Therefore, Chapter 5 puts the impacts of climatic change in context (all for 2050):

- What is the combined impact of climatic change, genetic improvement and management change (genetic improvement and management change jointly stand for technological change) on actual crop yields in the different scenarios?
- What is the relative impact of climatic change on actual yields?

Problematic with crop simulation models is that they mainly address gradual climatic changes (i.e. changes in average conditions) and their effects on product quantity, and that they cannot assess all types of adaptation strategies. In practice, climatic extremes may have more impact than a gradual climatic change. At the same time, many adaptation strategies to such extremes are available and for farmers these may be more relevant. Therefore, Chapter 6 assesses the impacts of climate extremes on crop production, the frequencies of these extremes for the current situation and changes towards the future, and based on the major climate risks, adaptation strategies are identified. Main questions include:

- What are possible weather induced limitations for operational farm management?
- What are the main climate factors influencing crop production and what is the expected damage?
- What is the current frequency of, for crop production, climate extremes and what are the projected changes in these frequencies?
- What are the major climatic risks and opportunities related to the change in frequency of climate extremes?
- What are relevant adaptation strategies for the major climate risks, and what are indicative annual and investment costs to implement these strategies?

The assessment in Chapter 6 is based on literature, expert knowledge and stakeholder discussions. The main result is an overview of major climatic risks and relevant adaptation strategies, but quantifications are not accurate. Therefore, more data have been collected to investigate the impacts of climatic risks in more detail and more quantitatively in Chapter 7. Chapter 7 addresses:

- How can we quantify the impact of climate extremes on crop production?

Together, these four methods provide a good picture of the impacts of climatic change on crop production, the most relevant adaptation strategies and their effects. An integration of their results is required for the farm level analysis.

2.5 Experimenting: farm level

Different models at different time horizons are used to assess climate change impacts and identify adaptation strategies at the farm level (Chapter 8, 9, 10). Chapter 8 describes the Farming System Simulator (FSSIM), which is a bio-economic farm model using mathematical programming. FSSIM can be applied with the Positive Mathematical Programming (PMP) approach, to reflect the observed behaviour and responses of farming systems, or with a normative approach, considering income maximization and/or other objectives such as minimization of labour use or nitrate leaching. Chapter 9 describes a method called the 'Fixed cropping pattern method', which can be applied for the same farm types and with the same input data. Instead of projecting changes in cropping patterns based on an objective function and constraints, this provides a simple and transparent method to show the (relative)

impacts of climatic change, technological development, policy and market changes along with farm structure on farmer's income.

Chapter 10 describes the use of Data Envelopment Analysis (DEA). Often farm models like FSSIM are applied for average farm types, using average data on inputs and outputs for these farms. For most FSSIM applications, 'simple survey' data based on expert knowledge were used, which were collected in the SEAMLESS project (Van Ittersum et al., 2008) and were based on expert knowledge for a region, characterizing the inputs-output coefficients of the most common activities. DEA provides an approach that can capture data on inputs and outputs from actual and individual farms. By using these data, it can recover current technical relationships (the current production functions) and rank individual farms based on their capacity to convert inputs into outputs. Farms that are superior with respect of converting inputs into outputs form the production frontier, while other farms are enveloped by this frontier. Based on the technical relationships and without any behavioural assumption (e.g. profit or utility maximization), DEA can furthermore suggest realistic farm level adaptation strategies to these farms. These are strategies to adapt to current conditions, including climate, markets and policy, to improve farm performance. When the input-output relationships of future agricultural activities are defined, realistic adaptation strategies for 2050 can also be identified for future farms. DEA can be coupled to a bio-economic farm model like FSSIM, where behavioural assumptions can be made to identify optimal strategies of farmers. DEA is thus a substitute for 'simple survey' data that are averaged per farm type, and besides, can answer additional questions. The main difference between using FSSIM with expert knowledge from 'simple survey' data and with DEA is that when using expert knowledge more specific agricultural activities and adaptation strategies can be included (rotations linked to management), whereas DEA depends on data available for actual farms. With DEA the most efficient rotations or production methods (in terms of input-output relationships) result from the analysis, and only these are included as input-output relationships in FSSIM.

2.5.1 Experimenting: farm level - 2010

A farm level assessment is performed for current farms and their activities (2010), but assuming climatic conditions for 2050. This is done to explore effective adaptation strategies that are available for current farms if a change in the climate occurs. Even with a gradual change in climatic conditions extreme events and extreme years can occur already now (as experienced in 2003; Schar et al., 2004).

Two farm level assessment methods are used for the 2010 assessment (Figure 2.1): i) DEA + FSSIM and ii) Expert knowledge + FSSIM. DEA + FSSIM uses data on 27 actual farms in Flevoland as a basis for the assessment, whereas Expert knowledge + FSSIM uses data for typical farms using the 'simple survey' data.

Future climate conditions as based on respectively the A1 and B2 scenarios for 2050, are used, whereas the other conditions are assumed to be as in 2010. As inputs for these farm level assessments, input-output relationships for current and alternative activities need to be identified. As mentioned above, the current activities (base year simulation) are based on either DEA or on expert knowledge. When assessing the

impacts of an extreme climate year (baseline assessment), input-output relations for these activities will change. Changes in crop yields are based on changes in actual yields (Chapter 5), but only considering the changes in climate (Chapter 4), not in genetic or technological improvement. Impacts of extreme climate events on crop yields (Chapter 6) will also be considered. Lower yields may lead to higher prices and vice versa and hence, co-variation of yields and prices is considered.

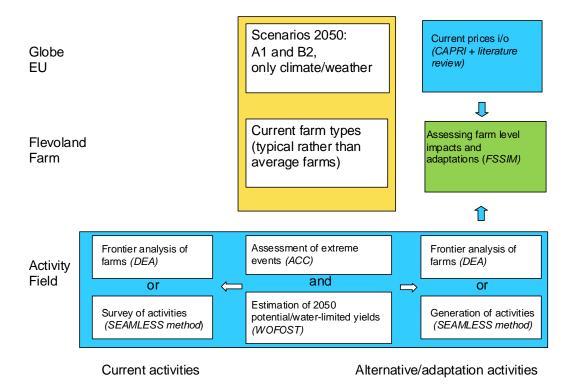


Figure 2.1 Methodologies for farm level assessment in 2010

Assessing the impacts of adaptation strategies and identifying which will be selected by different farms, requires the quantification of specific strategies in terms of input-output relations. These include crop level adaptation strategies (Chapter 6), but also include new crop rotations or strategies at the farm level. The methods provide answers to different questions, for instance:

DEA +FSSIM:

- Which farms are currently technological forerunners with respect to converting inputs into outputs?
- What are realistic farm level adaptation strategies to adapt to current conditions, including climate, market and policy to improve farm performance, i.e. what should be changed in terms of inputs and outputs?
- Will the selected adaptation strategies be different when climate conditions are different, and what is their impact on total outputs?

When using FSSIM, it is assumed that farmers aim to maximize profits. This will indicate the strategies that will increase their profit. It is also possible to include other objectives, which will likely result in other effective strategies.

Expert knowledge + FSSIM:

- What is the impact of climatic change on cropping patterns and associated economic, environmental and social indicators, considering different objectives of farm types?
- Which adaptation strategies are effective and therefore selected on different farm types, considering their objectives, and what are the impacts?

The main difference between the two methods (DEA+ FSSIM and Expert Knowledge + FSSIM) is related to the definition of the current production technology. The DEA+ FSSIM method uses individual farm data to recover the current technology capturing variable returns to scale among individual farms, whereas the Expert knowledge + FSSIM approach uses discrete activities specified by the experts of the region and by assuming constant returns to scale. The methods are to some extent complementary and they allow addressing different questions.

2.5.2 Experimenting: farm level, 2050

As climatic change is expected to have significant impact in the longer term in association with other drivers of change, a farm-level assessment is done for the year 2050 with the images of future farms (Chapter 3). The main method used (Figure 2.2) is the 'Fixed cropping pattern method' (Chapter 9), but additional explorations will be done using DEA+FSSIM (Chapter 10). Towards 2050 many developments will take place simultaneously, and technological development cannot easily be separated from adaptation. It is assumed that the technological development (i.e. crop genetic and management improvement) includes adoption of the most effective crop level adaptation strategies.

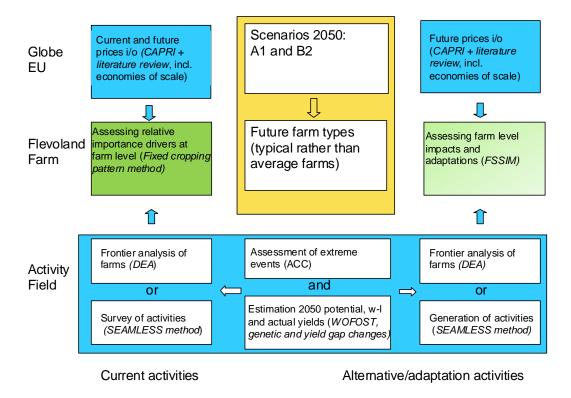


Figure 2.2 Methodologies for farm level assessment in 2050

Main questions answered with the fixed cropping method are:

- What is the the relative importance of climatic change, technological development, markets and policy changes for the farmer's income on the main farm types, if the cropping patterns are not changed?
- What is the impact of farm size and specialization on the farmer's income, if the cropping patterns are not changed?

The A1 and B2 scenarios for 2050 are used to project changes, not only with respect to the climate, but also for e.g. farm structural change and technological development. For estimating future actual yields, estimates on potential yields are combined with estimated improvements in the crop's genetic characteristics and its management (Chapter 5). Future prices are estimated by the agricultural market model CAPRI. Effects of economies of scale and farmer's technical efficiency (e.g. effects of specialization on labour use efficiency), which determine the differences between different farm types, are estimated from the base year DEA application in 2010.

Although the adoption of crop level adaptation strategies cannot be separated from technological development, it is still interesting to assess the most effective farm level strategies. DEA + FSSIM is used for this. The method is similar to for 2010, but yields and prices are adapted to the A1 and B2 scenarios for 2050. Furthermore, alternative activities are included that reflect relevant adaptation strategies. Main questions answered with DEA + FSSIM are:

– What are realistic farm level adaptation strategies considering a range of possible changes towards 2050, and what are the impacts on inputs and outputs?

2.6 Learning: integrating and iterating knowledge

The last phase includes learning, evaluation and monitoring. During the experimenting phase, internal evaluation takes place continuously, as different methods give answers to different questions, and interactions help to improve assessments. Outputs are also evaluated with stakeholders: do the modelling results reflect what will likely happen in reality? This stage potentially provides the basis for a next ISA-cycle, leading to a reframing of the shared problem perception (e.g., climatic change may be more or less important than expected), and adjustment of the sustainability vision and related pathways, and reformulation of experiments to be conducted. Images of future farms can be further refined based on the crop and farm level simulations.

In conclusion, the final aim of this research is to assess the impacts of climatic change on farming in Flevoland, in the context of other developments, and to explore adaptation strategies for farmers with different objectives. The results will contribute to a viable and sustainable agricultural sector in the future.

3 Development of scenarios of farm structural change towards 2050

3.1 Introduction

Farms in the Netherlands have been changing considerably during the last few decades due to the changing context of the economic and social environment in which they were embedded. Those changes affected not only the total number of the farm population, but also accounted for new farm types through structural changes. Structural changes fall into the category of strategic, medium to long-term investment decisions to fundamentally change farm size, specialization or production intensity (Zimmermann et al., 2009). Since the impacts of climatic change will be relatively minor in the short term, assessments are done at a long time scale (2050 in present study), when climatic change will likely have large impacts. A long time horizon is necessary for the strategic anticipation of changes that will take place in the future. By that time one would have to take into account that the farms are not the same as the current ones anymore: they evolved due to adaptation to changing climate, policy and markets. While studying farm structural change we need to be clear about the definition of this concept: at a regional scale farm structural change is an adaptation strategy to climatic change and other important drivers by itself, while at a farm scale it is setting the context for other adaptation strategies. Such strategies to climatic change, as adjustments in agro-management operations or new technologies, have to be designed for the future farms which are a result of certain structural changes.

The scenario approach has become a popular tool to be used in agricultural studies with the aim to assess impacts of certain changes on the adaptive capacity of a system. Regarding the possible trends in market developments and policy settings, detailed scenarios have been developed for the future of rural Europe (Westhoek et al., 2006). The hierarchical scenario development approach to arrive at scenarios at regional level has been performed in several studies (Abildtrup et al., 2006; Audsley et al., 2006; Dockerty et al., 2006; Rounsevell et al., 2003). These works, however, were focused on modeling spatial distribution of agricultural land use at regional and the EU scale under global environmental (climatic change) and EU policy drivers and did not consider farm structural changes induced by the driving forces. Reidsma et al. (2006) made an attempt to project change in intensity in farm types in order to assess changes in agricultural biodiversity, but this study lacked other farm structural characteristics besides intensity. Possible farm structural changes as a result of adaptation to policy drivers were investigated in the study on the regional and farm scale responses to future CAP by Piorr et al. (2009). It was concluded that different farm types develop different strategies of adaptation to the changing policy context. Climatic change and other drivers having possible impact on farm structural change at regional level (i.e. water and landscape management, regional planning) were not included into scenarios. Development of hierarchically consistent scenarios of farm structural change at farm and regional level defined by most possible climate and

socio-economic developments and sharpened by other regionally and locally important factors has not been performed previously. We need these scenarios to assess adaptation strategies to climatic change in the long term. Ultimately, these scenarios can be re-used in other regions in the Netherlands or elsewhere in Europe.

The actual responses of farms to different drivers of change, and particularly to changing climatic conditions within the context of policy and market developments are likely to be diverse. To account for the heterogeneity of farm level responses, but in the mean time reduce the total number of farms in the regional farm population, a farm typology was developed. The use of a farm typology for assessment of impacts of different agricultural and environmental policies on farm structural changes was investigated by Zimmermann et al. (2009). To perform an integrated assessment of EU agriculture a farm typology was developed by Andersen et al (2006), which was based on the European standard grouping of farms from the EU dataset Farm Accountancy Data Network (FADN). An important dimension, however, that would indicate the possible direction of structural change with respect to multifunctionality was missing. Through the new typology proposed in the report which includes a dimension of farmers objectives/farming styles farm structural changes can be assessed which will be further translated into images of farms of the future. The use of a typology methodologically complements the scenario approach in order to perform an integrated assessment of farm structural change at regional level.

For the purpose of our study we see more utility in use of a normative rather than in a positive approach for exploration of possible states of the future. A positive approach is aimed at predicting the actual behaviour of a farmer, and is more suitable for assessments of policy impacts, as done by Zimmermann et al. (2009). A normative approach aims to identify the possible alternative developments for arable farming in a region, considering certain objectives. By using a normative approach, images of future farms are developed, and it is described what ought to be done in order to stay viable in the changing context of climate, market and policy in the future 40 years.

The province of Flevoland in the North of the Netherlands with large scale intensive arable farming as the main type of agricultural activity has been chosen as a case study for the scenario development of farm structural change. Contribution from the stakeholders from the region (farmers and policy makers) was an important element of the study.

3.2 Description of methodology

3.2.1 Deriving images of future farms

The procedure to derive the images of future farms in 2050 includes several steps (Figure 3.1).

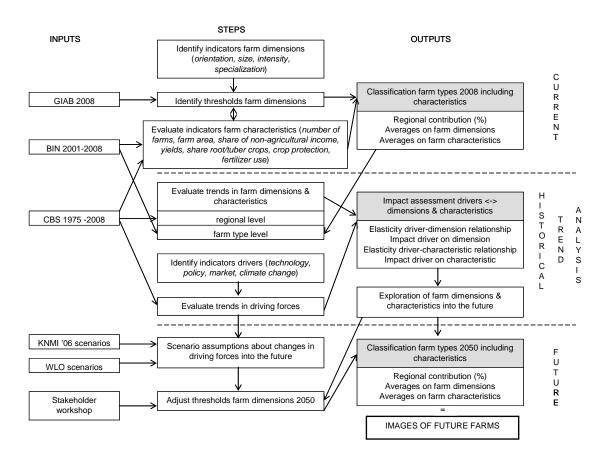


Figure 3.1. Step-wise approach to derive images of future farms

As the first step, regional data were used to adapt the farm typology developed for the European context (Andersen et al., 2007) to Flevoland. One dimension, orientation, was added and thresholds were adapted to reflect the regional situation. This farm typology was used to get a picture of the current farm population and its characteristics.

Secondly, a historical data analysis on developments in arable farming systems in Flevoland has been performed (section 3.2.3). The trends in past developments were analyzed and projections for the future in case of business-as-usual scenario (autonomous trends) were made by data extrapolation from the Dutch national agricultural census. The historical data analysis made it possible to observe the driving forces that contributed to farm structural changes and to evaluate their relative importance. The relative importance of driving forces has been assessed through indicators attached to each driver as suggested in section 3.2.3 (Table 3.2). Based on that it was possible to make an estimation of the influence that the driver has had on farm structural characteristics and to explore its potential impact in the future.

Subsequently, the scenario assumptions about changes in the driving forces of farm structural change from the studies elaborated at higher hierarchical levels (global and the Netherlands) were reconsidered for Flevoland. To be able to foresee the situation

of agriculture in the future, and more precisely arable farming in Flevoland in 2050, we used more detailed regional information from the study of (Riedijk et al., 2007). The farm typology was used for capturing the heterogeneity of arable farms in Flevoland and reduction of the number of farms under investigation as it could directly point at diversity of types and strategies of farm households and their differentiated performances.

Scenario assumptions and historical trends were discussed with stakeholders. Farmers, representatives of water boards, local policy makers and researchers shared their view on possible structural changes in arable farming as adaptation strategies to future market, policy and climatic change. They discussed future changes in important farm characteristics as farm size and specialization in different scenarios. Besides, they gave critical comments on the drivers of structural change.

The exploration of farm structural characteristics in the future under different scenario assumptions, the farm typology and information obtained during stakeholder discussions have been used to describe images of future arable farms in Flevoland.

3.2.2 Data sources

The major data source regarding farm structural characteristics in Flevoland is the Agriculture and Horticulture Accountancy Data Network which contains a sample of the farms and holdings from the Dutch Agricultural Census (CBS). The accountancy data was used for analysis of agricultural development in Flevoland over the period 1980-2008: number and size of arable farms, area of most important crops in rotations, dynamics in yields and prices. Due to the fact that Flevoland is a very young province (officially established in 1986), disaggregated historical information (before 1980) for Flevoland is not available. Information on prices and yields for a longer time horizon were obtained for the whole of the Netherlands.

The Agricultural Economic Institute (LEI) provided farm individual data from BIN (Farm Information Net) for Flevoland for the years 2001-2008. The data included disaggregated management information on inputs (fertilizers, crop protection and other used materials), costs of inputs and outputs, farm family income, subsidies, labour inputs and farm general characteristics (economic size, area). These data were used to assess differentiated performance of arable farms in Flevoland grouped by a farm typology and to quantify the impacts of technology on farm structural change.

Another important database was the Geographical Information System for Agricultural Businesses (GIAB). Farmer accountancy data available in GIAB was used for quantification of the farm typology and included the following parameters: farm economic size, farm area, farm type, amount and character of alternative activities on a farm, share of total farm income from alternative activities. Stakeholder interactions were very informative as well. Discussions with farmers, representatives of water boards, local policy makers from Flevoland and researchers were beneficial for understanding future visions on the farm structural development in the region.

3.2.3 Agricultural development in Flevoland

We first analyzed farm structural changes that occurred in the period 1980-2009 (for some indicators in the period 1975-2009) and the factors that contributed to these changes. First, a simple trend analysis of dynamics in several indicators of structural change (farm characteristics) in arable farming in Flevoland in the period 1980-2009 was performed. The analysis included the following indicators: 1) number of farms, 2) farm size (economic and area), 3) share of non-agricultural income, 4) increase in yields for major crops (winter wheat, potato, sugar beet), 5) share of root/tuber crops in rotation.

Next, the agricultural policy evolution and consequent developments of market were analyzed on the basis of price and subsidy changes for major crops (winter wheat, sugar beet, potato). Changes of regulations in the sphere of rural development and nature protection were considered in the analysis as well.

In the following step, identification of major driving forces that historically contributed to farm structural change has been performed based on the historical farm data analysis and the work of Zimmerman et al. (2009). The influence of each driver on farm structural characteristics was assessed with the help of a selected indicator per driver: prices as indicator for market, subsidies for policy, yields and/or production factor for technology. The indicators were chosen based on a literature review and available data.

The results of the historical data analysis will be combined with scenario assumptions regarding changes in driving forces in the future and their influence on farm structural characteristics (section 3.2.5) and information obtained during stakeholder discussions (section 3.2.6).

3.2.4 Farm typology

To capture variability of arable farming systems in Flevoland and indicate the direction in which they would most likely change in the future, a farm typology proposed by Andersen et al. (2007) was further elaborated. This typology is based on a combination of three different dimensions: size, combined specialization and land use and intensity. Size of farms is measured in European Size Units, or ESU (1 ESU equals to 1200 Euros). Intensity is calculated as output in Euro/ha. The dimension of specialization has been combined with the land use. The most important farm types in Flevoland according to this typology are large high or medium intensive arable specialized crops and large high intensive arable others. The farm typology was developed with the objective to evaluate agricultural systems at the EU level using farm management indicators. For the regional application, however, the typology is too general. The thresholds in the EU level typology were defined based on differences at the EU level and considering all types of farming, while for arable farming in Flevoland these do not give enough distinction.

A new dimension of farmers' objectives or farming styles has been introduced in the regional farm typology to provide better insight into farmers' decision making and allow incorporating these decisions into bio-economic models for the assessment of adaptation strategies to climatic change at farm and regional level. Farmers in the Netherlands are often seen in connection to the management strategy or farming style they follow. By farming styles we understand coherent sets of strategic notions about the way in which farming should be practiced, as defined by van der Ploeg et al. (2009). We distinguish three farm types based on their major objectives: production oriented, entrepreneur oriented and nature conservation oriented. These farm categories are recognized by Dutch policy makers. They mention farmers that invest in innovative sustainability, farmers that are focused on landscape management, farmers that invested in an optimal farm where they produce food only and farmers that are from the less suitable areas (Dokter and Oppewal, 2009).

To quantify the dimension of farmers' objectives we used share of income from alternative activities and the number of these activities on a farm, based on farm accountancy data provided by the GIAB database. The majority of arable farms in Flevoland are *oriented at primary production*. These are large capital intensive households producing for the EU and world market. Crop revenues combined in many cases with off-farm employment are the most important sources of income for these farms, whereas the share of income from alternative activities is less then 10%.

Next to traditional production of food, feed and fibers, other functions of agriculture from the societal, cultural and landscape perspectives have been emphasized by Dutch Ministry of Agriculture (Venema et al., 2009). Over the last decades farmers were inventing new ways of integrating farming activities in rural livelihood to adapt to policy, institutional and market adjustments and secure additional income through multifunctional agriculture (van der Ploeg et al., 2009). To account for other functions agriculture can provide to a society an entrepreneur oriented type of farmers is included into typology. These farmers diversify their incomes from alternative societal functions of agriculture: more than 10% of farm income is provided by such activities including sustainable energy production, keeping goods or animals, processing of agricultural products, recreation and care farming. Selling the farm for housing and providing work loan for third parties are not considered enough for a definition of an entrepreneur farm type if being the only alternative activities on a farm, since they do not require additional capital or infrastructural investment. A farm is also considered entrepreneur oriented when it gets less then 10% of income from at least two alternative activities besides selling farm for housing and providing work loan for third parties. In case the alternative source of income comes from a nature or landscape conservation practice, a farm belongs to the nature conservation oriented type.

Nature conservation farmers represent a separate farm type due to the significant role nature conservation plays in Dutch agriculture with respect to societal functions. In the Netherlands nature protection schemes are the widely acknowledged form of farm multifunctionality, whereas in France, for example, this notion will include broader entrepreneur functions, such as product processing on farm and direct selling (Daniel and Perraud, 2009).

Also other dimensions of the farm typology are operationalized by the information available from GIAB. Intensity is measured in NGE per ha. An NGE is a national size unit, representing gross income from cultivation of a certain crop or from keeping a certain animal (CBS). Farms with $0.4 - 2 \, \text{NGE/ha}$ belong to a category of medium intensive. Farms with intensity higher than $2 \, \text{NGE/ha}$ are high intensive. These thresholds are linked to the EU typology of Andersen *et al.* (2007) in order to place the arable farms in Flevoland in the EU context. For the same reason specialization was defined according to the national agricultural census, that supplies data to FADN. For the situation in the future (2050) the thresholds of the typology have been adjusted based on the trend analysis, scenario assumptions and discussions with stakeholders. Consequently future farm types for Flevoland will be described based on this typology.

3.2.5 Scenario development: translating global and EU drivers to Flevoland

Lack of knowledge and unpredictability of developments in states of future climate, policy and markets make us choose a scenario approach as an appropriate method to assess the structural changes that arable farms in Flevoland may undergo. Existing trends in driving forces may not continue into the far future; using scenarios is a favoured approach when the uncertainties are high, and some causality is known, which allows estimating possible states in the future. The most important drivers have been selected for the scenario development. Ultimately socio-economic conditions and climatic change are crucial for farm structural changes in a long time run and therefore they determine the selection of scenarios most suitable to answer the research question.

On the subject of climatic change, there are scenarios available which are developed by the KNMI to anticipate possible climatic change in the Netherlands (van den Hurk et al., 2006). These scenarios are based on global and regional climate models and can diagnose increase in temperature and change in air circulation for the Netherlands for the long time horizon: 2050 and 2100. For the purpose of this study the relevant changes in climate variables are considered for the period 1990-2050, as given in Table 3.1.

Table 3.1 – KNMI climate scenarios for 2050 (van den Hurk et al., 2006)

Scenario	Global temperature increase	Change of atmospheric circulation
G	+1°C	Weak
G+	+1°C	Strong
W	+2°C	Weak
W+	+2°C	Strong

Regarding possible trends in socio-economic developments, detailed scenarios have been developed for the future of rural Europe (Westhoek et al., 2006). Van Drunen and Berkhout (2008) adopted the above mentioned scenarios for the situation in the Netherlands. They propose the following set of scenarios: A1 Global economy; B1 Strong Europe; A2 Transatlantic Market; B2 Regional Communities. These scenarios are based on the IPCC approach. They also assume that climatic change will not have significant influence on agricultural systems in Europe before 2030.

An important part of the methodology was to find the best approach to combine climate and socio-economic dimensions in a workable set of scenarios that can capture the uncertainties in development of major driving forces and show the possible directions of farm structural change as a response to those drivers. There are several examples in literature on possible options for scenario choice and scenario combinations. A reduced number of socio-economic scenarios was proposed by Vandermeulen et al. (2009) for assessment of farmlands of tomorrow. The study on the future of sustainable agriculture in four rural areas in the Netherlands was also using a reduced number of socio-economic scenarios (A1 and B2) for the same reasoning: to have the most contrasting future development paths (van der Kolk et al., 2007). A climate dimension, however, was not considered in these studies. Combined socio-economic and climate scenarios were proposed by Henseler et al. (2009). The first and more economically and globally oriented A1 scenario included significant temperature increases. The second and more environmentally and regionally oriented B2 scenario was assumed to match with a moderate temperature increase. This approach is suitable when it is important to have a limited or workable set of scenarios.

For the purpose of our study we chose the scenario combination, where the economic future is fixed, or more consistent (A1 and B2), and climate brings more variation within the two economic futures making following combinations possible: A1W/W+ and B2G/G+. In this case it is the plurality of social-economic future that is assumed to have biggest influence on the farm structural change, and climate variation is also important here. By doing this, we also imply a dependency between climate situation and socio-economic situation. Different rates and directions of economic development would cause difference in degree of climatic change. Average global temperature raise is assumed to be highest for the A scenario family and is lowest for the B scenario family. This aspect is particularly important when considering synergy between climate adaptation and mitigation.

The work of Riedijk et al. (2007) has been used to determine the future development of the drivers of farm structural change previously identified in section 3.2.3 for two different scenarios compared to autonomous trends.

Since the study is focused on assessing farm structural change in the uncertain climate, policy and market future captured in scenarios, it is important to reference scenarios in line with their purpose. Scenario based on Global economy A1 and Significant climatic change W/W+ is labeled "Intensified climate challenge" or ICC, as scale enlargement and intensification will be the main directions of farm structural changes in the situation when the impacts of climatic change will potentially be

higher. The scenario of Regional communities B2 and Moderate climatic change G/G+ is named "Multifunctional moderate climatic change" or MMCC.

3.2.6 Stakeholder interaction

The input from stakeholders was crucial for evaluating and further defining the visions of the future farms. A stakeholder workshop was organized in the study area (Swifterbant, province of Flevoland) on the 1st of March 2010. The participant list included researchers, farmers, representatives of farmer organizations and an agricultural financial analyst (in total 10 people). The central part of the workshop was an interactive session aimed at revealing major adaptation strategies to climate, market and policy change for arable farming in Flevoland in the future for two contrasting scenarios socio-economic development and climatic change in 2050. The participants were asked to write down the most important adaptation strategies, one of them being strategy to climatic change. The adaptation strategies could be from the categories including, for example, market opportunities, farm size, technology and crop choice (specialization). Stakeholders were also asked to prioritize the strategies, so that a link to a relative importance of driving forces of farm structural change could be made. The results of the exercise were discussed at a round table panel afterwards. Quantitative and qualitative farm characteristics named by the stakeholders, as well as their critical comments on scenario assumptions, were used in deriving images of future arable farms in Flevoland in 2050 under two contrasting scenarios.

3.3 Short example of the application of the Methodology

3.3.1 Images of future farms

Scenario assumptions about changes in driving forces in the future, analysis of outcomes from related modeling studies of the future, historical trend analysis on farming system evolution using agricultural census data and stakeholder consultations resulted into a regional and farm level vision of arable farming in Flevoland towards 2050 under two contrasting scenarios. The dimensions of the farm typology (objectives, size, intensity, specialization) have been used as indicators to assess farm structural change. The direction and magnitude of change of these indicators determined which farm types would be more likely dominating in each of the scenarios and be the desired visions on farms of the future in Flevoland (Table 3.2). By these we mean possible alternative developments for arable farming in Flevoland, considering their ability to stay viable in the changing context of climate, market and policy.

To arrive at the distribution pattern of different farm types in 2050 certain transition rules have been applied. These rules accounted for changes between the farm types in absolute numbers and percentages from utilized agricultural area in two scenarios. The set of rules for the ICC scenario includes the following: a) small farms stop

farming; b) intensification (shift from medium intensive towards high intensive farms which is accompanied by shift in specialization (towards flower bulb and vegetable farms); c) diversification (shift in objective dimension towards entrepreneur and nature conservation farms); d) scale enlargement. For the MMCC scenario the set of rules comprises the following: a) still place for small farms; b) limited intensification compared to ICC scenario; c) higher rate of diversification compared to ICC scenario. The above mentioned rules have been applied to the current factual farm counts and percentages of utilized agricultural area they occupied (GIAB 2008) to arrive at the situation in 2050. The control values (i.e. total values for 2050 in both scenarios) were taken from the Riedijk et al (2007).

Table 3.2 – Classification farm types 2050

					2008		2050 ICC		2050 MMCC	
n	Object.	Size	Int.	Specialization	count	%UA	count	% UAA	count	% UAA
1			med	other arable/specialized arable	43	0.5	0	0	22	0.2
2		small	mea	vegetables	4	0.04	0	0	8	0.08
3			la i aula	other specialized/specialized arable	85	2	0	0	0	0
4		medium	high	flower	8	0.05	0	0	0	0
5		medium	med	other arable/specialized arable/other specialized	257	8	0	0	60	4
6	unus altrestis u		mea	vegetables	14	0.4	0	0	20	0.8
7	production	large	high	flower	12	0.2	0	0	10	0.2
8				other specialized/specialized arable	92	5	150	12	0	0
9			med	other arable/specialized arable/other specialized	243	17	0	0	90	6
10			high	flower	51	3	100	8	0	0
11		very large	nign	other specialized/specialized arable	48	6	100	18	0	6
12			med	other specialized	52	8	0	0	30	3
13	entrepre-	medium	med	other specialized/specialized arable	30	1	0	0	120	9
14	neur	large	med	other specialized/specialized arable	51	4	130	11	180	13
15		lavna	high	other specialized	3					
16	nature	large	med	other specialized	8	2	20	4	60	6
17	nature	vary large	high	other specialized	5	2				
18		very large med		other specialized	3					
				Total	1009	56	500	53	600	48

To stay viable in the future uncertain situation of changing climate, policy and market the above mentioned farm types should implement adaptation strategies. At regional level these strategies are put into practice through farm structural changes, which are different per scenario. In the ICC scenario increase of economic size and intensity of a farm can secure income through the scale effect. Specialization will be determined by climate robust crops with high gross margins combined with less profitable crops that are necessary for maintaining soil quality (i.e. winter wheat). In the MMCC scenario a stable farm income can be achieved through provision of alternative

functions to the society. The overall adaptation strategy is heading towards multifunctionality. Intensification of arable production will be limited by strong environmental regulations, as a consequence farms will have moderate economic size. The climate will not be threatening arable crops to the extent of ICC scenario.

In the *ICC scenario* the most common farm types in Flevoland identified in Table 3.2 are described below including farm characteristics:

Production oriented large high intensive specialized crops is the dominating farm type. It is an efficiency-based, cost-oriented farming model. Such a farm is a large scale capital intensive holding with an average farm size of 60-135 ha and an output intensity amounting to 3.5 NGE/ha. The share of rented land in the total amount of utilized agricultural area is considerable (up to 75%). The farm is operating in close collaboration with neighbouring farms in terms of management operations and (partial) processing of the products. Technical advances on such farms are the attributes of precision agriculture, which contribute to high labour efficiency and productivity. The farms produce mostly onion, seed potato and winter wheat. Sugar beets cultivation disappears due to the high competition on the global sugar market. Flevoland guarantees its position as a leading export of seed potato by maintaining extra high quality of the product. The quality issue remains important for all groups of products, driven by consumer preferences. Efficient arrangement of processing of products on the farm makes favourable conditions for retail sales. In general, the production-processing-delivering chain is high technically efficient on these farms. The major "survival" strategy for this farm type is orientation on the world market where it has guaranteed its niche through delivering high quality products (consumption and seed potato, flower bulbs) and innovative technology. Enlargement of a farm size through land rental schemes and cooperation with other farmers can provide benefits of economy of scale.

Entrepreneur oriented high intensive specialized crops is the second largest arable farm type in Flevoland. Besides cultivation of traditional market crops like seed potato and winter wheat, the farm gets stable income from multifunctional activities: sustainable energy production, keeping goods or animals, processing agricultural products and selling farms for housing. The farm structural characteristics of size, intensity and specialization can be identical to the production oriented farm. Nevertheless, due to a stable share of income from alternative on-farm activities the intensity might be lower. Besides, farms might not need to maintain large areas through rental schemes and cooperation linked to economy of scales. The direction of a farm development is in deepening of functions and expansion as defined by Venema (2009) rather than extension. These additional services are supplied to the society using the available production factors on the farm. These farms are better integrated into the regional landscape and are the examples of merging of rural and urban area.

Nature conservation oriented large medium intensive specialized crops are farms that get stable share of income from landscape- and nature conservation and other activities important for the society (care farming, education, recreation). Farmers from this group are diversified, environmentally-friendly farmers.

In the *MMCC scenario* the farms types look as follows:

Production oriented high intensive specialized crops is a large high intensive farm which often produces biologically. The farm size increases considerably (up to 60-120 ha), but on average remains a bit smaller that in the ICC scenario. The output intensity is kept to the current level of 1.8-2 NGE/ha by strict environmental legislation aimed at limiting growth potential of agriculture. The share of rented land varies between 50 and 75 %. Cooperation between neighbours is strongly supported by regional development policy. Technological progress is focused on environmentally friendly production means (environmentally beneficial technology) and development of biological crop varieties. The balance between consumer demand and production supply is regionally based. The consumer preferences result in promotion of regional products. Traditional crops dominate in arable farm specialization: consumption potato, seed potato, winter wheat, sugar beet. In the MMCC scenario this farm type is expected adjust to the regional/local market situation and consumer behaviour, oriented at sustainably produced local products. A farm becomes a part of a local market chain (retail, direct sells from a farm, local supermarkets). Clean and energy saving technologies get priority in the production circle on a farm.

Entrepreneur oriented large medium intensive specialized crops becomes the most typical farm type in Flevoland which successfully combine food production with multifunctional activities on the farm. For most of these farms share of income from alternative activities will be close to 50 % of whole farm income. Cropping pattern and production means on these farms have inherited characteristics of production farms in the same scenario.

Three times as many farms as compared to ICC scenario will be doing *nature* conservation in the MMCC scenario.

3.4 Discussion of potential and limitations of the Methodology

The proposed methodology of assessment of farm structural change towards 2050 as the result of climatic change, policy evolution and market development has its potential and limitations.

Although the main issue under investigation was the assessment of farm structural changes due to climatic change, socio-economic factors were assumed to play potentially at least equal role. In this respect the methodology has potential to place climatic change among other drivers, or to show relative importance of climatic change compared to other drivers. Another strong point of the methodology is that it includes the attempts to quantify relations between farm typology dimensions and drivers of structural change based on the empirical data evidence.

Stakeholder involvement in the study was very beneficial. The incorporation of stakeholder's input in the study reflects the recognition of a plurality of valid sources of knowledge and the search for integration to produce increasingly relevant information outcomes. As Jasanoff (2004) argues, this co-production of knowledge constitutes a way to avoid strategic omissions.

Among the limited factors of the proposed methodology to be mentioned is the fact that in the end the final interpretation of the data analysis and information obtained from stakeholders is made by the researcher. For example, the translation of impact of drivers on farm structural changes is quite arbitrary. There is no guarantee that if all steps of the methodology would be completed by another research group they would arrive exactly at the same outcomes. This fact points at limitations to the replicability of the method.

4 Calculation of the potential yields for different climatic change scenarios for 2050 in Flevoland

4.1 Introduction

Actual yield levels of the main crop types in Flevoland in 2050 are required for the AgriAdapt analyses for different scenarios in 2050. These actual yields in 2050 are partly based (as described in Chapter 5) on simulated potential yields for different climate scenarios for 2050 in Flevoland. Such potential yields for the main arable crop types that are cultivated in Flevoland, The Netherlands, have been simulated for current conditions and next, for future conditions as based on four climatic change scenarios. These simulations have been done with the WOFOST crop growth model. The effects of management adaptation on crop yields under future conditions have also been calculated.

4.2 Description of Crop growth model WOFOST

WOFOST is a crop growth simulation model that calculates crop growth and production on a daily time step. The model uses as inputs daily weather data, soil characteristics, crop parameters and information about management practices (i.e. sowing density, planting date, etc.). After subtracting the respiration losses for maintenance of the crop from the calculated daily gross assimilation rate, the remaining assimilates are partitioned over the different plant organs (i.e. roots, stems, leaves and grains) as a function of the crop's development stage. This stage is calculated by integrating the daily development rate over time, which rate is a function of temperature. Assimilates are finally converted into structural plant material taking into account the respiration losses for this conversion. These processes that determine biomass accumulation and its distribution over the crop organs, are simulated from sowing to maturity on a hectare basis.

Growth simulations for arable crops are done (Boogaard et al., 1998) for two production situations: the potential and the water-limited. The potential situation is only determined by temperature, day length, solar radiation and crop parameters (e.g. leaf area dynamics, assimilation characteristics, dry matter partitioning, etc.). The daily gross assimilation rate is calculated from the absorbed radiation and the photosynthesis-light response curve of individual leaves by integration over the leaf layers of the canopy and over the day (Goudriaan, 1986; Spitters, 1986). For the potential situation the effect of soil moisture content on crop growth is not considered and a continuously moist soil is assumed. In the water-limited situation soil moisture content determines whether the crop growth is limited by drought stress or not. Therefore, soil water dynamics (as dependent on rainfall and water losses by surface run-off, soil evaporation, crop transpiration and downward percolation) are simulated over time applying the tipping bucket approach, which

gives the soil moisture content in the rooted zone. Both soil evaporation and crop transpiration are calculated on the basis of the potential evapo-transpiration (from Penman approach according to Frère and Popov, 1979), taking into account both moisture content in the root zone and degree of light interception by the crop canopy. In both the potential and water limited situations optimal supply of nutrients is assumed and damage caused by pests, diseases, weed and/or extreme weather events is not considered.

For more detailed information on model structure, required input data and modelled processes in WOFOST, see Boogaard et al. (1998) and Supit et al. (1994; available at http://www.treemail.nl/download/treebook7/index.htm from Supit and Van der Goot). WOFOST is a one-dimensional model, without a reference to geographical scale. For regional applications, WOFOST can be linked to geographical information systems (as for example in CGMS), in which per grid unit the crop type, soil type, weather and management (e.g. sowing date) should be specified. In principle, WOFOST is a generic model that can simulate the growth of any annual crop type growing at any location.

4.3 Climatic change scenarios and WOFOST parameterization for increased atmospheric CO₂

The CO₂ concentrations that are used as inputs for the WOFOST growth simulations are combined with the KNMI climate scenarios for 2050 (Table 3.1 etden Hurk al., 2006); see for more information http://www.knmi.nl/climatescenarios/knmi06/index.php), are derived from the SRES emission scenarios in the IPCC Third assessment report (IPCC, 2001: Scientific basis, Appendix II, Table II.2.1 with CO₂ abundances). See the link: http://www.grida.no/publications/other/ipcc_tar/ used the We concentrations from the ISAM model (reference) for 2050 for first the high emission scenario A1FI and second, the low emission scenario B2, being respectively 567 and 478 µmol CO₂/mol, and for the current situation around year 2000, we use 369 umol CO₂/mol. The CO₂ concentration from the A1FI scenario might correspond best with the W and W+ scenarios of KNMI and the CO₂ concentration from the B2 scenario with the B and B+ scenarios (Table 3.1), but initially we have done simulation runs for all (4* 2) combinations.

Daily weather data for the four scenarios for 2050 in Flevoland have been supplied by Janette Bessembinder (KNMI). These weather data are based on observed daily weather data for Lelystad around year 2000 with transformation of mainly minimum and maximum temperature and rainfall to produce the four scenario datasets for 2050.

We assume that the relationship between the CO₂ increase and the growth processes is roughly linear, and that it is alright to change the WOFOST model parameters for C3-crops (see Table 4.1) for the A1FI and the B2 scenarios as follows:

```
- change in EFF= +11% * (567-369)/355= +6% and +11% * (478-369)/355= +3%
```

-change in AMAX= +60% * (567-369)/355= +33% and +60% * (478-369)/355= +18%

-change in RTRA= -10% * (567-369)/355 = -6% and -10% * (478-369)/355 = -3%

For C4-crops (i.e. maize) the model parameters EFF and AMAX are not affected by the increase in atmospheric CO2 but the change in RTRA = -26% * (567-369)/355= -15% and -26% * (478-369)/355= -8% (as based on literature reviews by Cure & Acock, 1986 and model analyses by Goudriaan & Unsworth, 1990 for maize).

Table 4.1 Changes in initial angle (EFF) and in maximum (AMAX) of the CO2 assimilation - light response curve and in the reduction factor for potential transpiration (RTRA) for adaptation of the WOFOST model to doubling of the actual atmospheric CO2 concentration (i.e. increase by 355 µmol/mol) on C3-crops (as based on literature reviews by Cure & Acock, 1986 and Allen et al., 1990, and studies by De Temmermans et al., 2002 and Wolf & Van Oijen, 2002, 2003). The relative figures are given in brackets.

Atmospheric CO ₂ concentration (μmol/mol)	EFF <u>(kg/ha/h</u> J/m ² /s)	AMAX (kg/ha/h)	RTRA
355	0.450 (100%)	40.0 (100%)	1.000
710	0.500 (111%)	64.0 (160%)	0.900

4.4 Example of simulating potential yields for 2050 in Flevoland

4.4.1 Introduction

Model runs with WOFOST have been done for current and future conditions for Flevoland. As an example, results from modeling spring wheat and ware potato are presented.

The used model parameters have been initially the standard crop parameter sets for the different crop types in CGMS-WOFOST (Boogaard et al., 2002, Lazar & Genovese, 2004). This crop parameter set was largely based on the crop data set compiled by Boons-Prins et al. (1993) and has recently been updated on the basis of newly compiled crop data sets (Wolf et al., 2008, 2010). Subsequently, growth characteristics for the main crop types in Flevoland have been compiled (see Table 4.2), such as the sowing and maturity dates and yield levels under optimal growing conditions. These data have been used for calibrating and evaluating the WOFOST model parameters for the different crop types for this study.

Table 4.2 Crop characteristics for main crop types in Flevoland, The Netherlands to calibrate and evaluate the WOFOST modeling results for potential growing conditions

		J 1	0 0					
P)	owing/ lanting ate ¹	Emergence date ¹	Date of Flowering,	Maturity date ^{1,4,5}	LAI- max	Total biomass above-	Yield ²	Harvest index ³

			Tuber initiation, or Start seed filling/tap rootgrowth ^{1,4}			ground ²		
Winter wheat	290-300	300-310	150-170	210-230	4 to 7	17000 to 22000	8000 to 11000	0.45 to 0.55
Spring wheat	75	90	155-175	215-235	3.0 to 6.0	14000 to 18000	7000 to 9000	0.50 to 0.55
Spring barley	75	90	155-175	215-235	3.0 to 6.0	14000 to 18000	7000 to 9000	0.50 to 0.55
Potato ware	105	125	140-150	255-275	4.0 to 6.0	16000 to 22000	12000 to 18000	0.70 to 0.80
Potato seed	105	125	140-150	220-230	3.0 to 6.0	12000 to 16000	9000 to 13000	0.70 to 0.80
Sugar beet	100	120	170-180	285-305	3.0 to 6.0	16000 to 24000	12000 to 18000	0.65 to 0.85
Maize fodder	115	130	205-215	275-295	4.0 to 7.0	16000 to 22000	16000 to 22000	0.45 to 0.55

¹ Julian day; for winter wheat and winter rapeseed the growth simulation with WOFOST starts at January 1 with the estimated amount of biomass after the winter, as WOFOST cannot simulate the effect of vernalisation on the crop's phenological development

4.4.2 Model runs for current conditions for Flevoland and for Scenario conditions in 2050 with and without management adaptation

Simulation runs with WOFOST have been done first for the main crops (13 in total) in Flevoland and the current weather conditions (period 1992-2008). These runs have been done for the current crop varieties and current sowing dates and next, the runs have been repeated for the four KNMI climate scenarios (Table 3.1) for a period around 2050. In all simulation runs the soil is at field capacity at the start of the year, has an available moisture fraction of 20% (being representative for the loamy and clay soils in Flevoland), is well-drained (hence, water excess practically does not affect crop growth), and is deep (hence, soil water availability is only limited by the maximal rooting depth as dependent on the crop type).

The effectiveness of management adaptation to climatic change has been established by repeating the simulations for the four KNMI scenarios and changing both the sowing date (i.e. 15 days earlier except for winter wheat and winter rapeseed) and the varieties (assuming more southern varieties with temperature requirements for phenological development that are 10% higher than those of the current varieties).

² kg dry matter per ha

³ Yield / Total biomass above ground

⁴ Early date applies in general to period 1991-2009 and Late date to period 1970-1990

⁵ With respect to sugar beet and maize, the crop is harvested at the latest indicated date, also if physiological maturity is not yet attained

4.4.3 Description of the simulation runs and results

Simulation runs for the thirteen crop types in Flevoland have been done for

- a) the current climate conditions for Lelystad, the Netherlands,
- b) the four KNMI scenarios for Lelystad with the high emission scenario A1FI (section 4.3),
- c) the four KNMI scenarios for Lelystad and the moderate emission scenario B2, and
- d) the four KNMI scenarios with the high emission scenario A1FI plus management adaptation to climatic change.

Results are available for respectively winter wheat, spring wheat, potato ware, potato seed, sugar beet, fodder maize, grain maize, winter rape seed, spring barley, sunflower, peas, onion and tulip. For both spring wheat and ware potato the results are presented in Tables 4.3 and 4.4 and discussed in section 4.4.4. The simulations have been done for both potential (i.e. irrigated, optimal nutrient supply and management) and water-limited conditions (i.e. rainfed, optimal nutrient supply and management). Both mean yield values and the standard deviation (SD) of the simulated potential and water limited yields over 17 years are given in these tables.

Increase in atmospheric CO₂ in 2050 results in higher biomass production and yields for most crop types compared to the current productions and yields. Note that it is assumed that the crop types in 2050 will have an increased sink and yield forming capacity to allow such higher yield levels. This assumes a gradual improvement of crop varieties and their adaptation to the gradually changing conditions by continuous plant breeding work.

Note also that the yield changes for the four KNMI climate scenarios for 2050 and the two atmospheric CO2 concentrations compared to the simulated current yield levels can be considered as valid for the whole of the Netherlands, because of first, the limited differences in climate conditions over the Netherlands and second, the uncertainty in the generated future weather data.

4.4.4 Results for spring wheat and ware potato

For spring wheat, the potential yields increase by 10 and 20% for respectively the low and the high CO₂ concentration and the G, G+ and W climatic change scenarios and the yield increase is less for the W+ scenario due to its highest temperatures. The water limited yields increase by 10 and 20% for respectively the low and the high CO₂ concentration and the G, G+ and W climatic change scenarios and the yield increase for the W+ scenario is nil to small due to its warmest and driest summers.

The increase in yields for the four KNMI scenarios (compared to current yields) is highest for the scenario with the smallest temperature increase (i.e. G) and smallest for the scenario with the largest temperature increase (i.e. W+). The effect of management adaptation is as follows: cultivation of a wheat variety with a higher temperature demand for phenological development and a 15 days earlier sowing date results in a small increase in yield, being largest for the warm W+-scenario, but this yield increase only occurs under potential growth

conditions; under water limited conditions the advantage of a longer grain filling period is counter balanced by the larger risk for drought during the summer.

The difference between water limited and potential yields under current conditions appears to be small (i.e. yield reduction by 2% due to drought). The difference between water limited and potential yields under future conditions appears to be small too and similar to that under current conditions.

Standard Deviation: SD of potential yields is practically the same for future and current conditions and SD of water-limited yields is the same or slightly lower for future conditions.

For ware potato, the potential yields increase by 5 and 13% for respectively the low and the high CO₂ concentration and the G, G+ and W climatic change scenarios, and the yield increase is less for the W+ scenario due to its highest temperatures. The water limited yields increase by 0 and 10% for respectively the low and the high CO₂ concentration and the G, G+ and W climatic change scenarios, and the yields considerably decrease for the W+ scenario due to its warmest and driest summers.

The increase in yields for the four KNMI scenarios (compared to current yields) is highest for the scenario with the smallest temperature increase (i.e. G) and smallest (mostly a decrease) for the scenario with the largest temperature increase (i.e. W+). The effect of management adaptation is as follows: cultivation of a potato variety with a higher temperature demand for phenological development and a 15 days earlier planting date results in a slight increase in yield but this yield increase only occurs under potential growth conditions; under water limited conditions the advantage of a longer tuber filling period is counter balanced by the larger risk for drought during the summer.

The difference between water limited and potential yields under current conditions appears to be large (i.e. yield reduction by 23% due to drought). The difference between water limited and potential yields under future conditions appears to be large too (i.e. yield reduction by 20 to 35%), being largest for the W+-scenario.

Standard deviation: SD of potential yields is higher for future conditions than for current conditions and SD of water-limited yields is practically the same for future and current conditions.

4.5 Discussion of the Methodology and the Model outcomes

Effects of climatic change and increase in atmospheric CO₂ for different scenarios in 2050 on the growth and yields of the main crop types cultivated in Flevoland can be easily calculated with the WOFOST model. The main assumption required to use these simulated yields for 2050 to derive the actual yields for 2050 (section 5), is that the simulated yields and yield changes towards 2050 under optimal growing conditions are practically similar to those under actual farming conditions. As the actual management and yield level is high in Flevoland (i.e actual yields are almost 80% of the simulated yields), this assumption is alright.

Changes in climate and increase in atmospheric CO_2 in year 2050 for the four scenarios result in yield increases for all crop types in Flevoland, except sometimes for the most extreme climatic change scenario W+. These yield increases for 2050 are mainly caused by the increase in atmospheric CO_2 , resulting in considerably higher yield for the high emission (HC) scenario than for the low emission scenario (LC). The four different climatic change scenarios for 2050 from KNMI result in simulated yields for the different crop types that in general change from highest to lowest yield for the scenarios in following order: $G \rightarrow G+ \rightarrow W \rightarrow W+$; this yield order can be explained from the fact that the G scenario has the coolest summer with an increase in rainfall and the W+ scenario has the warmest summer with a considerable decrease in rainfall (hence, this scenario leads to yield reduction by shortened periods for e.g. grain and tuber filling at warmer temperatures and by more severe drought periods), and the other scenarios have in-between changes. The simulated yield changes due to climatic change and increase in atmospheric CO_2 appear to be reliable. This is in particular the case, because the main part of these yield changes are caused by the increase in atmospheric CO_2 , being a stable and simple relationship.

For changed climatic change conditions the crop simulations have been done for both current and adapted crop management. The applied adaptations are: earlier sowing or planting date and a variety adapted to warmer climate. Note that for the crop simulations optimal management is assumed and that most options to optimize the crop management (e.g. different nutrient application and crop protection methods, change in soil tillage and in timing of filed operations, and/or use of more disease-resistant crop varieties) are not possible. The applied management adaptations result here for most crop types in nil to slightly higher yields under potential growth conditions. The reason that the effects of management adaptation are limited, is due to the fact that the warmer conditions under changed climate lead also under current crop management to an increased rate of phenological development of the crop and hence, automatically advance the growth period to the cooler periods in spring. This partly counterbalances the negative effects on yield of warmer temperatures under climatic change and limits the positive effects of management adaptation on yields. Under water limited growth conditions the advantage of a 'more southern' variety with e.g. a relatively longer grain or tuber filling period is generally counter balanced by the larger risk for drought during the summer.

Table 4.3 Mean and Standard deviation (SD) of grain yields of **spring wheat** (in kg dry matter per ha) for both potential (**Pot**) and water limited conditions (**Wat**) as simulated with the WOFOST model for current weather conditions (period 1992-2008; **Base**) and for future weather conditions (also 17 years) around year 2050. The calculations for future conditions have been done for the four KNMI climatic change scenarios for 2050 (see Table 3.1, scenarios **G, G+, W, and W+**) being combined with first, high CO₂ concentration of 567 µmol CO₂/mol from the ISAM model (reference) for 2050 for the high emission scenario A1FI (**HC**), second, the same high emission scenario but with management adaptation (**HC-Ad**, i.e. sowing date 15 days earlier except for winter wheat and rape seed, and 10% higher temperature sums required for phenological development) and third, CO₂ concentration of of 478 µmol CO₂/mol from the ISAM model (reference) for 2050 for the low emission scenario B2 (**LC**)

		-, J											
	Base	HC-G	HC-G+	HC-W	HC-W+	HC-Ad-G	HC-Ad-G+	HC-Ad-W	HC-Ad-W+	LC-G	LC-G+	LC-W	LC-W+
Pot Yield Mean	9072	11212	10886	10683	9857	11339	11062	10894	10201	10355	10039	9831	9030
Pot Yield SD	670	743	729	598	559	845	838	719	657	693	674	553	528
WatYield Mean	8925	11084	10678	10515	9672	11106	10702	10589	9832	10197	9795	9635	8820
Wat Yield SD	845	846	771	646	619	1061	1022	934	872	803	726	604	579

Table 4.4 Mean and Standard deviation of tuber yields of **potato ware** (in kg dry matter per ha) for both potential and water limited conditions as simulated with the WOFOST model for current weather conditions (period 1992-2008; **Base**) and for future weather conditions (also 17 years) around year 2050. The calculations for future conditions have been done for the four KNMI climatic change scenarios for 2050 (see Table 3.1, scenarios **G, G+, W, and W+**) being combined with CO₂ concentrations from low emission scenario (**LC**), high emission scenario (**HC**) and high emission scenario with management adaptation (**HC-Ad**). See Table 4.3 for more information.

	Base	HC-G	HC-G+	HC-W	HC-W+	HC-Ad-G	HC-Ad-G+	HC-Ad-W	HC-Ad-W+	LC-G	LC-G+	LC-W	LC-W+
Pot Yield Mean	15614	18248	17555	17313	15963	18842	18123	17889	16637	16931	16282	16054	14800
Pot Yield SD	1136	1539	1603	1456	1792	1471	1539	1430	1751	1459	1519	1386	1701
WatYield Mean	11963	14110	12584	13020	10443	14106	12496	12966	10357	12758	11324	11751	9359
Wat Yield SD	3286	3760	3587	3638	2753	3724	3626	3744	2804	3512	3325	3385	2545

5 Calculation of Actual yields for different scenarios in 2050 for Flevoland

5.1 Introduction

Actual yield levels of the main crop types in Flevoland in 2050 are required for the AgriAdapt analyses for different scenarios in 2050. For calculating the actual yields in 2050 for the main arable crops in Flevoland, we have to consider the following factors that determine the yield changes towards 2050 compared to the actual yields at present: 1) increase in atmospheric CO₂, 2) change in climatic conditions, 3) genetic improvement of crop varieties, 4) decrease in yield gap due to improved crop management, and 5) changing effects of extreme conditions on crop yields (Chapter 7; possibly occurring before crop emergence and/or after crop maturity).

Actual yields in 2050 can partly be based on simulated potential yields for different climate scenarios for 2050 in Flevoland (as described in Chapter 4). In this way the effects of increases in atmospheric CO₂ and changes in climatic conditions on the actual yields in 2050 can be taken into account.

5.2 Description of first results from literature research on possible increases in yield potential by genetic improvement towards 2050

We would like to know which are the possibilities to increase the potential yield level in 2050 due to changes in physiological, phenological and morphological characteristics of crops. For that we have done a short literature review to derive the probable increase in yield potential by genetic improvement for main crop types over the coming 40 years. As a starting point, yield potential (YP) can be expressed in its simplest form as a function of light intercepted (LI), radiation use efficiency (RUE), and the partitioning of biomass to yield, or harvest index (HI): YP= LI * RUE * HI. LI and HI appear to have been optimized for, in particular, grain crops during the last decades, and future genetic progress in yield of grain crops will most likely be achieved by focusing on constraints to RUE, being indirectly influenced by sink strength (Reynolds et al., 2005). For minor crops as e.g. rape seed, it is possible that LI and HI can still be improved to increase the yield potential, indicating the need for further literature research on this topic.

Elaborate reviews of the possibilities to raise the yield potential in the coming decades by increasing RUE are given by Reynolds et al. (2009) and Long et al. (2006). Long et al (2006) states that 'many recent experiments that compare the growth of a genotype in current and future projected elevated [CO2] environments show that increase in leaf photosynthesis is closely associated with similar increases in yield. Are there opportunities to achieve similar increases by genetic manipulation? Six potential routes of increasing ac by improving photosynthetic efficiency (Table 3-from Long)

were explored, ranging from altered canopy architecture to improved regeneration of the acceptor molecule for CO₂. Collectively, these changes could improve the radiation convertion efficiency sc and, therefore, Yield potential by circa 50%.

Table 3. Summary of possible increases in solar radiation conversion efficiency (ε_c) that may be achieved and the speculated time horizon for provision of material that can be introduced into plant breeding programs (Adopted from Long *et al.* 2005b)

Change	% Increase in ε_c relative to current realized value	Speculated time horizon (years)
Rubisco with decreased oxygenase activity but without decreased catalytic rate	30% (5–60%)	???
Efficient C ₄ photosynthesis engineered into C ₃ crops	18% (2-35%)	10-20
Improved canopy architecture	10% (0-40%)	0-10
Increased rate of recovery from photoprotection of photosynthesis	15% (6-40%)	5-10
Introduction of higher catalytic rate foreign forms of Rubisco (Table 2)	22% (17-30%)	5-15
Increased capacity for regeneration of RuBP via overexpression of SbPase	10% (0-20%)	0-5

The time to realizing sufficient seed for commercial cultivation would be longer.

The value under the heading '% Increase ...' is the suggested mean, followed by the range of possible change, calculated by substituting the changed properties into the simulation model of Humphries & Long (1995). See text for references. Rubisco, ribulose 15-biphosphate carboxylase/oxygenase; RuBP, ribulose biphosphate.

The increases in yield potential during the coming decades by genetic improvement can be derived roughly on the basis of the mentioned literature reviews and can be estimated at 1% per year in an A1F-W/W+ scenario. This estimate corresponds well with the estimate as based on the historical yield trends to the future (Ewert et al., 2005; Reilly & Fuglie, 1998). For example, these yield trend analyses show that the actual relative yield increases are about 1.5 to 2% per year around year 2000 and gradually decrease over time. Besides, Slafer & Andrade (1991) give some estimates about the contribution of genetic improvement to actual yield increases, being generally around 50%. Hence, we may assume that relative growth rate of actual yields around year 2000 that results from genetic improvement, is about 1% or slightly less. Assuming that the genetic improvement will result in a gradually decreasing relative growth rate, which will become about nil in year 2050, we estimate the total increase in yield potential from genetic improvement for the A1-W/W+ scenario (with rapid economic growth, global free trade and strong increase in wealth and thus food demand) for year 2050 at 30% of the current yield potential in Flevoland (being lower than Long's estimate for the maximal increase in yield potential of 50% by genetic improvement, assuming some reduction due to sink limitation). For the B2-G/G+ scenario (with limited economic growth, trade blocks and environmental taxes, and more limited increase in wealth and thus food demand) we estimate the total increase in yield potential from genetic improvement for 2050 at 10% of the yield potential in Flevoland (assuming less pressure to use improved crop varieties and less investment in research to increase the yield potential due to less increase in food demand and less increase in other drivers such as less globalization, less available capital and more environmental restrictions).

5.3 Description of present yield gap and of the Methodology to calculate Actual yields for different scenarios in 2050

In Flevoland the yield gap between the potential yields and the actual yields in 2006-2008 is for the main crops nil to slight (maximally 20%), indicating optimal crop management at present. We assume that this yield gap of 10 to 20% for main crops (Table 5.1), can practically not be reduced further, being related to yield losses in the few years with extreme conditions (e.g. strong rainfall during harvest) and by disease infestations in wet years. For crops like spring wheat and silage maize, the yield gap appears to be somewhat higher, however, their cropping areas are limited and hence, this is of less importance.

Table 5.1 Comparison of yield data (kg/ha air dry) for Flevoland, actual yield change over time and yield

_gap							
	Simple manag. data ^a	1994- 1996 ^b	2006- 2008 ^b	Yield change ^c	Potential yield (airdry) ^d	DM % in yield	Yield gap ^e
Winter wheat	8100	9100	9000	0	9500 to 13000	84	S
Spring wheat	7100	7200	6900	-	8300 to 11900	84	m
Potato ware	53400	54100	53700	0	55000 to 82000	22	S
Sugar beet	58300	66000	78200	++	60000 to 90000	20	n
Fodder maize	13200	12400	14500	++	16000 to 22000	100	m
Onion	52400	52000	60600	++	53000 to 70000	20	n

^a Yield data in the Simple management file for loamy soils in Flevoland (in SEAMLESS database) as based on KWIN (2001), 25th edition, PPO report 301, being averages for 1995-1999; yields on sandy and clay soils are respectively lower and higher

As the present yield gap for the main crop types in Flevoland is limited, we assume that for the scenarios in 2050 the yield gap will remain practically similar to that at present. This yield gap for 2050 is set to the lowest value of either 0.2 or the actual yield gap at present. Note that for crops as winter wheat, sugar beet and onion, there is a clear difference between the yields in the SEAMLESS data base and the actual yields in 2006-2008 (Table 5.1), indicating the problem of choosing the base year for use in the FSSIM analyses and for calculating future yields. *For the AgriAdapt analyses we will use the actual yield data for 2000-2008*.

The used data for the calculation of actual yields in Flevoland for scenarios in 2050 are the following: a) actual yields (AYc) at present (see Table 5.1, yield data for 2006-2008), being used to calculate the current yield gap), b) simulated potential yields for current conditions (PYc) and for the scenarios in 2050 (PY50) that take into account the effects of climatic change and increase in atmospheric CO₂ (note that for

b Derived from CBS (http://statline.cbs.nl/statweb/)

^c Yield change over time is very positive, positive, nil, negative or very negative as indicated by ++, +, 0, - and --

^d Based on experiments under potential growing conditions (Boons-Prins et al., 1993), crop modeling and expert knowledge

^e Yield gap in 2006-2008 is nil, small, moderate or large, as indicated by n, s, m and l

regions with high groundwater levels and deep alluvial soils as Flevoland, we assume that water supply is generally not limiting for crop growth during the summers and that simulated potential yields can best be used), c) increase in yield potential by genetic improvement, which factor (GI) is estimated at 30% and 10% of the yield potential for respectively the A1-W/W+ and B2-G/G+ scenarios (from section 5.2), d) yield gap for 2050 (GAP50), being equal to the minimum of either the yield gap set for 2050 (GAP50s) or the actual yield gap (GAPc) at present per crop type (GAPc = 1 – (AYc / PYc)), e) effect of extreme events is included in the current yield gap and hence, is not included separately in these yield calculations for 2050; the possible integration of the changing effects of extreme events towards 2050 into the actual yield calculations for 2050 is discussed in section 11.2.

Summarizing, the actual yield for the different scenarios in 2050 can be calculated as follows: AY50 = PY50 * (1 + GI) * (1 - GAP50) with GAP50 = Min (GAPc, GAP50s) and GAPc = 1 - (AYc / PYc). GAP50s is described in the next paragraph.

The yield gap in Flevoland is near or at its minimum value (Table 5.1) and will not change much towards 2050. However, if we would like to apply this actual yield calculation to other regions over Europe, we have to specify the yield gap for the different scenarios for 2050. Current yield gaps range from 0.3 to 0.7 in regions over Europe (Nonhebel, 1997). Yield gap for the A1-W scenario in 2050 (with rapid economic growth, global free trade and strong increase in wealth and thus food demand) is assumed to become small and GAP50 is set at the minimum of either the set value for year 2050 (GAP50s) of 0.2 in all regions over Europe or the actual yield gap (GAPc) if even smaller. For the B2-G scenario for 2050 (with limited economic growth, trade blocks and environmental taxes, and less increase in wealth and thus food demand) it is assumed that half of the difference between the current yield gap (e.g. GAPc=0.5) and its minimum value (= 0.2) is filled towards 2050. In that case, the yield gap set for 2050 (GAP50s) is calculated for the B2-G scenario as follows: 0.5 * (0.2 – GAPc) + GAPc= 0.5 * (0.2 – 0.5) + 0.5 = 0.35. And also for this scenario, GAP50= Min (GAPc, GAP50s).

We assume that for most regions over Europe (except for regions with high groundwater levels as Flevoland and Po basin and regions with irrigation) crop growth during the summers and yields will be limited by water supply, and both under present and future scenario conditions. Hence, the simulated yields for both current conditions (PYc) and for the scenarios in 2050 (PY50) with changed climate and increased atmospheric CO₂ that are used in the actual yield calculations for 2050 (see above: AY50), should then in general be derived from simulations for water limited conditions over Europe.

5.4 Example of the application of the Actual yield calculation for 2050

Actual yield levels in 2050 are required for the AgriAdapt analyses for different scenarios in 2050. We present here two calculation examples for two scenarios, i.e.

first the high emission A1-W scenario with the strongest temperature increase (Table 3.1; section 4.3) and second, the low emission B2-G scenario, with atmospheric CO₂ concentrations of respectively 567 and 478 µmol/mol. For the A1-W scenario we assumed that management adaptation was needed due to its strong temperature rise. Note that the simulated yields are generally in dry matter (DM) and the actual yields are generally air dry (DM content in air dry yield is 84% for winter wheat, see Table 5.1).

For the A1-W scenario for 2050, using the current yield (air dry) for winter wheat of 9000 kg/ha (Table 5.1), a current (around year 2000) simulated potential yield of 10347 kg DM/ha, a DM content in air dry wheat grain yield of 0.84, a genetic yield improvement factor of 0.30 (section 5.2), and a simulated potential yield for the W-scenario in 2050 inclusive management adaptation of 11242 kg DM/ha, the actual wheat yield (air dry) becomes in 2050: 1.30 * (11242/0.84) * Maximum(either 1 – (9000 * 0.84/10347) or 0.8; i.e. actual value versus maximal value for one minus yield gap) = 13919 kg/ha

For the B2-G scenario for 2050 using the current yield (airdry) for winter wheat of 9000 kg/ha, a current (around year 2000) simulated potential yield of 10347 kg DM/ha, a DM content in air dry wheat grain yield of 0.84, a genetic yield improvement factor of 0.10 (section 5.2), and a simulated potential yield for the G-scenario in 2050 without management adaptation of 11438 kg DM/ha, the actual wheat yield (air dry) becomes in 2050: 1.1 * (11438/0.84) * Maximum(either 1 – (9000 * 0.84/10347) or 1 – GAP50s) = 11458 kg/ha. Note that GAP50s (see end of section 5.3) is equal to 0.235.

The variability in the actual yields for 2050 can be calculated in the following way. Standard deviation (SD) of actual yields in 2050 = (SD of actual yields (from statistics) in 2000) * (SD of simulated potential yields for 2050) / (SD of simulated potential yields for 2000). Note that the mentioned simulated potential yields should be replaced in this formula by simulated water limited yields for most regions over Europe (except for regions with high ground water level as Flevoland), as described in the last paragraph of section 5.3. It is probably not possible to estimate an additional change in SD of the yields due to changing effects of extreme events on crop yields (Chapter 7) towards 2050.

5.5 Discussion of the Method for Actual yield calculation for 2050

The Method for the calculation of actual yields for the different scenarios in 2050 is straightforward. However, the calculated yields for scenarios in 2050 are depending on a number of assumptions that are uncertain to a different extent. Based on the two examples of the calculation method presented in section 5.4, we can assume that the effects of climatic change and increase in atmospheric CO₂ on the actual yields are represented reasonably well by the simulated potential yields for 2050, but that the changes in yield by genetic improvement and by yield gap reduction due to improved management are both uncertain, in particular when the method is applied

to many regions over Europe. Only in Flevoland where the crop management is almost optimal and hence, the yield gap is almost at its minimum (Table 5.1), the calculated yield gap reduction towards 2050 will be precise enough and the uncertainty in the calculated actual yields for scenarios in 2050 will be mainly caused by the estimated yield change by genetic improvement (section 5.2).

There appears to be a clear difference between the yields in the SEAMLESS data base and the actual yields in 2006-2008 (Table 5.1). This indicates the problem of choosing the base year for calculating the future yields. As shown in the calculation examples in section 5.4, the chosen actual yield at present may determine the future yield gap in the actual yield calculation. For the analyses for Flevoland for the AgriAdapt project we will use the actual yields in 2000-2008. For other regions over Europe both options to derive the actual yields (i.e. yields for 2000-2008 from statistics or the yields from the SEAMLESS data base) are still open. Anyway, if for in particular the B2-G scenario for 2050 a lower value is chosen for the actual yield at present and thus the current yield gap (GAPc) becomes larger, the yield gap set for 2050 (GAP50s, see end of section 5.3) becomes larger too and hence, the calculated actual yield in 2050 becomes lower.

Changes in the effects of extreme events on crop yields towards 2050 (see Chapter 7) cannot easily be included in the actual yield calculations for 2050. Part of the effects of extreme events on yields are already included in the current yield gap. Changes in these effects towards 2050 might result in changes in the yield gap, however, such changes in yield gap are probably difficult to quantify. This is discussed further in section 11.2.

6 Agro-climate calendars and Adaptation measures

6.1 Introduction

In the second phase of the BSIK project 'Adaptation agriculture and climate North of the Nederlands' the climatic change sensitivity of 15 cropping and 2 animal production systems have been studied (De Wit et al., 2009). For the cropping systems this has been done with the Agro-climate calendars (Schaap et al., 2009). This sensitivity has been derived from a combination of literature study and interviews with experts from research and practice. The climate sensitive periods of the crops and systems are determined on the basis of long-term (30 year) weather data. To determine future changes in the occurrence of weather extremes and in the climate sensitivity of cropping and animal production systems, we have used climate scenarios from KNMI. These analyses are focused on the time frame around 2050. For the occurring management problems, adaptation measures have next been proposed.

The climate sensitivity of the main cropping systems and the two animal production systems in the Netherlands have already been studied earlier, as reported by De Wit et al. (2009) and Schaap et al. (2009). We are mainly interested here, how the information from this approach can be combined with and integrated in the modeling results from the other approaches applied with the AgriAdapt project. This is discussed in section 6.4.

6.2 Description of the method

The climate data for each time frame and the specific climate factors per crop type (Tables 6.1 and 6.2) have been compared to establish the impact of climatic change: the climate calendar. Not all climate factors (see Table 6.2) have a solid basis in science. Some threshold values can be found in the scientific literature and others are based on expert knowledge and knowledge from practice. The most important part of the climate calendar consists of the effects of the (changed) climate on the crop growth and its management, for which both indirect (e.g. pests and diseases, salinization) and direct factors (e.g. heat wave, frost) are considered. The subsequent information about the Agro-climate calendar method is derived from the reports by De Wit et al. and Schaap et al (2009).

General information

For each crop type general information with respect to the crop management is given. Besides, a map shows the present cultivation areas in North-Nederlands. Mean yields and product prices fort hat crop are based on KWIN data for 2002.

Climate factors, impact on crop and damage

Based on the Wageningen UR study (Schaap et al., 2009), the sensitive periods and climate factors per crop type are presented (Tables 6.1 and 6.2). Table 6.3 gives the following information:

- Climate factor: the weather condition that has a certain impact on a specific crop type. The definition of the climate factor is given in Table 6.2;
- Period: period within a year in which the climate factor effects the crop;
- Impact on crop: effect of the occurrence of the climate factor on the crop;
- Damage: percentage of estimated yield loss due to the occurrence of the climate factor; damage is estimated on the basis of literature, historical data and expert knowledge, and can be the result of a lower yield, quality loss or a combination of both;
- Indication damage: indication of the financial loss in case a maximal damage occurs (basic assumptions for this calculation are given in De Wit et al., 2009, annex 3).

Description of two time frames: current situation and year 2050

Per crop type the consequences of climatic change for the time frames have been worked out. The crop calendars show how often per month a certain climate factor does occur. The crop calendars are given for the current situation (i.e. 30 years around 1990; Table 6.4) and for the scenario for 2050. In the calendar for 2050 the change in a number of climate factors for two KNMI climatic change scenarios (i.e. G+ and W+; section 3.2.5) compared to those for the current situation are presented in the following (Table 6.5).

Based on the maximal damage as a result of the climate factor and the number of times that a certain climate factor does occur in a period of 30 years, both for the current situation and for the 2050 scenario, an indication is given of the maximal annual management costs and the maximal one-time investments (respectively Tables 6.4 and 6.5). Basic assumptions for these calculations are given in De Wit et al. (2009). Note that the indicated figures only allow to make a very rough comparison between the costs of the possible damage due to a certain climate factor and the costs of possible adaptation measures. Such figures cannot be used to judge if certain measures are economically feasable within a certain farming system.

Adaptation measures

To protect crops against the most risky climate factors in 2050 or to limit their effects, adaptation measures can be taken. Per crop type the most risky climate factors are given and the possibly implemented measures (Table 6.6). For each measure it is indicated, at which level (crop, farm, sector or region) the measure should be applied or developed. Besides, an indication, if possible, is given of the required investments and the annual costs of the adaptation measures.

Other climate factors and measures

Certain climate factors cannot be quantified on the basis of the KNMI climatic change scenario data. Such climate factors can only be elaborated in a qualitative way, as done by Schaap et al. (2009) and generated during the sector meeting. The indicated adaptation measures are described in a qualitative way.

Positive results of climatic change

Per crop type it is indicated what the positive results from climatic change might be. This is based on: a) decreases in a number of sensitive climate factors versus the current situation, b) consequences of such decreases for crop management.

Summary

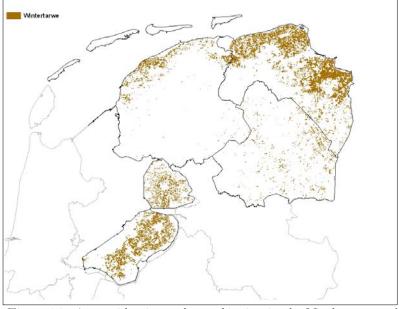
Based on the results from identification and quantification of the climate factors, their damage, and possible adaptation measures per crop type, the most relevant information is given here.

6.3 Short example from Report on Climate and Agriculture in North of the Netherlands (De Wit et al., 2009)

For additional information about the following, see the issues in section 6.2 with the same headings. The example given is mainly for winter wheat and sometimes also for sugar beet and potato, and the same information is available for the other main crops in the Netherlands too.

General

Wheat is the main grain crop in the world, it supplies food for 21% of the human population, and is cultivated on 200 million hectares. Wheat can be cultivated as both a winter and a spring variety. The winter variety needs a cold period, after which wheat becomes dormant. With rising temperatures in spring the wheat growth starts again. Wheat is cultivated in large parts of the Netherlands within a large variety of crop rotations. The Oldambt region is typically a grain cropping area with the crop rotation consisting mainly of grain crops.



Area in 2008 Error! Bookmark not defined.

Northern-Nederland: 54.504 ha
Groningen: 31.646 ha
Friesland: 7.186 ha
Drenthe: 2.326 ha

13.346 ha

Crop characteristics

• Flevoland:

- Sowing: September Februari
- Harvest: Augustus September
- Cultivation in rotations with a broad range of crop types
- Deep rooting crop (until ca. 1 m)
- Indicative yield⁷:
 - ° Grains: 8.000 kg/ha
 - O Price: €0,10 per kg
 - ° Revenues: €800 per ha
 - O Straw: €200 per ha

Figure 6.1 Areas with winter wheat cultivation in the Northern part of the Nederlands and some characteristics

The timing of the main operations in winter wheat cultivation is given in Table 6.1. This indicates when wheat cultivation may be affected by weather conditions. For example, wet conditions may result in larger yield losses due to disease infestation and/or due to a delay in harvesting. The main climate factors for winter wheat, their effects on crop growth and yields, and the yield losses are given in Table 6.2.

Tabel 6.1 Timing of the operations for winter wheat cultivation per month and possible limitations due to weather conditions.

Operations	J	F	M	А	M	J	J	А	S	0	N	D	Limited by:
Sowing bed preparation									х	хх	xx	х	Too wet conditions in the field
Sowing	х	х							х	xx	хх	х	Too wet conditions in the field
Fertiliser application			х	х	х								Too wet conditions in the field
Biocide application				Х	XX	Х							Many windy and wet days
Harvest, grains do not dry out sufficiently								х	х				Rising relative humidity
Harvest, harvesting the straw with combine become dificult								х	х				Dew formation
Plowing: occurs during the whole winter, but is dependent on soil properties and crop rotation	х								x	XX	XX	Х	Wet conditions soil

Climate factors, impact on crop and damage

Table 6.2 Climate factors for sugar beet and winter wheat cultivation and their meteorological definition (source: Schaap et al., 2009)

(source: Schaap et al., 2	007)	
	Prolonged dry	Dry period of 30 days with rainfall < 5 mm
	Variable wet weather	Minimally on 10 % of 28 days more than 10
	variable wet weather	mm of rain
	Permanent wet weather	Minimally 75 % of 14 days with more than 0.5
Sugar beet	remailent wet weather	mm of rain
	Permanent warm winter	Period of minimally 14 days with daytime
	remanent warm winter	temperature > 10°C
	Ground frost	Period of minimally 1 day with minimal night
	dround frost	temperature < -3°C
	Prolonged dry	Dry period of 40 days with precipitation < 10
	Froidinged dry	mm
	Permanent wet	Minimally on 75 % of 21 days more than 0.5
	1 emianem wet	mm of rain
Winter wheat	Permanent moist	Minimally on 75 % of 14 days more than 0.5
willer wheat	T emanent moist	mm of rain
	Wind gusts combined with heavy	Precipitation of 45 mm in 1 day
	showers	11 Colpitation of 45 min in 1 day
	Permanent wet	Minimally on 75 % of 21 days more than 0.5
	1 Cimanent wet	mm of rain

Table 6.3 Climate factors and their impacts on winter wheat cultivation

Climate factor	Period	Impact on crop	Damage	Indication damage
Prolonged dry	June - Aug.	In the period after stem elongation drought may play a role and will result in yield reduction	10 – 50%	Max. €500 per ha
Permanent wet	April - May	Occurrence of septoria or leafspot disease	25 - 75%	Max. €800 per ha
Permanent moist	May - July	Occurrence of Ear fusarium with moist varying conditions from anthesis to harvest; Ear fusarium produces mycotoxins.	25 - 75%	Max. €800 per ha
Wind gusts combined with heavy showers	May - Aug.	Lodging occurs when wet ears become heavy and sensitive to wind gusts; this complicates harvesting	unknown	-
Permanent wet	July - Sept.	Harvest may be delayed to September; this may delay the sowing date of the subsequent crops in the rotation	10 - 75%	Max. €800 per ha
Variable weather	Nov. – March	Freezing of the roots	10 - 50%	Max. €500 per ha

Descriptions of the two time frames for the winter wheat cultivation

Current situation

In Table 6.4 it is indicated per climate factor how often the factor occurs per month in a period of 30 years. Under the current climatic conditions (around year 1990) permanent moist weather in the periode May - June (Ear fusarium is a problem) and permanent wet weather in the period July - September (harvest delayed to September) are the most frequently occurring climate factors.

Table 6.4 Frequency of occurrence of climate factors in Eelde measured by KNMI in the period 1976-2005 and indicative values for management costs and investments (see adaptation measures in Table 6.7 for more detail)

			Manag.costs	Investment										
Climate factor 1)	J	F	М	Α	М	J	J	Α	S	0	N	D	(k€/ha) ²⁾	(k€/ha) ³⁾
Prolonged dry						0	1	0					0 - 0,05	0,2 - 0,3
Permanent wet				0	5								0,1 - 0,15	1 - 3
Permanent moist					4	9	8						0,5 - 0,6	8 - 9
Gusts/showers					0	0	0	1					nd	nd
Permanent wet							7	5	2				0,3 - 0,4	5 - 6
Variable weather	1	0	1								0	0	0 - 0,05	0,5 - 0,6

¹⁾ see Tables 6.2. and 6.3 for further information

Situation 2050

Prolonged drought slightly increases over the periode 2026-2055 (Table 6.5), which during stem elongation may result in yield reduction. Variable weather appears to occur slightly more often, which may increase the chance of root freezing. This effect of variable weather on the yield is probably small.

Table 6.5 Change in the frequency of the occurrence of climate factors in Eelde as calculated by KNMI for the period 2026-2055 for respectively the G+ (white column per month) en W+ (grey column per month) scenarios and indicative values for management costs and investments (see adaptation measures in Table 6.7 for more detail)

	Month													Manag.costs	Investment											
Climate factor 1)	·	J		F	ı	M	/	4	ı	V	,	J	,	J	/	4	3	S	C)	١	1)	(k€/ha) ²⁾	(k€/ha) ³⁾
Prolonged dry											+1	+2	+1	+1	+1	+2									0,05 - 0,1	1 - 2
Permanent wet							0	0	-2	-2															-	-
Permanent moist									-1	0	+1	-2	-1	-4											-	-
Gusts/showers									0	0	0	0	0	0	+1	+1									nd	nd
Permanent wet													-2	-5	-4	-3	0	-1							-	-
Variable weather	0	0	+2	+3	0	+1															0	0	0	0	0,05 - 0,1	1 - 2

²⁾ Indication of the maximal annual management costs in Euro x 1.000 per hectare (see De Wit et al., 2009, annex 3 for further information)

³⁾ Indication of the maximal one-time investment costs in Euro x 1.000 per hectare (see De Wit et al., 2009, annex 3 for further information) nd: not determined because of insufficient information

Summarizing, the main increases in climatic risk for winter wheat cultivation in 2050 compared to the current situation, are:

- Prolonged dry weather (in W+ scenario)
- Variable weather (in W+ scenario)

Adaptation measures in 2050

In Table 6.6 the possible adaptation measures for winter wheat cultivation in 2050, to prevent or limit damage due to climatic change, are given.

Table 6.6 Adaptation measures for the most risky climate factors in 2050 (see adaptation measures in Table 6.7 for more detail)

	Level	Indicative costs					
Prolonged dry– Yield loss (June - Aug.)		Annually (k€/ha)	Investment (k€/ha)				
Increase water holding capacity of the soil 1)	Farm	0,1 - 0,5	-				
Develop drought resistent crop variety	Sector	-	1.000 - 10.000 *)				
Variable weather - Freezing of the roots (Nov March)							
Early sowing	Field/farm	nil	-				
Remarks:							
1) for possible measures see De Wit et al. (2009), annex 4							
*) costs cannot be expressed per hectare							

The low gross margin of winter wheat cultivation does allow only a limited number of adaptation measures. To limit the damage from prolonged dry conditions, the farmer may improve the water holding capacity of the soil, e.g. by not selling the straw but by plowing it in. Possibly, breeding may lead in the long term to more drought resistant cultivars. For example, in Australia experiments are done presently with genetically modified drought resistant grain crops. Farmers hope that such future wheat varieties may give high yields also under dry conditions. The negative effects of variable weather may possibly be reduced by sowing at an earlier date. Whether this is possible or not, depends on the harvest date of the previous crop and the weather and soil conditions.

More detail about the climate factors that are considered as risks and the required adaptation measures is given in Table 6.7, also for potato and sugar beets. For each climate factor a number of measures are described and for each measure the scale (e.g. field, farm, or sector) at which it can be applied, its effectiveness, and the costs involved are given. Also it is described if the information about the adaptation measures can be used in crop modeling to calculate for example the actual yields. More discussion about this point is given in section 6.4 and in particular in its last paragraph.

¹⁾ see Tables 6.2. and 6.3 for further information

²⁾ Indication of the maximal annual management costs in Euro x 1.000 per hectare (see De Wit et al., 2009, annex 3 for further information)

³⁾ Indication of the maximal one-time investment costs in Euro x 1.000 per hectare (see De Wit et al., 2009, annex 3 for further information) nd: not determined because of insufficient information

Table 6.7 Climate factors that are considered as risks and adaptation measures for potato, winter wheat and sugar beet in 2050; for each measure the scale at which it can be applied, its effectiveness, the costs involved and its possible use in crop modelling are described

Crop	Climate factors and potential impact (period of impact)	Crop loss profile	Adaptation measures	Spatial level	Effectiveness	Cost estimate of adaptation and constraints	Evaluation possible with a cropping system model
1) Ware potato and seed potato	1) High intensity rainfall – partial rotting of harvest (May-Sept. (Ware potato), May-Aug-(Seed potato))	High	1) Improve the hydraulic conductivity of the soil by improving the soil structure (adoption of best practices) 2) Improve the surface drainage 3) (Intensive) drainage 4) Breed variety that can cope with water stress	1) Field/Farm 2) Field 3) Field 4) Sector	1) Low 2) Medium – high 3) High 4) Unknown	1) Low –high, variety of measures available 2) Low 3) Medium 4) High, if at all possible	1) maybe possible if crop model does include detailed modeling of soil processes 2) no 3) maybe possible if crop model does include detailed soil process and data that determine the water holding capacity 4) yes if threshold of new variety is known otherwise no
	2) Heat wave – Second growth (July-Sept.)	High	1) Plant potatoes in wide beds with more soil cover 2) Choose a variety that allows early planting and harvesting 3) Cooling by drip irrigation 4) Better crop cover by optimal planting distance and plant nutrition 5) Breed heat resistant variety	1) Farm 2) Field 3) Farm 4) Farm 5) Sector	1) Medium – high 2) Medium – high 3) High 4) Low – medium 5) Unknown	1) Medium 2) Low 3) High 4) Medium 5) High	1) maybe, with assumptions about the consequence of heat stress 2) partially 3) maybe, with assumptions about the consequence of heat stress 4) partially, crop cover might be simulated 5) no
	3) Warm and Wet – Erwinia spp. (July-Sept.)	High	Breed resistant variety against Erwinia spp. Biological control Optimal plant nutrition (healthy plant is less vulnerable)	1) Sector 2) ? 3) Field/Farm	1) Medium (but is largely unknown) 2) ? 3) Low - medium	1) High 2) ? 3) Low	1) no 2) no 3) no

	4) Warm Winter – Problematic storage (DecMarch.)	Medium - Low	Mechanical climate control Germination control by with chemicals Breed new variety	1) Farm 2) Farm 3) Sector	1) High 2) High 3) Unknown	1) Medium 2) Low 3) High	1) no 2) no 3) no
2) Winter wheat	1) Long dry period – yield decrease (June- Aug.)	Low	Increase the soil water holding capacity of the topsoil Breed a drought resistant variety	1) Field 2) Sector	1) Low - Medium 2) High	1) Low 2) High	1) maybe, if soil parameters are well validated in the crop model 2) partially, by simulation of existing varieties
	2) Frost and thawing – root damage (Nov March)	Low	1) Early sowing	1) Farm	1) Low	1) Low	1) yes
3) Sugar beet	1) Warm winter – decrease of sugar content (DecMarch)	Low - Medium	1) Prevent damage to beets during harvest, transport and building storage heap 2) Prevent soil(tarra ??), plant material and weeds to be included in storage heap (in order to have optimal ventilation) 3) Make storage heap max. 2 m high and not too wide 4) Mechanical ventilation 5) Optimise planting distance (big beets loose less sugar content than smaller beets) 6) Grow beet variety that has less losses of sugar content 7) Shorten storage time (earlier delivery at sugar factory)	1) Farm? 2) Farm? 3) Farm 4) Farm 5) Farm 6) Farm 7) Sector	1) Low – medium 2) Low 3) Low – medium 4) Medium – high 5) Low – medium 6) Medium 7) High	1) Low 2) Low 3) Low 4) Medium 5) Medium 6) Low 7) High	1) no 2) no 3) no 4) no 5) no 6) no 7) partially yes

Other climate factors and measures

The following threats are not described in the dataset, because the relationship between specific weather conditions and their impacts is insufficiently clear and/or too complex. If it is prolonged dry during the beginning of the growing season, the fungi yellow-rust may infest the crop and may give severe damage later on. The infestation occurs first mainly on the leaves but if the development of the fungi goes further (under moderate temperatures), also stems and ears will be affected. Drought at the beginning of the growing season promotes development of rust or yellow rust.

If aphids infect the crop in September-October and survive the winter, this may result in severe damage in spring due to barley-yellowing disease. In addition to more resistant variety selection, yellow rust can be effectively treated by applying biocides.

The farmer has no possibilities to combat the barley-yellowing virus. The only approach is to prevent the spreading of aphids. Yield losses can be prevented by the farmer through:

- Biocide application
- Later sowing date

An early natural attack by e.g. beetles and spiders may prevent that aphids migrate and may infect more plants. The sector may take measures to develop a resistant wheat variety. Several research projects on this topic have been carried out abroad.

Positive results of climatic change

Permanent wet weather will occur in the future less often, which might lead to improved trafficability during the harvest period (July - August).

Summary

Possible climatic risks for winter wheat cultivation are prolonged drought in the summer and variable weather in the winter. There are measures available to prevent or limit the damage from these climate factors. Besides, the effect of variable weather on the yield is probably very limited, making this effect no focus point. It is possible that (yellow) rust and barley-yellowing diseases may become a larger problem and require more attention (e.g. more biocide application and/or development of resistant varieties).

6.4 Discussion of potential and limitations of the Method

For the main crops in Flevoland, the Agro-climate calendars give the possible impacts of unfavourable weather conditions on crop growth and yields. Using climatic data, the frequency of such unfavourable weather conditions in sensitive periods per crop type can be determined for the current climate in Flevoland. Next, for the different KNMI future climate scenarios (Van den Hurk et al., 2006) the changes in these frequencies per crop type can be determined.

In a next step we need to translate the frequency of unfavourable weather conditions during sensitive periods per crop type and the change in their frequencies per crop type for a climatic change scenario for 2050 into a relative yield reduction per crop type for that scenario. This would allow to correct both future mean yields and yield variations for scenario weather conditions. Furthermore, costs and benefits of adaptation strategies need to be quantified, in order to assess whether farmers (see Chapter 8-10) are likely to adopt these strategies or not. However, see the remarks in the next paragraph.

In the quantification of consequences of extreme events some points should be considered: a) actual yields have a yield level that is lower than the potential yield level, being partly due to the factors (e.g. disease losses, delayed operations) described in the agro-climate calendars; b) cumulative yield losses indicated in the agro-climate calendars (Table 6.3) are generally higher than the average actual yield gap (=potential yield minus actual yield), c) the agro-climate calendar (ACC) information cannot easily be quantified in such a way that it can be used to calculate the mean yields and yield variation for future scenario conditions and even to calculate the yield changes under scenarios of climatic change, d) the strong point of the ACC approach is the elaborate information about the impacts of unfavourable climate conditions on crop growth yields, about the degree that such impacts may become more frequently under different scenarios of climatic change in the future and the required adaptation measures, e) model simulations of crop growth and yields for future scenario climates assume generally optimal crop management and sufficient management adaptation under a changing climate, because for the long term technological development cannot be separated from adaptation; this means that the adaptation measures under point d are taken for granted as part of technological progress.

We propose that initially the actual yields for future conditions in 2050 are calculated in the straightforward way as described in Chapter 5, considering point e as mentioned above. This means that the information on climate risks (i.e. effects of extreme events) and adaptation strategies is not integrated in the methodology for yield calculations. It complements the yield calculations, as it indicates which adaptation is required to prevent damage from climatic risks and indeed obtain these projected yields. However, this implies that the adoption and impact of adaptation measures is not explicitly assessed for 2050.

To also explicitly address adoption and impact of adaptation measures, we perform an additional assessment for 2010, assuming climate conditions of 2050, reflecting an extreme climate year. For 2010, no technological development is assumed and therefore, this does not interfere with the adoption of adaptation measures. In order to integrate the impacts of climatic risks and adaptation measures to extreme events and the actual yield calculations, the first need to be quantified into yield reduction factors. Exact damage of climatic risks, and costs and benefits of adaptation measures cannot be calculated, as these largely depend on local conditions and farm management. Furthermore, climatic extremes do not give an average yield reduction, but only in the years in which they occur. One option is to use the average of the estimated damage range (see Table 6.3) and another option is to improve the yield reduction with new knowledge based on empirical data (Chapter 7), and translate

these into reduction factors due to extreme events for yields without (current activities) and with adaptation (alternative activities). In farm models (Chapter 8-10) the possible adoption of the adaptation measures and their impacts can be assessed. Sensitivity analyses can be performed to investigate whether the adoption of the adaptation measures are sensitive to estimates on the damage of climatic risks, costs and benefits of adaptation measures, or frequencies of climatic risks. Another option is to use an approach that does not force to quantify the effects directly, but to use a method that allows fuzzy quantification. Fuzzy set theory (see e.g. Rufino et al., 2007) allows to value influencing factors (e.g. damage) as low, medium or high, and aggregating the different influences into yield reduction factors between 0 and 1, using if-then functions.

7 Analysis of the effects of extreme events on crop management, yields and yield quality

7.1 Introduction

Along with rising temperatures, climate scientists anticipate an increasing incidence of weather extremes. Weather extremes are still poorly understood. Firstly, we lack proper definitions of weather extremes. There are 1001 definitions of weather extremes possible, but just a few of them have a noticeable effect on crop yields or quality. We do not yet know which are the weather extremes that really matter. Secondly Global Circulation Models are, with their course spatial scale, poorly equipped to predict future incidence of extremes. Thirdly we cannot trust crop growth models to simulate the effect of weather extremes since they have in general not been calibrated under those conditions. Data to investigate weather extremes are often lacking. What we will show below is that for a selected number of crops in the Netherlands sufficient data are available to identify and define those weather extremes that have an impact on potato and sugar beet production, quantify their effect on loss of production and quantify the past and future frequency of these extremes.

7.2 Description of the Methodology to analyse the effects of extreme events

In short, our method was to:

- 1. Compile time series of crop yield data (e.g. Figure 7.1)
- 2. Select years and locations in which production was significantly lower (> 20%) than expected on the basis of the long term trend
- 3. Find out what happened in those years based on reports. This in almost all cases turned out to be qualitative definitions of weather extremes
- 4. Link time series of crop yield data to a weather station (Figure 7.2)
- 5. Calibrate and validate quantitative operational definitions of weather extremes
- 6. Calculate past and future frequencies of the extremes.

Data sources were (1) annual reports from experimental farms, all publicly available through the library of Wageningen University, (2) regional statistics from www.bietenstatistiek.nl, www.irs.nl/zaaidata/central.asp and www.cbs.nl and (3) weather: historical from <a href="https://www.knmi.nl and downscaled scenarios of climatic change from www.knmi.nl/klimaatscenarios/index.php. The annual reports often contained qualitative descriptions of the weather each year as needed in step 3 above.

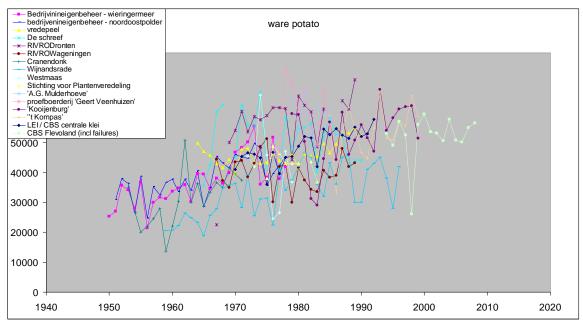


Figure 7.1 Time series of ware potato yields (kg/ha)



Figure 7.2 Location of potatoes, rainfall weather stations and official weather stations in the 12 provinces of the Netherlands. Fine dots: potato, small black dots rainfall stations, grey circles official KNMI weather stations

7.3 Short example of the analysis of the effects of extreme event from field trial information

The year 1998 was a dramatic year for Dutch ware potato production (Figure 7.1), for the whole of the country. Written reports indicate the end of season was so wet that farmers had problems in harvesting their crop. Depending on the soil type and the part of the country, between 13% (Overijssel, sand) and 56% (Zeeland, clay) of the area planted with ware potato was not harvested. We first studied total rainfall in September + October, for the provinces of the Netherlands and for the 15 years (1994-2008) in the timeseries from www.cbs.nl. This analysis showed that indeed 1998 had an exceptionally wet sept+oct, but there were also other years (1994, 2001), in which similar amounts of sept+oct rainfall as in 1998 fell in parts of the country, but with no harvesting problems. Through trial and error we searched for a more accurate definition, which is shown in Figure 7.3. Based on these we can define our weather extreme for Flevoland as: "rainfall from 20-aug till 4 nov > 300 mm" and we can estimate (Table 7.1) which % of the land is not harvested. Thresholds and % not harvested may differ between regions.

Table 7.1 Models for predicting % of area of ware potato not harvested.

Those 7:1 Tribues for premering 70 by their by	010110 1101 13011 1 0010011	
Region	% not harvested	Threshold (mm rain
		in 20 aug-4 nov)
Zeeland + Noord-Brabant (ca 40 % of	0.86*(rainsum-280)	280
total ware potato area on clay)		
Flevoland + Zuid-Holland (ca 42 % of	0.4*(rainsum-300)	300
total ware pot area on clay)		
Limburg + Noord-Brabant (64 % of total	0.21*(rainsum-280)	280
ware potato area on sand/peat)	•	

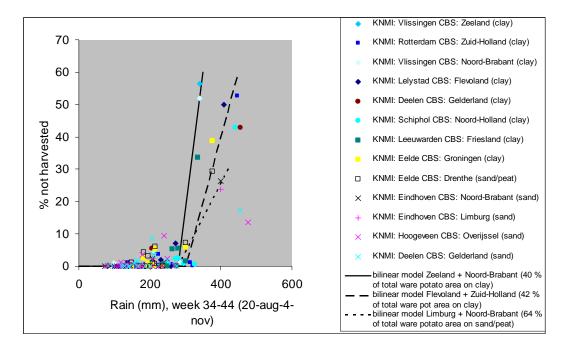


Figure 7.3 Harvesting problems associated with extreme rainfall, with on the x-axis the sum of rainfall over the period 20 aug. to 4 nov.

7.4 Example how to use the results from the analysis of extreme events towards 2050

7.4.1 Historical frequencies

How often does an extreme like 1998 occur, and may we expect more of this extreme in the future? For the past we checked how often the thresholds of 300 mm (start of risk of harvesting problems) and 350 mm (serious problems) was exceeded. Table 7.2 next page shows for the official KNMI stations those years in which the threshold was exceeded. Frequencies are shown in columns F300 and F350:

- > 300mm: on average once in 20 years (8 36, varying spatially)
- > 350mm: on average once in 42 years (0 104, varying spatially)

For example for De Bilt, there are 7 years > 300 mm over a period of 104 years (1906 to 2009), so the average frequency (F300) is once in 15 years. The results indicate that the frequencies vary spatially, with the North Sea coast having a higher frequency than the inland. Calculation of the extremes is quite sensitive to the start date of the time series and one could argue that most of the time series are too short to make inferences about the frequencies of the extremes. 1998 was the largest extreme in its kind and occurred in the whole of the Netherlands. The second largest extreme, in 1974, occurred only in the west of the country (where a large part of the potato production occurs). Newspapers and senior researchers confirm that indeed 1974 was the second largest extreme and that it occurred only in the west. This confirmation increases our confidence in the accuracy of our definition of this weather extreme. One interesting fact about the 1974 extreme is that in 1974, the army was employed to help in harvesting, because problems were so big.

7.4.2 Future frequencies

For each of the stations in Table 7.2 we also show the frequencies in the KNMI downscaled climatic change scenarios. A green colour indicates the extreme will occur less often, a red colour indicates it will occur more often. The impacts of climatic change vary spatially and vary between scenarios. Change in atmospheric circulation is more important than change in temperature. In case of no change in circulation (G, W), the scenarios indicate a higher frequency of the extreme. If atmospheric circulation changes strongly (G+, W+) then in some locations the frequencies increase and on others they decrease.

Table 7.2 Past and future frequency of rainsum 20 aug. to 4 nov. being larger than 300 mm

Table 7.2 Pasi and juliure frequency	, ,					0	3											2006 - 2035		
stn	12	18	32	57	60	68	74	92	94	98	00	01	04	first	F300	F350	G^*	G+*	W^*	W^+
Valkenburg (Zuid-Holland)							375		303	412		324	304	1972	8	19	6	15	8	15
De Kooy (Noord-Holland)				328	327		391	309	325	388	319			1957	8	27	5	8	5	6
Schiphol (Noord-Holland)										441			325	1971	20	39	6	8	6	10
De Bilt (Utrecht)	323	304	319	330	312				302	470				1906	15	104	10	3 0	10	15
Soesterberg (Utrecht)										420				1974	36	36	15	15	10	30
Leeuwarden (Friesland)										336			301	1974	18		15	15	10	30
Eelde Groningen)				303		334				376		302		1957	13	53	15	15	15	30
Twenthe (Overijssel)										404				1974	36	36	30	30	30	30
Vlissingen (Zeeland,																				
Brabant)					301		396			341				1957	18	53	15	3 0	15	15
Rotterdam (Zuid-Holland)							351		320	447		314		1974	9	18	6	6	6	10
Volkel (Noord-Brabant)										421				1974	36	36	30	30	30	30
Maastricht (Limburg)					318					339				1957	27		30	30	30	30
Average	323	304	319	321	315	334	378	309	313	399	319	313	310		20	42				

^{*}KNMI scenarios: G, G+, W and W+, see Table 3.1 for their characteristics

7.5 Discussion of potential and limitations of the Methodology

A strength of our method is that it is based on empirical data. That way we avoid the risks of artefacts that one could get when using crop growth models and we avoid the risk of a blind eye for processes not included in models. For example, harvesting problems are not included in crop models. And often in climatic change impact studies a fixed sowing date is assumed whereas our analyses (not shown here) indicate that in the Netherlands a prolonged wet start of the season can cause strongly delayed sowing resulting in losses of production of more than 20%.

A limitation of our method is that it is as good as the quality of the input data. For example if there are no data on quality of harvested product, then we will not be able to investigate weather extremes that affect product quality. A second limitation of our approach is its narrow focus on weather and crop. The harvesting problems in the 1998 event depend on the inflow of rain water but also on water holding characteristics and drainage of the soil. The adaptation option to increased frequency of this weather extreme is therefore also clear: improve the drainage. Quantitative recommendations are however more difficult to make, and would require data and modeling of:

- the full water balance including management interventions to improve drainage;
- the economics of management interventions, which in turn depend a.o. on frequencies of the extreme.

While the lack a water balance in our model may be considered a limitation, it can at the same time be considered positive thing. Even without more detailed information on soil and drainage, we can just on the basis of total rainfall predict when serious harvesting problems will arised.

Our analysis provides comforting and worrying results. Comforting is the fact that it is possible to derive definitions of weather extremes. There are sufficient data, in any case for the crops potato, sugarbeet and winter wheat. Preliminary results indicate that the largest losses of production in the past 50 years in ware potato were caused by a prolonged wet start of the growing season which delayed sowing and by a prolonged end of the growing season which caused harvesting problems. This is worrying because these happen to be weather extremes that meteorologists say are very difficult to predict. And it is also worrying because climatic change scenarios are particularly uncertain about possible changes in rainfall in spring and autumn.

Results thus far indicate that weather extremes do have a large impact on actual production. The methods and data allow for better defining these weather extremes and quantifying their impact and frequencies. To our best knowledge this has to date not been done for the Netherlands.

8 Optimization of the farming systems in Flevoland with FSSIM model for scenarios in 2020

8.1 Introduction

Bio-economic models can be used for integrated assessment of policy decisions. They have been also used in future oriented land use studies to explore options for future development and facilitate negotiation between stakeholders. The main objective of this type of analysis is to calculate trade-offs between various criteria and demonstrate consequences of decisions. A large number of different scenarios can be tested and sensitivity analysis is performed to deal with the uncertainty involved for some parameters of the study. A typical bio-economic farm model, which has been used within SEAMLESS for integrated assessment of agricultural and environmental policies is the Farm System SIMulator (FSSIM). As it will be demonstrated in the next paragraphs, FSSIM can be an useful tool in Agri-Adapt for detailed exploration of adaptation strategies of farmers in the Netherlands. The presented example is related to nutrient management; in the application phase of the project we will elaborate adaptation measures.

8.2 Short description of the FSSIM model and its use for 2020

The main objectives of FSSIM are to calculate price-supply relationships of arable farming systems across the European Union (EU) and to enable detailed policy analysis at regional level. In Agri-Adapt FSSIM could be used for detailed policy analysis at regional level. FSSIM for arable farms consists of two main components (7.1). The first component, is the agricultural management component (FSSIM-AM), which is used to identify, generate and quantify the technical coefficients (inputs and outputs) of current and alternative activities (Janssen *et al.*, 2010) while the second component is a constraint optimization model (FSSIM-MP) which is used to evaluate different scenarios by allocating activities to the available farm land (Louhichi *et al.*, 2010).

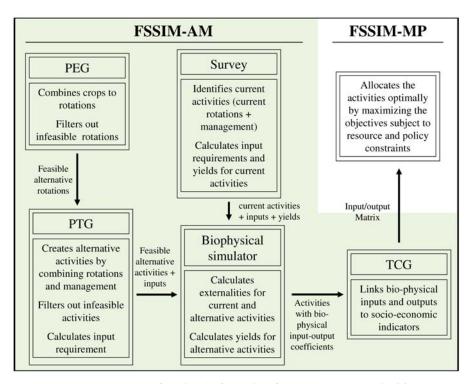


Figure 8.1: Functionality of and relationships between components of FSSIM

8.2.1 FSSIM agricultural management (FSSIM-AM)

The agricultural management component of FSSIM consists of a number of sub-components which are presented in Figure 8.1 and are briefly described below. A more detailed description can be found in Janssen (2009).

The current activities, which are combinations of rotations and management options that are currently practised in the farm types of a certain region, were identified in a survey (Borkowski et al., 2007; Zander et al., 2009). Important input-output coefficients (e.g. yields, nitrogen application, pesticides) and prices are collected based on advisory handbooks and knowledge of experienced crop scientists. These input output coefficients are then used in bio-economic farm models to enable the calculation of a number of agro-ecological indicators.

Crop rotations that are not currently used in the region are generated in a combinatorial procedure, the Production Enterprise Generator (PEG) (Janssen, 2009). A number of crops, which are either available or expected to become available in the future are combined in crop rotations. The PEG is an extension of ROTAT (Dogliotti et al., 2003). It is assumed that the areas of all crops in each rotation are equal (e.g. each crop of a four year rotation of four different crops gets 25% of the total area) and all crops of a rotation are grown every year. In this way interactions between crops can be taken into account in a static way. A number of agronomic filters related to crop frequency and crop sequence are used to filter out rotations that are not feasible from an agronomic point of view because of characteristics of the crops and the bio-physical environment (e.g. crop rotations with a large share of crops vulnerable to soil-borne pests and diseases are filtered out because they would never be selected by the farmer due to substantial yield losses). Expert knowledge, empirical data and the literature are used to design such filtering rules.

The Production Technique Generator (PTG) (Janssen, 2009) describes current and alternative production techniques (i.e. water management, nutrient management, pest management, conservation management, planting-sowing and harvesting) for each feasible rotation (both current and alternative) generated by PEG. Most of the production techniques are defined per crop in the rotation but interactions between the different crops can be taken into account (e.g. N-inputs of a specific crop might be reduced in case the previous crop is a legume and/or if crop residues are incorporated into the soil). Filters related to production orientation (e.g. organic, conventional, irrigated) are used to filter out inconsistent activities.

The current and alternative activities (combinations of rotations and managements) and their input requirements can be assessed with a biophysical simulation model which quantifies yields and externalities. The Technical Coefficient Generator (TCG) (Janssen, 2009) links the input requirements, the yields and the externalities to economic parameters (prices and costs) to formulate the matrix of input-output coefficients that can be used in a bio-economic farm model like FSSIM-MP.

8.2.2 FSSIM mathematical programming (FSSIM-MP)

The mathematical programming part of FSSIM (Louhichi et al., 2009) is a model that maximizes an objective function (e.g. gross margin or utility) subject to a set of resource and policy constraints. Positive Mathematical Programming (PMP) is used to calibrate to the observed activity levels (Kanellopoulos et al., 2010). Activities generated by the agricultural management component of FSSIM are optimally allocated to the available farm land. Since the areas of crops in a rotation are fixed in the process of generating the activities there is no need for additional rotational constraints. The mathematical programming part of FSSIM is designed to be generic and easily adaptable to new regions and farm types (Louhichi et al., 2010). The constraints and objectives of the model can be easily switched on and off depending on the policy question, the farmer's objectives and the geo-political framework. A general formulation of FSSIM-MP is the one presented in (1).

$$\max \ f(x), \quad subject \ to: \ Ax \le b, \ x \ge 0 \tag{1}$$

Where f(x) is the farmer's objectives, x is a $n \times 1$ vector of available agricultural activities (current and alternative), A is the $n \times m$ matrix of input-output coefficients and b is the $m \times 1$ vector of the right hand sides of the policy and resource constraints (e.g. the available land constraint per soil type, the on-farm available labour constraint, the irrigated land constraint, the sugar beet quota constraint and the obligatory set-aside constraint).

8.3 Short example of the application of the Methodology

A good demonstration of the applicability of FSSIM for future oriented land use studies including alternative activities, has been presented in Kanellopoulos (2010). A similar setup is used here to demonstrate the type of analysis that is aimed by FSSIM and to provide an overview of the advantages and disadvantages of the method.

8.3.1 Background Information

In Flevoland, dairy farms import nutrients in the form of concentrates. Although a part of these nutrients return to the grasslands as organic manure for fertilization, a substantial surplus remains. The last decades, manure production, nutrient accumulation and reduction of nutrient surpluses have been the topic of policy debate (Berentsen and Tiessink, 2003). A viable option for reducing the nutrient surplus is to use manure on arable land replacing artificial fertilizers. A relevant question concerns the effects of an alternative management of arable crops where more organic manure is used to cover the nutrient requirements of the crops. A bio-economic farm model like FSSIM could be used to assess the consequences of such a decision on a number of important indicators for arable farms in Flevoland.

8.3.2 Generating rotations

The agricultural management component of FSSIM was used to generate alternative rotations which are feasible from an agronomic point of view and quantify their inputs and outputs. In total 8 crops that are currently grown in Flevoland (i.e. fodder maize, onions, potatoes, spring barley, spring soft wheat, winter soft wheat, sugar beet, set-aside) and 3 crops that according to experts may become more important in the near future due to economic and political changes (i.e. peas, winter rape seed, and tulips) were combined in rotations of maximum 5 years using the PEG. A number of filters of the PEG were used to select only the ones feasible from an agronomic point of view. Those filters are related to crop frequency, crop repetition, crop sequence, maximum number of different crops in the rotation, frequency of crop groups (e.g. cereals, oil seeds), repetition of crop groups, sowing dates and harvesting dates. According to experts, a crop frequency of tulips lower than 1 to 6 years is not possible because of increased incidence of pest and diseases and associated phyto-sanitary risks. To include rotations with tulips we also allowed 6 year crop rotations but only those with tulips. Clay soils are most common in Flevoland and for that reason only clay soils were simulated in this exercise. After the filtering procedure the full set of activities numbers 831 activities that will be evaluated in FSSIM-MP.

8.3.3 Crop nutrient management

The starting point for the management of the activities was that from the survey for Flevoland (section 3.1). For alternative activities, for each crop we used two different management options with respect to nutrient application. The total nitrogen application and the achieved yields were assumed the same in both management options but the type of fertilizers (artificial and/or cattle slurry) differ. The first management is the one that is currently mostly used in the region and it is based on artificial fertilizers (thus the data from the survey), while the second one is an alternative nutrient management which is based on (partial) replacement of fertilizer by organic manure (cattle slurry). Artificial fertilizers were used in the second option only when this was necessary to meet the crop's total nutrient requirements. The one to one replacement of part of the nitrogen coming from artificial fertilizers with organic manure is possible only because the current nitrogen input from fertilizer in Flevoland is very high. Activities with applications of cattle slurry have higher labour requirements (Table 8.1) but also higher gross margins because of lower costs for fertilizers. To reduce the number of activities to feasible and operational levels we did not allow for combinations of crops with different management options in the same rotation. The nutrient management of all crops in a rotation is either based on artificial fertilizers (current management) or the management with cattle slurry complemented with artificial fertilizers when this was necessary. This decision limited the number of activities to only twice the number of rotations.

Important environmental indicators of the activities, like nitrogen leaching and content of soil organic matter were quantified using NDICEA (Van der Burgt et al., 2006). The NDICEA model uses region specific soil and climate data and crop-specific information to calculate states and flows of nutrients. The user defines a yield and nutrient inputs in different forms (e.g. artificial fertilizers, livestock manure) and the model calculates the nutrient balance based on the weather, soil, crop's nutrient requirements, nutrient uptake rate and nutrient availability which is different for chemical and organic fertilizer. In NDICEA, when the user defined yields are not attainable with the given inputs (the nutrient uptake of the crop is higher than the available nutrients in the soil) the user have to adjust inputs and/or outputs so that nutrients available are always higher than nutrient uptake. It was assumed that cattle slurry can only be applied before sowing and artificial fertilizers were used when necessary to keep the available nitrogen well above the uptake during the season. More precisely, by choosing the proper combination of artificial fertilizers and cattle slurry, it was taken care that the available nitrogen was at least 20 kg N/ha above the nitrogen uptake of potatoes, onions and sugar beet and 10 kg N/ha above the nitrogen uptake of cereals and other crops. The nutrient composition of cattle slurry (i.e. 4.9 kg N, 1.8 kg P₂O₅ and 6.8 kg K₂O per ton of cattle slurry) available in NDICEA was used for calculations. The amounts of phosphate and potassium in the management with cattle slurry were at least equal to the application of the current management. Artificial phosphate and potassium fertilizers were added if necessary (i.e. peas, seed potato). For this exercise, to reduce the computational requirements we used NDICEA to calculate nutrient surplus of individual crops. It was assumed that differences between nutrient inputs of different rotations with the same nutrient management were only caused by different shares of crops in the rotations.

Table 8.1: Crop specific information, inputs and outputs for two different nutrient managements in Flevoland.

				N	lanagemen	t with artific	ial fertiliz	ers	Mar	agement w	ith cattle ma	anure and arti	ficial fertil	izers
	Harv est (wk)	Sow (wk)	Yield (tons/ha)	Gr. margin (€/ha)	Labor (hrs/ha)	Fertilizer s (kg N/ha)	N- leachi ng (kg N/ha)*	Organic matter change (score)	Gr. margin (€/ha)	Labor (hrs/ha)	Manure (tons/ha)	Fertilizers (kg N/ha)	N- leachin g (kg N/ha)	Organic matter change (score)
Barley (spring)	32	10	6.3	1199	9.6	120	87	4.0	1264	16.2	24		46	6.0
Maize (silage)	41	17	40.8	533	7.1	185	135	2.5	662	13.7	38		69	5.2
Onions	36	14	58.4	3099	37.6	220	168	2.5	3249	44.2	40	24	98	6.0
Peas	30	13	5.7	1309	6.6	30	102	4.0	1340	13.2	6		100	4.2
Potatoes (seed)	33	15	38.7	4325	90.0	180	125	2.8	4418	96.6	20	82	93	4.5
Potatoes (ware)	39	15	56.8	3820	27.5	255	134	2.7	3945	34.1	30	108	81	5.0
Rape (winter)**	30	42	3.3	497	11.5	180	89	11.3	571	18.1	30	33	66	12.6
Set-aside	-	-	-	388	0.1		116	1.0	388	0.1			116	1.0
Sugar beet	42	14	65.5	2147	19.6	170	69	5.0	2218	26.2	19	77	41	7.0
Tulips	26	5	18	12974	604.0	120	167	1.2	13049	610.6	24		126	3.5
Wheat (spring)	36	11	7.8	1097	9.6	175	72	6.0	1158	16.2	25	53	32	7.7
Wheat (winter)	32	42	8.7	1324	10.4	205	74	8.8	1369	17.0	18	117	60	9.4

^{*} No cover-winter crops were used for calculating the N-leaching.

** According to current management straw of cereals is removed while straw of winter rape (alternative crop) was incorporated into the soil.

To account for crop frequency effects on crop yields (increased incidence of pest and diseases and phyto-sanitary risks) we used a yield correction factor which depends on the frequency of a crop in the rotation (Habekotté, 1994). The crop yields from the survey of current activities (Table 8.1) were corrected according to the frequency of the crop in the rotation using the correction factors of Table 8.2. It was assumed that the increased incidence of pest and diseases did not affect the nutrient inputs and the nutrient uptake of the crop.

Table 8.2: Yield correction factor for different crop frequencies (the value of one corresponds to yield from the survey).

	Frequency (ha of crop per ha of rotation)							
Crops	1:1	1:2	1:3	1:4	1:5	1:6		
Potatoes (ware)	0.86	0.98	0.98	1	1.05	1.10		
Potatoes (seed)	0.86	0.98	0.98	1	1.05	1.10		
Onions	0.92	0.94	0.96	0.98	1	1.02		
Sugar beet	0.55	0.66	0.78	0.95	1	1.05		

8.3.4 The bio-economic farm model

It was assumed that the farmer of an average farm in Flevoland maximizes the gross margin subject to the available land constraint, the labour availability constraint, the obligatory set-aside constraint and the sugar beet quota constraint. Two additional constraints were used to set an upper bound to the total nitrogen leaching and a lower bound to the soil organic matter content. These two last constraints can be seen as imposed restrictions of a hypothetical policy instrument that aims to restrict environmental impacts of arable farms.

8.3.5 Optimizations

To present the type of results expected in such a bio-economic analysis we performed three different optimizations.

- 1. An optimal farm plan was calculated for an average farm type in Flevoland. The resource endowments of the average farm type were calculated as weighted averages of the identified farm types of the SEAMLESS farm typology (Andersen *et al.*, 2007). No decrease in total content of soil organic matter was allowed.
- 2. Same as simulation 1, but now with different combinations of lower bounds on the total change in content of soil organic matter and upper bound on the total N-leaching.
- 3. Same as 1, but now with different combinations of upper bounds on total labour requirements and total N-leaching.

The right hand side of the equations of FSSIM-MP for the three simulations are summarized in Table 8.3.

Table 8.3: Right hand side (all expressed per farm) of the equations in FSSIM-MP in the three simulations.

	Simulation 1	Simulation 2	Simulation 3
Objective	maximized	maximized	maximized
Available land (ha)	45	45	45
Available labor (hrs)	4754	4754	Parametric (from 0 to 5993)
Sugar beet quota (tons)	511	511	511
Obligatory set-aside (ha)	1.4	1.4	1.4
Change of organic matter (score)	225	Parametric (from 0 to 383)	225
Nitrogen leaching (kg N)	unbounded	Parametric (from 0 to 6555)	Parametric (from 0 to 6555)

8.4 Results

Results of FSSIM-MP for the average arable farm type in Flevoland (first simulation) are presented in Table 8.4. The selection of multiple rotations per farm was allowed in FSSIM-MP; three six-year rotation and one three-year rotation were selected in the optimum farm plan. For reasons of management and efficiency, in reality such a large number of crop rotations per farm might not be attractive to farmers; this could be solved by adding an extra constraint to the model. All six-year rotations included tulips which is the most profitable crop in the region. The higher labour requirements of activities with tulips are the reason for the three year rotation entering the solution. Activity 4 of Table 8.4 enters the solution because of the obligatory set-aside constraints and the high score in content of soil organic matter. Activity 3 of Table 8.4 enters the solution because of the obligatory set-aside constraint but also because of the lower labour requirements compared to activity 3. All constraints of FSSIM-MP except of the sugar beet quota constraints were binding. Despite the higher gross margins, activities with the alternative nutrient management (i.e. with cattle slurry) were only marginally selected (5.2 %) in the optimum farm plan. The reason for this are the higher labour requirements. Changing from conventional to alternative nutrient management increases the total gross margin with ca. 4, 2 and 2 % for simulated activities 1, 2 and 3, respectively. However, the labour requirements increase more, i.e. with 42, 6 and 5 %, respectively.

Table 8.4: Selected activities, corresponding inputs and outputs and farm level results in simulation 1 of Table 8.3.

		Simulated activities					
	1	2	3	4	level results		
Number of periods							
Period 1	Spring barley	Sugar beet	Set-aside	Set-aside			
Period 2	Potatoes	Winter wheat	Onion	Onion			
Period 3	Winter wheat	Potatoes	Winter wheat	Winter wheat			

Period 4		Winter wheat	Potatoes	Potatoes	
Period 5		Spring barley	Winter wheat	Winter wheat	
Period 6		Tulip	Tulip	Tulip	
Management	Fertilizers	Fertilizers	Fertilizers	Cattle slurry	
Gross margin (€/ha)	2071	3925	3937	4010	3770
N-leaching (kg N/ha)	98	101	122	90	103
Org. matter (score/ha)	5.2	5.1	4.2	5.7	5.0
Labour (hrs/ha)	16	114	115	121	106
Simulated level (ha)	3.9	32.7	6.1	2.3	45.0
Onion (ha)			1.0	0.4	1.4
Potatoes (ha)	1.3	5.4	1.0	0.4	8.2
Set-aside (ha)			1.0	0.4	1.4
Spring barley (ha)	1.3	5.4			6.8
Sugar beet (ha)		5.4			5.4
Tulip (ha)		5.4	1.0	0.4	6.8
Winter wheat (ha)	1.3	10.9	2.0	0.8	15.0

The trade off between gross margin, N leaching and change in soil organic matter of the second simulation of FSSIM-MP is presented in Figure 8.2. As expected, the gross margin increases with increasing allowed leached nitrogen, while it decreases with increasing the lower bound to the score of soil organic matter.

The trade off between gross margin, nitrogen leaching and total labour requirements of the third simulation of FSSIM-MP is presented in Figure 8.3. The gross margin increases with increasing labour availability and increasing level of allowed nitrogen leaching.

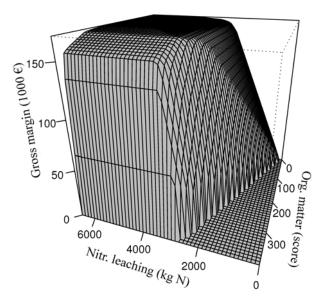


Figure 8.2: Trade-off curve between total gross margin, change of soil organic matter and nitrogen leaching.

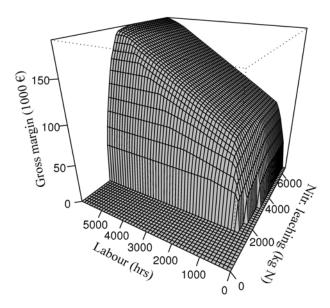


Figure 8.3: Trade-off curve between total gross margin, total labour requirements and nitrogen leaching.

8.5 Discussion of potential and limitations of the Methodology

The most important advantage of using a bio-economic farm model like FSSIM to explore alternative activities (and options for future scenarios) is the capacity of the approach to generate and assess a large number of alternative activities in a n explicit, transparent and reproducible way (using combinatorial procedures and filtering rules). Different scenarios and policies can be easily evaluated without major changes to the setup of the model.

A limitation of the procedure is that it requires detailed information on how technology (technical relationships) but also the prices of inputs and outputs will change in the future. This type of information is difficult to find in existing databases or to recover them using expert's knowledge and most of the time are treated as fixed information within the setting of the scenario. Of course the capacity of the procedure to deal with a large number of scenarios with out major changes to the model's setup compensates partially for this limitation (since many scenarios can be tested in limited amount of time). Sensitivity analysis can be performed relatively easy for a large number of parameters and calculate trade-offs between various criteria. Policy makers and stakeholders can be informed based on the trade-offs rather than the single model solutions.

Another limitation of the FSSIM type of modelling is related to the way activities are generated. A single activity is often far from what is observed in reality and many rotations needs to be combined to result in more realistic farm plans. Within a Linear Programming context this implies that many binding constraints need to be identified or a calibration procedure should be employed to add non-linearities by

recovering the un-observed parameters that are related to e.g. risk aversion, compensation and substitution. Parameters that are recovered with calibration based on historical data are not always valid for long term forecasts and for that reason a calibration solution is not always useful. For Agri-adapt NL a calibration procedure is preferable for short term predictions (e.g. 2010-2020) while a normative approach is preferable for longer term predictions (i.e. 2050).

The proposed optimization approach of the farming systems in Flevoland implied also that an average farm has a single objective function (i.e. maximizing gross margin) corrected for risk, thus no distinction has been made between objective functions of different farm types. To overcome this limitation a follow-up study will be performed aimed at assessing farm type specific climatic change adaptations at farm level under contrasting climate and socio-economic scenarios. In this study it will be assumed that arable farming systems in Flevoland are diverse in terms of their characteristics, agricultural performance and management styles (objectives) and thus are having different objective functions. We distinguish between farms that are focused on primary production (1), farms that also do nature conservation (2) and farms that get stable income from multifunctional activities (3). These farm types have been identified based on the methodological procedure described in Chapter 3. Adaptation strategies to be proposed for different farm types should account for the differences in farm objectives. Different sets of objectives will be identified for different farm types prior to assessment of adaptation strategies for these farm types with a bio-economic model FSSIM. The methodological procedure that has been specifically developed to deal with multiple conflicting goals and therefore is suitable for the aim of this study is Multicriteria Decision Modeling approach (MCDM) (Romero and Rehman, 2003). With the help of the MCDM procedure different farmers objectives will be assigned weights of importance that will later be used in FSSIM to assess farm type specific climatic change adaptations at farm level. In proposed follow-up study it has been decided to model typical arable farms in Flevoland rather than average farms. This will provide opportunities for getting feedback and model validation through multiple iterations with stakeholders (farmers).

9 Fixed cropping pattern method for main farm types in Flevoland for different scenarios in 2050

9.1 Introduction

FSSIM, a static mathematical programming model (Janssen & Van Ittersum, 2007), has been developed to quantify the integrated agricultural, environmental, economic and policy aspects of farming systems (Louhichi et al., 2006, 2010) and is suited to assess the responses of the major farm types to new policies and agro-technologies. More information about FSSIM is given in Chapter 8. FSSIM was calibrated on the cropping pattern in many regions over Europe, such as Flevoland, for a Base year (i.e. 2003), using PMP to calibrate FSSIM exactly to the observed activity levels. Simple survey data were used to define management, costs and prices, whereas FADN data were used to define the available resource endowments. Crops with high gross margins which however are not selected in practice, are made less attractive by the PMP method, assuming non-linear unobserved costs related to limited capacity for management of such crops.

For farm analyses for the year 2050 we know that FSSIM cannot be applied with the same objective function (i.e., including the PMP method), because we cannot establish to what extent such unobserved costs still apply in 2050. Furthermore, although images of future farms have been developed (Chapter 3) it is difficult to project to what extent farm structure in 2050 is related to the farm structure in 2003. Hence, we cannot relate the farm structure and the cropping pattern in 2050 to those in 2003. Hence, the FSSIM approach including the PMP method will be applied to the more nearby future (year 2020, see Chapter 8). For year 2050, being of interest from a climatic change impact point of view, we developed a much more simple approach (without optimization) that uses the input data for the Base year from FSSIM and gives roughly the same type of outcomes as FSSIM. The basic assumptions and ideas of this approach are described in section 9.2.

9.2 Description of the Fixed cropping pattern method

We can see that the cropping pattern in Flevoland in 2003 (see Table 9.1) is already near its economic optimum with 70 to 80% of the area cultivated with root crops (i.e. potato, onions and sugar beet) and will practically not change towards the future. Optimization of the cropping pattern with a model as FSSIM is then not needed. This means that we can use these cropping patterns also as an optimal cropping for year 2050. Additionally, we can use the data used for FSSIM modeling for Flevoland for Base year 2003 (see sections 9.1 and 9.3.2) also for this Fixed cropping pattern calculation. Data for 2050 can partly be based on the data from FSSIM modeling for the Base year, but are also based on assumptions about the long-term trends in the product prices, costs and yields (see section 9.3.3).

Relative changes in yields, product prices, variable costs, additional labour costs, farm size and subsidies towards 2050 are of course uncertain. This indicates the need for a simple approach that still can show in a clear way to what extent there are trade-offs and interactions between changes in these variables. For example, if the income level in the Dutch society increases more rapidly than the product prices, this means that a reasonable income of the farmer's family in 2050 cannot be achieved by continuation of farming in the same way (e.g. same crops and farm area) but should be attained by e.g.: a) larger size of farm, b) larger area fraction with specialized crops (e.g. tulips, vegetables) with a high gross margin, c) more income from non-farm activities (i.e. moving to multi-functional farm type and/or more external income), d) strong yield increase per ha, and e) higher subsidy level (e.g. for nature and/or landscape conservation).

Table 9.1 Cropping patterns on the main arable farm types in Flevoland, Netherlands in 2003

	11 01	3 31	•	
Farm type	Medium scale	Large scale	Large scale	Large scale
	High intensity Arable/Specialised	Medium intensity Arable/Specialised	High intensity Arable/Specialised	High intensity Arable/Others
Crop type	crops FT2303	crops FT3203	crops FT3303	FT3304
Spring				
barley	0.2	7.1	1.9	0.3
Sugar beet	3.1	11.2	9.1	1.3
Spring				
wheat	1.2	4.7	5.2	0.9
Fallow	0.0	1.8	1.3	0.9
Winter				
wheat	1.5	5.7	6.3	1.1
Fodder				
maize	1.5	2.0	0.6	0.1
Tulip	0.0	0.3	0.3	0.2
Peas	0.0	0.3	0.4	0.4
Onion	2.2	3.2	9.4	22.0
Potato seed	2.4	9.0	12.4	1.8
Potato ware	2.4	9.0	12.4	1.8
Winter				
rapeseed	0.0	0.0	0.0	0.0
Total area	14.5	54.3	59.3	30.8

9.3 Example of the application of the Fixed cropping pattern calculation method

9.3.1 Main steps of the application

Fixed cropping pattern calculations have been done for arable farming in Flevoland. First, this is done for the four main arable farm types in Flevoland in 2003 (see Table 9.1 for their crop rotations and total farm area). Second, the calculations are repeated

for the four main arable farm types in Flevoland with the same cropping patterns and farm area but for 2050. Third, the calculations are done again for 2050 and the same farm types but assuming a more specialized cropping patterns (e.g. tulips as included here, but may also be vegetables; they require relatively large labour and capital input). Fourth, the calculations are done for 2050 and the same farm types and cropping patterns (as in calculations 1 and 2), but with a tripled farm area.

9.3.2 Description of current farm types and assumptions for 2003

For the farm types in Flevoland in 2003 the product prices, yields, costs and labour demand are derived from the Simple management file for FSSIM. We used the data as specified per crop type on loamy soils. The subsidies as used in FSSIM calculations for 2003, are 298 euro per ha and are given to grain crops, fallow land, peas and rape seed.

Huib Hengsdijk (PRI) gives the following additional information about the compilation of the prices, yields, labour demand and costs in the Simple management file for Flevoland: 'Most numbers are based on KWIN (2001), 25th edition, PPO report 301 and for tulip based on KWIN bloembollen en bolbloementeelt (2005); most crop yields in KWIN (2001) are averages of 1995-1999; cereal output prices are the EU intervention or support prices in 2002, for other crops it is the average price level 1995-1999 or prevailing contract prices; all prices include VAT; total variable costs include costs for contract work, taxes, energy, N, P and K fertilizers, and crop protection. '

The cropping patterns in the four main arable farm types in Flevoland in 2003 (Table 9.1) are based on mean data per farm type calculated on the basis of data from the represented individual farms. Note that the used FADN data are for arable farms in the whole of the Netherlands and not only for Flevoland but that will practically not change the calculation results. We applied the following assumptions to attain the cropping pattern in Table 9.1: a) potato area is half ware and half seed potato, b) wheat area is 45% spring wheat and 55% winter wheat, c) fodder maize area is based on area of other fodder plants, d) onion area is based on area of field scale fresh vegetables, and e) tulip area is based on area of flowers open. The economic results for Base year 2003 from the Fixed cropping pattern calculations are given in Table 9.2.

Table 9.2 Economic results for Flevoland in 2003, assuming actual cropping patterns and farm size (Table 9.1) in 2003. Note that additional price for sugar beet is not taken into account

Farm type	FT2303	FT3203	FT3303	FT3304
Gross production (Euros)	51350	175292	232309	134935
Premiums (Euros)	863	5835	4507	1072
Variable costs (Euros)	23731	79883	106968	61608
Gross margin (Euros)	28483	101244	129848	74398
Labour demand (hour)	465	1767	2313	1211
Gross margin/labour hour	61.2	57.3	56.1	61.4

9.3.3 Description of future farm types and assumptions for 2050

We take the product prices, yields, costs and labour demand in 2003 as starting point (section 9.3.2) and next, we assume for year 2050 the following: a) trend of product prices for all crop types of +1% per year, b) trend of costs for all crop types of +2% per year, c) no change in labour demand compared to year 2003, considering the roughly 50% yield increase over time and assuming a similar increase in labour efficiency, d) yields in 2050 to be equal to 1.3 (due to plant breeding that results in more productive crop varieties) times the simulated potential (i.e. with sufficient water and nutrient supply and crop protection for optimal growth) yield for the Wclimatic change scenario from KNMI with a CO₂ concentration of 567 µmol/mol from the high emission scenario A1FI for 2050 (section 4.3) and some management adaptation times one minus the yield gap in 2050 (as crop management in Flevoland is nearly optimal, we assume that the yield gap will practically not change from 2003 to 2050; see section 5.4 for the actual yield calculation for 2050), e) subsidies to be reduced in 2050 to 85 euro per ha and to be given to grain crops, fallow land, peas, rape seed and fodder maize (as based on subsidies from FSSIM modeling for Base line scenario for 2013 which reductions are due to the effects of the CAP reform of 2003), and f) trend of labour costs of +2% per year.

The cropping patterns and the farm sizes in 2050 for the four main farm types in Flevoland are in the first calculation for 2050 kept similar to those for 2003 (Table 9.1). The economic results are given in Table 9.3. Next, the calculations are repeated for the same farm types for Flevoland in 2050, but with a more specialized cropping pattern. For this pattern, the following changes are applied: a) tulip area is 10% of total farm area at the cost of fallow and wheat area, b) onion area is increased at the cost of sugar beet area which area becomes nil. The economic results for the more specialized farms are given in Table 9.4. In the last calculations the cropping patterns are similar to those in 2003 but the farm size is tripled. The economic results are given in Table 9.5.

Table 9.3 Economic results for Flevoland in 2050, assuming cropping patterns and farm sizes to be similar to the ones in 2003 (Table 9.1)

Farm type	FT230	03	FT3203	FT3303	FT3304	
Gross production (Euros) Premiums (Euros) Var. costs (Euros) Gross margin (Euros)	132362 374 60181 72554	4459 1836 2025 2451	83	597244 1338 271270 327312	374617 315 156238 218693	
Labour demand (hour) Gross margin/labour hour	465 156.0	1767 138.7	•	2313 141.5	1211 180.5	

Table 9.4 Economic results for Flevoland in 2050, assuming farm sizes to be similar to the ones in 2003 (Table 9.1) but with more specialized cropping patterns in 2050. See the text for information about the main changes in the cropping patterns

Farm type	FT230)3 FT3203	FT3303	FT3304
Gross production (Euros)	227500	777446	941183	534102
Premiums (Euros)	247	1403	862	68
Var. costs (Euros)	92847	317269	388231	208355
Gross margin (Euros)	134899	461579	553814	325815
Labour demand (hour)	1411	5015	5813	2966
Gross margin/labour hour	95.6	92.0	95.3	109.8

Table 9.5 Economic results for Flevoland in 2050, assuming cropping patterns to be similar to the ones in 2003 (Table 9.1) but with tripled farm areas

Farm type	FT23	303 FT320	3 FT3303	FT3304
Gross production (Euros) Premiums (Euros) Var. costs (Euros)	397085 1122 180544	1337799 5508 607748	1791006 4007 813472	1123850 944 468715
Gross margin (Euros)	217663	735559	981541	656078
Labour demand (hour)	1396	5302	6932	3634
Gross margin/labour hour	156.0	138.7	141.6	180.5

9.3.4 Outcomes per farm type

Results for 2003 (Table 9.2) show that a) farm type FT2303 is mainly a weekend farm, b) premiums are not important for farm income, c) gross margins per labour hour are about 60 euro for all farm types, which is roughly similar to modal labour costs in the Netherlands.

Results for 2050 with similar cropping pattern and farm size (Table 9.3) show that a) gross productions increase over time for all farm types, b) gross margins increase for all farm types over time, c) gross margins per labour hour have changed from 60 to between 139 and 181 euro for the different farm types, d) assuming labour costs of 60 euro per hour in 2003 and an increase of $\pm 2\%$ per year, the labour costs become 152 euro in 2050; hence, about $\pm 100\%$ of the labour costs are covered by the gross margin under point c. Note that we have assumed (see section 9.3.3) a yield increase from 2003 to 2050 of about 50% due to climatic change, increased atmospheric $\pm 100\%$ and in particular genetic crop improvement in 2050. This assumption has a considerable effect on the outcomes (Table 9.3) which is discussed in the next paragraph.

If genetic improvement of crop varieties towards 2050 is considered to be much more limited or practically nil, the yield increase due to only climatic change and increased atmospheric CO₂ between 2003 and 2050 becomes about 20% for the

different crop types. This yield increase results in a much smaller increase in gross production and thus also in a much lower total gross margin and gross margin per labour hour, being about 90 euro per labour hour. If the labour costs in 2050 become about 152 euro per hour (see previous paragraph), this means that only 60 % of the labour costs are covered by the gross margin.

Results for 2050 with similar farm size as in 2003 but more specialized cropping pattern (Table 9.4) show that in comparison to the farm types with unchanged cropping pattern (Table 9.3) a) both gross production and variable costs become much higher, b) gross margin is almost doubled, c) labour demand has become 2.5 to 3.0 times as high, d) gross margin per labour hour has decreased from about 150 to about 97 euro, e) if the labour costs become 152 euro in 2050, only 65% of the labour costs are covered by the gross margin.

Results for 2050 with similar cropping pattern and tripled farm size (Table 9.5) show that in comparison to the farm types with unchanged farm size (Table 9.3) a) gross production, variable costs, gross margin and labour demand are all tripled, b) gross margins per labour hour are identical, being between 139 and 181 euro for the different farm types, c) if the labour costs become 152 euro in 2050, about 100% of the labour costs are covered by the gross margin, d) increased farm size may lead to a more efficient labour use for the cultivation of labour-intensive crops as onions, potato, and in particular tulips (i.e. scale effect), but this is not taken into account in these calculations due to lack of such information.

9.4 Discussion the calculation method and some results

The relative changes in yields, product prices, variable costs and additional labour costs, here assumed to be respectively about 1% (of which 0.3 % from climatic change and increased atmospheric CO₂ and 0.7% from genetic improvement), 1%, 2% and 2% per year, are strongly determining the economic results of the main farm types in 2050 in Flevoland. Therefore, projections on prices and costs will be further improved by data analysis and literature review. Specifically, we will analyze (a) covariance yield level and prices, (b) labour use efficiency: trends and relation with crop types and intensification, and (c) economies of scale, i.e. change in labour and other input costs with increasing size. We may assume that the effects of climatic change are of minor importance compared to the other factors (e.g. farm size and specialization, changes in product prices and variable costs, and yield increases due to genetic improvement of crops) for the economic results in the period towards 2050. In Flevoland, subsidies currently have a minor influence on gross margins of major farm types, and therefore it can be assumed that this will be similar in 2050. Nevertheless, smaller and more extensive farms are not expected to be viable in 2050 (Chapter 3); if society wants to keep these farms for environmental and social services, subsidies will likely be required and are essential for these type of farms.

Comparison of the calculation results with the previous ones for year 2050, in which the effects of genetic improvement of crop varieties respectively was and was not taken into account, indicates that such an assumption has a strong effect on the results. In the two cases respectively 100% and 60% of the labour costs are covered by the gross margin, of course assuming that the labour requirements are roughly similar. This shows that the economic results are strongly determined by rather uncertain assumptions about the increase in yield potential towards 2050 due to genetic improvement being 30 or 0%.

Fixed cropping pattern calculations should next be done for a range of different scenarios for farming in Flevoland in 2050. Such scenarios should indicate the plausible future situation with respect to variable costs, product prices, cropping pattern and specialization, farm size, and yields (from Chapter 5); the range of scenarios for 2050 may cover: two emission/climatic change scenarios (A1FI /W and B2/G) * four farm types (as based on Table 9.1) * farm orientation (e.g. production oriented farm with its income mainly from farming, a multi-functional farm with e.g. 30 and 100% of modal labour income in the Netherlands from non-agricultural activities, etc.) * specialisation in high-value (e.g. bulb flowers and/or vegetable) crops * increase in farm size (e.g. present vs. tripled size).

The four main arable farm types in Flevoland have currently between 60 to 80% of the total farm area in use for potato, sugar beet and onion production; this indicates that the quality of the soil structure and the soils in general are in danger; collaboration between arable and animal production farms by growing the mentioned arable crops partly on the animal farm area in exchange for growing annual fodder crops (e.g. lucerne) on the arable farms appears to be essential for arable farming in Flevoland.

Calculations for farm types in 2050 with similar farm sizes as in 2003 and a more specialized cropping pattern (with large labour and capital input for bulb flower and/or vegetable crops) indicate a large increase in labour demand and a low gross margin per labour hour; this specialized cropping appears to be only of interest, if the additional labour can be hired in the future from low-income countries (as occurring already at large scale in Dutch horticulture).

Increased farm size may lead to a more efficient labour use for labour-intensive crops as onions, potato, and in particular bulb flowers and vegetable crops. Information about the possibilities of further mechanization at increasing farm size and their cost effectiveness is essential for establishing future farming possibilities at increasing farm size.

10 Exploring adaptation strategies using Data Envelopment Analysis

10.1 Introduction

Integrated assessment can be facilitated by interdisciplinary and quantitative tools (i.e. bio-economic models) that link resource management decisions to biophysical models that describe production processes and the conditions of natural resources (Janssen and Van Ittersum, 2007; Bardier & Carpentier 2000; Barbier & Bergeron, 1999). Often, experts are used to identify a number of agricultural activities. The inputs and outputs of the activities are quantified using the bio-physical component of the bio-economic model while the economic component maximizes the utility of the farmer subject to a number of resource and policy constraints.

Using bio-economic models to describe production processes and quantify inputs and outputs of agricultural activities reduces the data requirements substantially, however very often for simplification purposes and because of lack of data existing variation in agricultural activities and farmer's decision making is not captured adequately. Rotational constraints are taken into account with strict constraints when in reality there is more flexibility, only the most important management options are offered to the model because, input substitution is ignored, returns to scale are not taken into account, while it is assumed that all farmers are fully efficient and profit maximizers.

Data Envelopment Analysis (DEA) (Charnes et al., 1978) is a method used in operational research to rank entities that convert multiple inputs into multiple outputs based on their capacity to convert those inputs into outputs. Such entities are defined as decision making units (DMU). The definition of a DMU is quite flexible and encompasses firms, farms or even agricultural activities. In general, the production process of a DMU, like a farm, involves multiple inputs and outputs, which makes the ranking complicated. Mathematical programming methods are employed to rank or screen multiple input multiple output DMUs in terms of converting inputs into outputs. The capacity of each DMU to convert inputs into outputs is evaluated and compared to the capacity of all other existing DMUs to convert inputs into outputs. A multi dimensional frontier is created by the superior decision making units while all other inferior decision making units are enveloped (enclosed) in this frontier. The inputs and outputs of DEA could be also seen as attributes or criteria of multi-criteria decision making (MCDM) methodology (Bouyssou, 1999; Stewart, 1996). Inputs can be seen as criteria to be minimized while outputs as criteria to be maximized.

The objectives of this section are: first, to propose a DEA based approach for identifying the current technology of existing farming systems, second, to demonstrate how technological innovation can be taken into account in the DEA model and third, to use the identified current and future technology in a bio-economic model to assess adaptation strategies of current farming systems to climatic change. The arable farming systems of Flevoland (the Netherlands) towards adaptation to climatic change are used for demonstration purposes.

First, the basics of DEA for identifying a production frontier are revealed and an approach for including technological innovation and alternative agricultural activities is

presented. Second, the proposed DEA based methodology is used to identify the current technology of Flevoland (the Netherlands) and based on this current technology to demonstrate how alternative activities or technological advances can be taken into account. Third, the results of the experiment in Flevoland are presented. finally, a number of discussion points are raised and discussed.

10.2 Methodology

10.2.1 Data Envelopment Analysis for identifying current technology

A simple DEA example involving a set of farms using one input to produce one output is shown in Figure 10.1. Farms A, B and C are located on the frontier which reflects the best practice among the observed farms. These farms are efficient since their use of inputs cannot be decreased or production of outputs cannot be increased without decreasing outputs or increasing inputs respectively (Cooper et. al., 2004, pg 3). Farm D is located below the frontier and is inefficient. Farm F reflects a combination of A and B and creates the same output as farm D, but uses less input. Farm D can also be projected on the frontier by expanding output and holding input constant (as reflected by farm H which is a combination of B and C). The input oriented efficiency score of D is calculated as $\theta = GF/GD$ while the output oriented efficiency score is calculated as $\theta =$ ID/IH. Farms A,B and C are fully efficient and have input and output oriented efficiency score of 1. Although the output oriented efficiency score of farm E is also equal to 1, it can be seen from the figure that the same output can be produced from a smaller quantity of input. In this example, farm E is weakly efficient. The frontier created by farms A, B and C can be seen as the current production frontier. In case of more complicated problems with multiple inputs and outputs a graphical solution is not possible. A Linear Programming model can be used to calculate the efficiency score of each farm and recover the multi-dimensional production frontier (see Appendix 1 for the LP models).

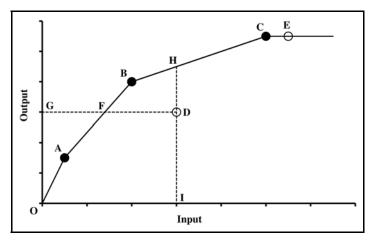


Figure 10.1: Graphical representation of a one input, one output DEA problem

The empirical implementation of a DEA model sets a number of requirements to the inputs and outputs (Cooper et al., 2007):

• The data must be non-negative for each of the farms; if not the data must be transformed to non-negative. At least one of the inputs and one of the outputs of each farm should be positive.

- The inputs, outputs and farms that enter the DEA model should reflect the interests of the decision makers with respect to the components that enter the relative efficiency evaluation.
- In general, inputs are items that are preferred to be at a minimum level (as small as possible) while outputs are items that are preferred to be at a maximum level (as large as possible).
- The units of measurement of each input and output should be the same for the different farms.

10.2.2 Accounting for technological innovations and alternative agricultural activities

Alternative agricultural activities are results of technological innovations and changes in the socio-economic and bio-physical environment that alter the way resources are allocated in farm production. Alternative activities causes a shift to the current production frontier and make possible increased production of one or more outputs per unit of one or more inputs. Alternative activities can also result in alternative outputs (not currently produced in the region) that can also require alternative inputs. This kind of alternative activities introduce "alternative" dimensions to the current production frontier. The DEA specified production frontier can be used as a basis for speculating alternative activities and construct the production frontier of the future. To demonstrate the proposed method we use the simple one input one output example of Figure 10.1. Assuming that the input is nitrogen use (kg N/ha) and output is potatoes (kg) we can show in a graphical way how the production frontier will change if an alternative improved variety of potatoes becomes available that increases yields with the same amount of inputs (Figure 10.2). All current farming systems (A,B, C) can have access to this new variety and consequently, for each farm on the current frontier there is a corresponding farm of the future (A', B', C'). The distance of each current farming system can be quantified while the new technical efficient production plan can be determined as a combination of farms of a number of future production plans (A', B', C').

An alternative activity might not be available to all farmers. For example, expensive weeding machinery become available that increases the capital requirements but also increases the total potato output. It might be the case that not all current farming systems can invest in such equipments. Assuming that only farms that currently have high capital inputs (farms C and E) have access to this new technological innovation we can create the production frontier of the future like in Figure 10.3 (input= capital).

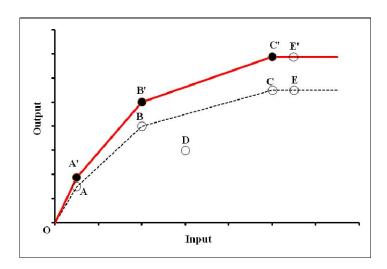


Figure 10.2: Graphical representation of an alternative production technology accessible to all farms. Output increases while the input level is the same.

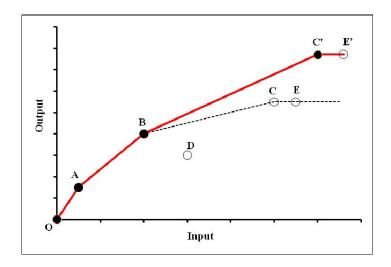


Figure 10.3: Graphical representation of an alternative production technology accessible to high input farms. More output is produced per unit of input.

It is important to notice that till now we have not made any behavioural assumption related to the farmer's decision making. We identified a production frontier and we can give advices for the direction that inefficient farms (like farm D) should change to become technically efficient. Having identified the current and alternative production frontier we can make different behavioural assumptions and make inferences for future developments, or we can explore options for improving (depending on the behavioural assumptions) current farming systems given a new technological, socio-economic and bio-physical environment. We can do this using a farm model like FSSIM. The proposed method can be summarized in three steps:

- 1. Use DEA to identify current technology
- 2. Use the current technology to formulate the production frontier of the future. Existing farm typologies (Chapter 3) can be used to identify which current farming systems have access to what alternative activity.
- 3. Use the current and future production frontier to explore possible adaptation strategies assuming different farmer's behaviour. The farm typology of Chapter 3 (and

more precisely, the farmer's orientation dimension) could be also used to account for variation in decision making between farms.

10.3 Short example of the application of the Methodology

We focus on exploring adaptation strategies of arable farming in Flevoland (the Netherlands). Individual farm data of the Farm Accounting Data Network (FADN) for year 2006 is used. In total 27 individual arable farms are identified. Those farms have been sampled and each of them is representative of a specific number of farms of the region. The production structure comprise from 7 inputs which are: UAA (utilized agricultural area in ha), CRPRO (crop protections in €), FERT (fertilizers in €), HLABR (hired labor in hrs), FLABR (family labor in hrs), OINPUT (other inputs in €) and CAPIT (average capital in €). In total, 9 main outputs are produced: WSWH (soft wheat production in tones), BARL (barley production in tones), POTA (potatoes production in tones), SUGB (sugar beet production in tones), OVEG (vegetable production in tones), ANOUT (animal output in €), OAROUT (other arable output in €) and OOUT (other output in €).

The alternative yields and prices for 2050 used also in Chapter 9 of this report were used. In general, crop yields increase. We assumed that increase of yields are mainly because of climatic change. The fertilizer inputs also increase while all other inputs remain exactly the same. The simple survey data of SEAMLESS (Zander et al., 2009) was used to estimate the increased fertilizer input. The estimated increase of yields and fertilizer inputs for 2050 but also the prices in 2006 and expected prices in 2050 are presented in Table 10.1.

Table 10.1 Prices for 2006 and expected yields increase, fertilizer inputs increase and prices in 2050

	Yield increase (%)	Fertilizers increase (€ / tone of yield increase)	Price 2006 (€/tone)	Price 2050 (€/tone)
Soft wheat	16.3	25.3	103	207
Potatoes	14.5	4.8	120	319
Sugar beet	44.6	2.9	45	80
Onions	33.8	4.2	95	144
Barley	26.8	19.0	110	223

To demonstrate the type of analysis proposed and the possibilities of using DEA we designed a number of simulations that have different aims:

Current situation: This simulation focused in describing the current situation. Farms are ranked according to their capacity of converting inputs into outputs. The current production frontier is formed by the efficient farms while the distance of inefficient farms from the current production frontier is measured.

Sim 1: The objective of this simulation is to assess the consequences of the hypothetical scenario that all farms become technically efficient. The corresponding efficient production plan of inefficient farms is identified and changes to inputs and outputs are estimated.

Sim 2: An economic farm model is used to maximize profit of all farms using input and output prices for 2006. It was assumed that levels of inputs like capital, utilized

agricultural area and family labour; and levels of outputs like animal output, other arable output and other output could not exceed the observed level.

Sim 3: Profit is maximized using input and output prices of 2050. It was assumed that levels of inputs like capital, utilized agricultural area and family labour; and levels of outputs like animal output, other arable output and other output could not exceed the observed level. A constant inflation rate of 1.19 per year was used to calculate price changes of aggregated inputs and outputs measured in momentary units.

Sim 4: Profit is maximized using input and output prices of 2050 only current technology is taken into account. It was assumed that levels of inputs like capital, utilized agricultural area and family labour could not exceed the observed level. However in this simulation, levels of all outputs are free to change. A constant inflation rate of 1.19 per year was used to calculate price changes of aggregated inputs and outputs measured in momentary units.

Sim 5: The objective of this simulation is to create the future production frontier including alternative activities (yield increase). Profit is maximized using input and output prices of 2050. It was assumed that levels of inputs like capital, utilized agricultural area and family labour; and levels of outputs like animal output, other arable output and other output could not exceed the observed level. A constant inflation rate of 1.19 per year was used to calculate price changes of aggregated inputs and outputs measured in momentary units.

Sim 6: It is the same with *Sim 5* but all outputs were allowed to change.

10.4 Results

Results of an average arable farm in Flevoland for the different simulations are presented in Table 10.2. The fraction of the value of each indicator in different simulations compared to the current situation is presented in Figure 10.4. Comparing the first two simulations with the current situation it can be stated that in general farmers are currently technical efficient and profit maximizers. The simulated results are very close to the 100% of the current simulation. Farmers use resources like fertilizers, hired labour and crop protection products in optimum level for maximizing their gross margin (given the available family labour, capital and other inputs).

In simulation 3 the much higher expected price increase for 2050 doubles the farm income. This is mainly because in this simulation we assume high price increase of main outputs and a moderate increase of input prices. The input and output levels of this simulation are not much different from corresponding input and output levels of simulation 2.

In simulation 4, the level of other outputs (OOUT, ANOUT, OAROUT) increases substantially causing a substantial increase to the farm income. However, in most cases it wouldn't be possible for farmers to increase OOUT and ANOUT without investing and consequently increasing the average capital of the farm. Nevertheless, this simulation provides information about the outputs farmers should aim but also where farmers should invest in the future. Other outputs, off farm activities and livestock production appears to be much more promising for the future (of course given our assumptions on future prices). As expected, the improved yield scenarios (sim. 5 and 6) also increase the expected farm income.

Table 10.2 Inputs and outputs of an average arable farm in Flevoland in different simulations

	UAA	CRPRO	FERT	HLABR	FLABR	OINPUT	CAPIT	WSWH	BARL	POTA	SUGB	OVEG	OAROUT	ANOUT	OOUT	INCOME
Simulation	(ha)	(€)	(€)	(hrs)	(hrs)	(€)	(€)	(tones)	(tones)	(tones)	(tones)	(tones)	(€)	(€)	(€)	(€)
Cur. Sit.	100	39025	12736	1561	3374	85728	1211976	139	4	1488	1088	937	58532	59391	40942	341050
Sim 1	97	37463	12203	1485	3230	81927	1187718	140	4	1502	1099	952	61068	59687	42723	355753
Sim 2	97	41195	13015	1265	3075	78491	1144083	159	5	1651	1196	1013	58392	50185	40942	368370
Sim 3	96	40967	12919	1226	2966	77846	1128802	153	5	1672	1163	986	58452	50363	40879	811333
Sim 4	98	39580	17248	3137	2714	64092	1176449	145		1978	1011	612	103921	94033	123083	1173397
Sim 5	96	41194	17719	1226	2974	78432	1135090	177	6	1919	1684	1325	58532	50232	40889	962841
Sim 6	98	39638	22226	2605	2397	63968	1176449	188		2401	1498	865	118778	85191	86101	1319682

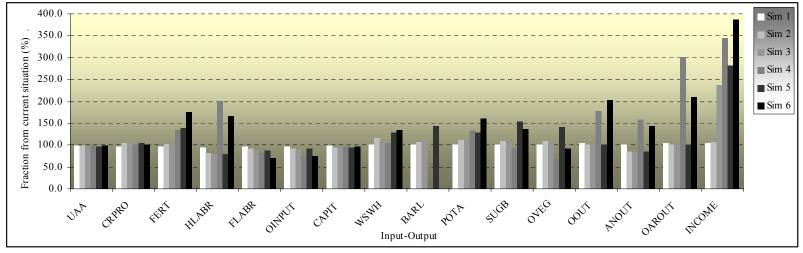


Figure 10.4: Fraction of the values of inputs and outputs from current situation in different simulations

10.5 Discussion of potential and limitations of the Methodology

Identifying the current technology using individual farm data captures variation in existing farming systems while estimation of efficiency is enabled. However, Individual farm data is not always available because of confidentiality agreements, while in many cases, inputs and outputs are measured in momentary units (e.g. fertilizers, crop protection). For AgriAdapt we must clarify if we can use aggregated results that comes from analysis of individual farm data

Alternative agricultural activities and technological innovation are taken into account as shifts of the current production frontier. We used as starting point the current farming systems and made inferences about how those farming systems will look in the future. We assessed the profitability of those new technologies and used this as indication of adopting specific adaptation strategies. Calibration procedures are not needed since optimum production plans are expressed as combinations of existing production plans resulting in realistic model solutions.

Bio-economic studies involve the calculation of environmental indicators (e.g. N-leaching, biodiversity) which are difficult to find in existing farm accounting databases. In case where such indicators are quantified (using expert's knowledge or bio-physical models), they can be taken into account in the proposed DEA method as additional inputs or outputs.

The challenging task of this method is to identify interesting (from a policy and stakeholder point of view) and realistic alternative activities and to predict future prices of inputs and outputs.

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